Defence Research and Development Canada
Recherche et développement pour la défense Canada

MIMO Radar: Literature survey of papers published between September 2008 and December 2012

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Defence R&D Canada – Ottawa

Canada

Contract Report
DRDC Ottawa CR 2013-018
June 2013

MIMO Radar: Literature survey of papers published between September 2008 and December 2012

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Contractor's Document Number:
Contract Project Manager:
PWGSC Contract Number: W7714-125466
CSA: P.W. Moo, GL/WAS Radar, 613-998-2879

Defence R&D Canada – Ottawa

Contract Report
DRDC Ottawa CR 2013-018
June 2013

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Abstract

Multiple-Input Multiple Output (MIMO) radars are present more than 10 years within the research community. There is significant number of papers in the open literature where MIMO radar is primary topic.
Basic principle of MIMO radar is that radar simultaneously transmit a set of waveforms, one waveform per transmit antenna. Reflected waveforms are collected by using set of receivers. This introduces a whole new concept for radar resource management, and different detection, localization, identification and tracking algorithms are required.
This Technical Memorandum reports on the literature survey of journal and conference papers on the topic of MIMO radars published between September 2008 and December 2012. Total number of papers given in the literature survey is 764.
Presented papers are analyzed and categorized according to their topic. The literature survey gives research trends in MIMO radar area.

This Technical Memorandum should be used along with previous work on this topic that cover MIMO radar literature from 2003 to September 2008.

P. Sevigny: Multiple-input multiple-output (MIMO) radar: Literature survey of papers published between 2003 and September 2008, DRDC Ottawa Technical Memorandum, 2008-33, March 2009.

Résumé

Les radars entrée multiple sortie multiple (en anglais *Multiple-Input Multiple Output* – MIMO) sont étudiés par les chercheurs depuis plus de 10 ans. La documentation publiée comprend un nombre important d'articles qui ont les radars MIMO comme principal sujet.
Le principe de base du radar MIMO consiste à émettre simultanément un ensemble de formes d'onde, une forme d'onde par antenne d'émission. Les formes d'ondes réfléchies sont captées par un ensemble de récepteurs. Cette nouvelle technologie introduit un concept entièrement nouveau pour la gestion des ressources radar; de nouveaux algorithmes de détection, de localisation, d'identification et de poursuite sont nécessaires.
Le présent document technique donne les résultats d'une recherche bibliographique sur les articles au sujet du radar MIMO publiés dans des revues scientifiques et des comptes rendus de conférence entre septembre 2008 et décembre 2012. La recherche porte sur un total de 764 articles.
Les articles présentés sont analysés et classés selon leur thème. La recherche dégage certaines tendances dans le domaine de la recherche sur les radars MIMO.
Le présent document technique devrait être utilisé avec les travaux précédents sur ce sujet portant sur la documentation sur les radars MIMO publiée entre 2003 et septembre 2008.

P. Sevigny. *Multiple-input multiple-output (MIMO) radar: Literature survey of papers published between 2003 and September 2008*, R & D pour la Défense Canada – Ottawa, DRDC Ottawa TM 2008-33, mars 2009.

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Executive summary

MIMO Radar: Literature survey of papers published between September 2008 and December 2012

L. Stankovic; DRDC Ottawa CR 2013-18; Defence R&D Canada – Ottawa; June 2013.

Introduction: Multiple-Input Multiple Output (MIMO) radars have clear advantage over conventional radar systems in many aspects. By increasing power of signal processing and communication system, the idea of simultaneously illuminating space with independent waveforms transmitted from multiple sources and analyzing reflected signals collected from multiple receiver stations is moved from pure theory to practical devices. This approach introduces new concepts for radar resource management, target detection, localization, identification and tracking.

Results: In this Technical Memorandum, the content of 764 journal papers and conference proceedings on the topic of MIMO radars were reviewed, summarized, and categorized. Analyzed papers are published from September 2008 to December 2012.

Significance: The literature survey on MIMO radars suggests potential benefits and challenges of MIMO radars usage compared to conventional radar systems. It is notable that most of the literature covers MIMO radar theory improvements, while experimental datasets are rarely used.

Sommaire:

Introduction: Les radars entrée multiple sortie multiple (en anglais Multiple-Input Multiple Output – MIMO) offrent des avantages indéniables par rapport aux systèmes radar classiques sous de nombreux aspects. L'augmentation de la puissance du système de traitement de signaux et de communication permet de faire passer de la théorie pure à la pratique l'idée d'éclairer simultanément l'espace avec des formes d'ondes indépendantes émises à partir de sources multiples et d'analyser les signaux réfléchis captés par de multiples stations réceptrices. Cette approche introduit des concepts entièrement nouveaux pour la gestion des ressources radar ainsi que pour la détection, la localisation l'identification et la poursuite des cibles.

Résultats: Dans le présent document technique, le contenu de 764 articles publiés dans des revues scientifiques et des comptes rendus de conférence et portant sur les radars MIMO sont examinés, résumés et classés. Les articles analysés ont été publiés entre septembre 2008 et décembre 2012.

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Portée: La recherche bibliographique sur les radars MIMO dégage des avantages et des problèmes à résoudre que pourrait présenter l'usage des radars MIMO au lieu des radars classiques. Il importe de remarquer que la plupart des articles proposent des améliorations de la théorie du radar MIMO et que des ensembles de données expérimentales sont rarement utilisés.

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1 Introduction

Multiple-Input Multiple Output (MIMO) radars were important research topic within past decade. It is notable that research community interest on MIMO radar was highest in 2010 and 2011 while there is notable lower number of published papers in 2012.

MIMO concept origin is in communications where multipath propagation is considered as undesired effect that should be eliminated and MIMO approach utilize multipath propagation in order to provide faster and more reliable data transfer compared with conventional single transmitter single receiver scenarios.

More detailed overview of MIMO radar systems can be found in

> P. Sevigny: Multiple-input multiple-output (MIMO) radar: Literature survey of papers published between 2003 and September 2008, DRDC Ottawa Technical Memorandum, 2008-33, March 2009.

In Section 2 a review of open literature on MIMO radars is provided. Journal papers are summarized within subsection 2.1 while conference papers review is presented in sunsection 2.2.

2 Litrature review

In this Section, a review of the open literature on MIMO radars is presented. The open literature was primarily searched for papers dedicating a large part of their analysis to MIMO radars, and explicitly using the term MIMO radar. The number of MIMO radar papers found per year is given in Table 1 to show the recent history of MIMO radars and the rapid increase in the number of publications. The Table includes papers published from September 2008 to December 2012. The papers are categorized as conference or journal papers. The result of this classification can be found in Table 1.

Table 1 *Number of open literature papers on the subject of MIMO radars published per year, since September 2008.*

Year	Journal papers	Conference papers	Total
2008 (from September)	9	34	43
2009	24	109	133
2010	64	156	220
2011	60	143	203
2012	55	110	165
2008-2012	212	552	764

**Note that year 2008 is incomplete as it only includes papers published in or after September 2008.*

2.1 Journal papers classification

The journal papers (references [1-212]) are divided here into categories, according to the main topic of the paper. The analyzed categories are:

1. MIMO radar theory
2. Target detection and tracking
3. Target parameters estimation
4. Waveform design
5. Radar imaging
6. Design and applications
7. Other topics

Since, there is no always a clear line between categories, we have categorized journal papers by choosing the "closest" category for each paper. Number of papers within each category, by year, is presented in Table 2.

Table 2 *Number of open literature journal papers by categories published from September 2008 to December 2012.*

Category \ Year	2008	2009	2010	2011	2012	Total
MIMO radar theory	2	10	14	10	28	64
Target detection and tracking	2	4	11	11	5	33
Target parameters estimation	1	2	14	17	11	45
Waveform design	3	4	9	10	2	28
Radar imaging	-	1	8	6	6	21
Design and applications	1	2	3	3	-	9
Other topics	-	1	5	3	3	12
Total	9	24	64	60	55	212

2.1.1 MIMO radar theory

Majority of the reviewed papers is within this category. The **general MIMO radar theory** is considered in [2], [9], [10], [13], [14], [17], [18], [22], [23], [24], [25], [33], [37], [39], [40], [42], [44], [56], [64], [66], [73], [75], [79], [88], [91], [97], [106], [107], [118], [120], [134], [136], [139], [143], [145], [151], [152], [159], [160], [161], [164], [167], [168], [169], [170], [171], [172], [173], [174], [181], [186], [187], [191], [192], [194], [197], [198], [200], [202], [203], [204], [206], [207], [210] and [211].

Beamforming is the main topic of [75], [97], [106], [139], [168] and [194]. The **antenna array geometry** and its analysis is considered in [14], [107], [187], [200] and [204]. The **compressive sensing and sparse processing** techniques are analyzed in [23], [44], [152] and [172]. **Jamming** caused by smart target ws the main topic of [160]. **Mutual interference** of several MIMO radars is considered in [134], while the **HFSWR** MIMO radar theory is presented in [13]. In [143] MIMO radar with **random waveform** is analyzed.

Beside mentioned subtopics an analysis for a specific class of problems has lead to a conclusion that MIMO radar performace are worse for these problems than the phased-array radar in [17]. In [10] authors explain class of problems when **MIMO system can be replaced with SIMO**. **Advantages of MIMO** radar systems are explained in details in [33], [37] and [56].

2.1.2 Target detection and tracking

Target detection is the main topic in the papers [3], [7], [12], [15], [27], [29], [41], [43], [49], [54], [57], [69], [77], [87], [89], [92], [96], [99], [100], [104], [110], [111], [112], [114], [126], [129], [148], [162], [175], [176] and [185].

Various forms of **clutter,** including Gaussian, non-Gaussian, non-homogeneous, correlated and heavy-tailed clutter, are considered. Analyzed scenarios include stationary, moving and fast moving target cases as well as multiple target detection problems.

The polarimetric MIMO radar is analyzed in [57], [175], [176]. Constant false alarm rate (**CFAR**) detection methods are presented in [49] and [77].

Target tracking is main topic of papers [101] (moving target scenario) and [183] (multiple targets).

2.1.3 Target parameters estimation

Estimation of various **target parameters** is considered in [4], [26], [32], [34], [35], [45], [52], [53], [58], [68], [72], [74], [85], [90], [93], [94], [95], [109], [113], [116], [120], [123], [124], [125], [127], [128], [130], [131], [135], [137], [149], [153], [155], [157], [158], [163], [165], [178], [179], [182], [184], [188], [195], [196], and [205].

Direction of arrival, direction of departure, **target location and velocity** (Doppler shift) are the target parameters of interest in most cases. Estimation methods include **ESPRIT** (the most often used high resolution method in MIMO radars), **MUSIC** [93], [188], **PARAFAC** [123] and **Capon** [68]. Analyzed scenarios include **Cramer-Rao bound** analysis [35], **multi-target** scenarios [72], [153], and **distributed targets** [113].

In [53] and [120] **clutter-rank** is estimated.

2.1.4 Waveform design

Waveform design for MIMO radar systems is considred in [5], [6], [8], [11], [20], [28], [31], [38], [50], [59], [60], [70], [78], [80], [84], [86], [102], [108], [117], [121], [122], [132], [133], [142], [150], [156], [166] and [180].

Subtopics in this area includes waveform design for usage in **colored noise** environment, waveforms designed having in mind known target position, chaotic and polyphase coded waveforms**, robust approaches** to waveform design, waveform design based on **ambiguity function** and various waveform **optimizations**.

2.1.5 Radar imaging

General **MIMO radar imaging** is topic in [115], [147] and [193]

MIMO based **ISAR systems** are considered in [48], [65], [67], [71], [76], [81], [82], [140], [190]. The analyzed subtopics within this categry are the **motion-compensation**, **3D imaging**, **near-field** and **far-field** imaging systems and **resolution analysis**.

SAR systems are considered in [30], [83], [103], [141], [146], [199], [201], [209] and [212].

2.1.6 Design and applications

Papers [51], [55], [98], [119], [154] and [199] consider possible **applications of MIMO radar** to medicine [51], through-the-wall imaging [55], concealed weapon detection [98], near-space located radar systems [119], breathing detection [154], and landmines detection [199].

MIMO **radar hardware design** (sensors, receivers, antenna…) is considered in [1], [16], [19] and [61].

2.1.7 Other topics

Energy efficiency of MIMO radar systems is considered in [105]. Experimental results for MIMO over-the-horizon radar (OTHR) are given in [21]. Reference [36] is introductory note for special issue of Selected Topics in Signal Processing dedicated to MIMO radar systems. Application of MIMO in sonars is considered in [63] while general distributed radar networks are analyzed in [62].

2.2 Conference papers classification

There are **552 conference papers about MIMO radar** published from September 2008 to December 2012. The conference papers are referenced form [213] to [764]. Here we will perform brief review and classification of these conference papers.

The conference papers are roughly divided into 5 categories. These categories are not disjunctive, 56 papers are included into two categories, while 5 papers fall into three categories. Moreover there are 239 conference papers about the MIMO radars which are ourside of this 5 category clasiffication. They are either papers about the general thery, more specific category, or cross several categories. Number of papers within specific category is presented in Table 3.

1. Papers where target detection and tracking is analyzed. There are 143 conference papers within this category: [222], [232], [245], [248], [251], [253], [260], [262], [263], [270], [284], [287], [291], [304], [305], [308], [310], [320], [324], [336], [338], [342], [346], [347], [353], [356], [358], [360], [365], [366], [367], [371], [374], [375], [380], [384], [385], [386], [387], [390], [392], [394], [396], [398], [400], [409], [413], [414], [418], [422], [424], [433], [442], [444], [451], [463], [467], [477], [478], [482], [483], [495], [496], [497], [500], [508], [509], [510], [512], [515], [516], [518], [522], [527], [535], [536], [541], [543], [545], [552], [553], [555], [561], [563], [567], [570], [571], [572], [574], [575], [577], [579], [581], [585], [591], [592], [594], [598], [602], [604], [607], [611], [613], [620], [633], [634], [638], [644], [647], [650], [651], [658], [659], [660], [662], [663], [664], [665], [669], [672], [679], [684], [687], [688], [689], [691], [702], [708], [709], [710], [713], [715], [716], [718], [725], [728], [729], [731], [732], [736], [741], [755], [762].

2. Papers where target (or clutter) parameters estimation is considered. Total of 114 papers are within this category. Papers are referenced with [216], [219], [220], [233], [235], [236], [245], [249], [252], [253], [257], [259], [278], [280], [289], [297], [298], [306], [315], [316], [328], [334], [337], [342], [343], [349], [350], [352], [354], [355], [365], [369], [370], [371], [372], [376], [377], [381], [382], [383], [385], [387], [390], [391], [393], [395], [400], [401], [403], [415], [423], [426], [432], [435], [436], [437], [439], [442], [456], [462], [463], [466], [467], [469], [471], [480], [481], [492], [499], [500], [513], [519], [521], [522], [538], [540], [542], [543], [547], [548], [550], [556], [559], [569], [576], [578], [580], [586], [597], [606], [611], [612], [613], [619], [622], [624], [625], [626], [629], [642], [643], [648], [656], [674], [698], [710], [714], [715], [726], [729], [735], [754], [756], [758].

3. Papers where experimental results are used, (49 papers) [214], [230], [269], [273], [278], [292], [302], [312], [320], [326], [340], [346], [361], [362], [396], [397], [402], [409], [425], [460], [470], [487], [496], [520], [522], [523], [529], [531], [554], [562], [577], [582], [600], [606], [608], [630], [631], [641], [642], [665], [680], [690], [701], [715], [716], [731], [739], [757], [762].

4. Conference papers where waveform-design techniques are analyzed (38 papers) [215], [234], [236], [237], [244], [245], [248], [252], [265], [279], [284], [285], [308], [330], [352], [353], [364], [367], [382], [390], [395], [420], [450], [457], [563], [566], [575], [576], [611], [612], [615], [627], [638], [639], [728], [732], [753], [763].

5. Papers where radar imaging is topic of interest (35 papers) [215], [223], [227], [239], [271], [273], [307], [319], [339], [340], [341], [362], [415], [438], [447], [479], [511], [518], [525], [565], [568], [591], [599], [600], [610], [633], [637], [641], [662], [692], [699], [730], [749], [750], [751].

6. Other papers that do not belong to one of these categories (239 papers)

Table 3 *Number of open literature conference papers by categories published from September 2008 to December 2012.*

Category	Number of published papers
Target detection and tracking	143
Target parameters estimation	114
Experiments	49
Waveform design	38
Radar imaging	35
Other topics	239

2.2.1 Keywords

In Table 4 we present an analysis of the conference papers based on the most often used keywords in each considered paper. This list include only keywords that appeared in 7 or more papers.

Table 4 *Conference papers keywords statistics.*

Keyword	Number of papers
MIMO	315
MIMO Radar	194
Radar	145
Arrays	106
Radar antennas	98
Clutter	56
Antenna arrays	49
Covariance matrix	41
Doppler radar	41
Radar imaging	36
Array signal processing	33
Imaging	27
Detectors	25
Direction of arrival estimation	25
Doppler effect	25
Estimation	25
Correlation	23
Receivers	22
Algorithm design and analysis	21
Apertures	15

Keyword	Number of papers
Azimuth	15
Interference	15
Phased arrays	15
Image resolution	13
Radar cross section	13
Receiving antennas	13
Compressed sensing	11
Doppler	11
Antenna measurements	10
Autocorrelation	10
Direction of arrival	10
Object detection	10
OFDM	10
Adaptive arrays	9
Jamming	9
Maximum Likelihood	9
Airborne radar	8
Bistatic radar	8
Diversity methods	8
Optimization	8
Transmitters	8
Aperture antennas	7
Closed-form solution	7
Delay effects	7
Frequency estimation	7
Matched filters	7
Radar detection	7
Sensors	7
Signal to noise ratio	7

3 List of papers

3.1 List of journal papers with abstracts

[1] Kwang-Jin Koh; Rebeiz, G.M.; ,"A -Band Four-Element Phased-Array Front-End Receiver With Integrated Wilkinson Power Combiners in 0.18- SiGe BiCMOS Technology," Microwave Theory and Techniques, IEEE Transactions on , vol.56, no.9, pp.2046-2053, Sept. 2008

Abstract: A four-element phased-array front-end receiver based on 4-bit RF phase shifters is demonstrated in a standard 0.18-mum SiGe BiCMOS technology for Q-band (30-50 GHz) satellite communications and radar applications. The phased-array receiver uses a corporate-feed approach with on-chip Wilkinson power combiners, and shows a power gain of 10.4 dB with an IIP3 of -13.8 dBm per element at 38.5 GHz and a 3-dB gain bandwidth of 32.8-44 GHz. The rms gain and phase errors are les1.2 dB and les8.7deg for all 4-bit phase states at 30-50 GHz. The beamformer also results in les0.4 dB of rms gain mismatch and les2deg of rms phase mismatch between the four channels. The channel-to-channel isolation is better than -35 dB at 30-50 GHz. The chip consumes 118 mA from a 5-V supply voltage and overall chip size is 1.4times1.7 mm2 including all pads and CMOS control electronics.

[2] Migliore, M.D.; ,"Some physical limitations in the performance of statistical multiple-input multiple-output RADARs," Microwaves, Antennas & Propagation, IET , vol.2, no.7, pp.650-658, October 2008

Abstract: The objective of the study is to clarify some physical limitations in the performance of statistical RADAR systems using multiple antennas. In particular, it is shown that the performance of the recently proposed statistical multiple-input multiple-output (MIMO) RADAR is limited by the number of degrees of freedom (NDF) of the scattered field. Furthermore, the true nature of statistical RADAR systems (single-input multiple-output, multiple-input single-output, MIMO) is not related to the number of transmitting/receiving antennas, but to the NDF of the scattered field exploited by the system.

[3] De Maio, A.; Lops, M.; Venturino, L.; ,"Diversity-Integration Tradeoffs in MIMO Detection," Signal Processing, IEEE Transactions on , vol.56, no.10, pp.5051-5061, Oct. 2008

Abstract: In this paper, a multiple-input multiple-output (MIMO) detection problem is considered. At first, the authors derive the generalized likelihood ratio test (GLRT) for arbitrary transmitted signals and arbitrary time-correlation of the disturbance. Then, the authors investigate design criteria for the transmitted waveforms in both power-unlimited and power-limited systems and the authors derive closed-form formulas for the probability of false alarm and the detection probability. Finally, the authors study the interplay among the rank of the optimized space-time code (i.e., the number of linearly independent transmitted waveforms), the number of transmit diversity paths generated in the signal space, and the amount of energy integrated along each

path. The results confirm that there is an inherent tradeoff between diversity and integration, and that no uniformly optimum waveform design strategy exists.

[4] Jinli, C.; Hong, G.; Weimin, S.; ,"Angle estimation using ESPRIT without pairing in MIMO radar," Electronics Letters , vol.44, no.24, pp.1422-1423, November 20 2008

Abstract: Recently, it has been shown [Duofang et al.] how the ESPRIT algorithm exploited the invariance property of both the transmit array and the receive array for target direction estimation in a bistatic MIMO radar. However, this method estimates the transmit angles and the receive angles separately in each dimension, and then requires pair matching between the two-dimensional angle estimation, which requires additional computational load. In this reported work, the interrelationship between the two one-dimensional ESPRIT is utilised to obtain automatically paired transmit angles and receive angle estimation without debasing the performance of angle estimation in a bistatic MIMO radar. Simulation results are presented to verify the effectiveness of the proposed method.

[5] Chun-Yang Chen; Vaidyanathan, P.P.; ,"MIMO Radar Ambiguity Properties and Optimization Using Frequency-Hopping Waveforms," Signal Processing, IEEE Transactions on , vol.56, no.12, pp.5926-5936, Dec. 2008

Abstract: The concept of multiple-input multiple-output (MIMO) radars has drawn considerable attention recently. Unlike the traditional single-input multiple-output (SIMO) radar which emits coherent waveforms to form a focused beam, the MIMO radar can transmit orthogonal (or incoherent) waveforms. These waveforms can be used to increase the system spatial resolution. The waveforms also affect the range and Doppler resolution. In traditional (SIMO) radars, the ambiguity function of the transmitted pulse characterizes the compromise between range and Doppler resolutions. It is a major tool for studying and analyzing radar signals. Recently, the idea of ambiguity function has been extended to the case of MIMO radar. In this paper, some mathematical properties of the MIMO radar ambiguity function are first derived. These properties provide some insights into the MIMO radar waveform design. Then a new algorithm for designing the orthogonal frequency-hopping waveforms is proposed. This algorithm reduces the sidelobes in the corresponding MIMO radar ambiguity function and makes the energy of the ambiguity function spread evenly in the range and angular dimensions.

[6] Bo Liu; Zishu He; ,"Comments on "Discrete Frequency-Coding Waveform Design for Netted Radar Systems"," Signal Processing Letters, IEEE , vol.15, no., pp.449-451, 2008

Abstract: For original paper see H. Deng, ibid., vol.11, no.2, p.179-182, (2004). This comment points out some errors in the correlation calculations and conclusions in the literature. The ambiguity function and cross-ambiguity function for discrete frequency-coding waveform (DFCW) with arbitrary firing order are analyzed in that letter to corroborate the judgement. It shows that range autocorrelation sidelobe peak (ASP) for DFCW fluctuates around 0.21, the Doppler tolerance has sinc function form, while the range cross-correlation peak (CP) between two DFCWs is heavily varied with the different firing order. The correlation values are recalculated.

[7] Petillot, Y.; Chaoran Du; Thompson, J.S.; ,"Predicted Detection Performance of MIMO Radar," Signal Processing Letters, IEEE , vol.15, no.15, pp.83-86, 2008.

Abstract: It has been shown that multiple-input multiple-output (MIMO) radar systems can improve target detection performance significantly by exploiting the spatial diversity gain. The authors introduce the system model in which the radar target is composed of a finite number of small scatterers and derive the formula to evaluate the theoretical probability of detection for the system having an arbitrary array-target configuration. The results can be used to predict the detection performance of the actual MIMO radar without time-consuming simulations.

[8] Abramovich, Y.I.; Frazer, G.J.; ,"Bounds on the Volume and Height Distributions for the MIMO Radar Ambiguity Function," Signal Processing Letters, IEEE , vol.15, no., pp.505-508, 2008

Abstract: The multiple-input multiple-output (MIMO) radar delay-Doppler ambiguity function is introduced as the sum of all auto- and cross-ambiguity functions of the set of K spatially diverse waveforms. The integral of this function over the range-Doppler frequency region occupied by spread clutter relates to the clutter's power at the output of the matched MIMO receiver, and it serves as a measure of orthogonality of the waveforms in this region. The authors derive the upper bound on the attainable "clear area" for the ambiguity function, and the authors show that, with respect to the conventional single-waveform ambiguity function, the maximum clear area is K times smaller for the MIMO system.

[9] Christensen, S.S.; Agarwal, R.; Carvalho, E.; Cioffi, J.; ,"Weighted sum-rate maximization using weighted MMSE for MIMO-BC beamforming design," Wireless Communications, IEEE Transactions on , vol.7, no.12, pp.4792-4799, December 2008

Abstract: This paper studies linear transmit filter design for Weighted Sum-Rate (WSR) maximization in the multiple input multiple output broadcast channel (MIMO-BC). The problem of finding the optimal transmit filter is non-convex and intractable to solve using low complexity methods. Motivated by recent results highlighting the relationship between mutual information and minimum mean square error (MMSE), this paper establishes a relationship between weighted sum-rate and weighted MMSE in the MIMO-BC. The relationship is used to propose two low complexity algorithms for finding a local weighted sum-rate optimum based on alternating optimization. Numerical results studying sum-rate show that the proposed algorithms achieve high performance with few iterations.

[10] Friedlander, B.; ,"On the Relationship Between MIMO and SIMO Radars," Signal Processing, IEEE Transactions on , vol.57, no.1, pp.394-398, Jan. 2009

Abstract: This correspondence explores the close relationship between multiple-input multiple-output (MIMO), single-input multiple-output (SIMO), and phased-array radars. It is shown that under certain conditions, the signals received by a MIMO radar and by a properly defined SIMO radar are identical. Several equivalent variations of MIMO and SIMO radars are presented. These relationships make it possible to study MIMO radars in terms of their equivalent SIMO radars, using the extensive body of algorithms and performance analysis which have been developed for SIMO radars.

[11] Zhang, Y.; Wang, J.; ,"Improved design of DFCW for MIMO radar," Electronics Letters , vol.45, no.5, pp.285-286, February 26 2009

Abstract: The successful design of a discrete frequency-coding waveform for MIMO radar which can achieve a lower range autocorrelation sidelobe peak and range cross-correlation peak is presented. The numerical results are presented to verify the effectiveness of this method.

[12] Jiankui, Zeng; Zishu, He; ,"Detection of weak target for MIMO radar based on Hough transform," Systems Engineering and Electronics, Journal of , vol.20, no.1, pp.76-80, Feb. 2009

Abstract: An effective method of multiple input multiple output (MIMO) radar weak target detection is proposed based on the Hough transform. The detection time duration is divided into multiple coherent processing intervals (CPIs). Within each CPI, conventional methods such as fast Fourier transform (FFT) is exploit to coherent integrating in same range cell. Furthermore, noncoherent integration through several range cells can be implemented by Hough transform among all CPIs. Thus, higher integration gain can be obtained. Simulation results are also given to demonstrate that the detection performance of weak moving target can be dramatically improved.

[13] Lesturgie, M.; ,"Improvement of high-frequency surface waves radar performances by use of multiple-input multiple-output configurations," Radar, Sonar & Navigation, IET , vol.3, no.1, pp.49-61, February 2009

Abstract: A multiple-input multiple-output (MIMO) configuration has been studied for communication applications, offering a lot of advantages to mitigate propagation effects because of multipath and fading environments. More recently, MIMO techniques in radar have been proposed. MIMO is discussed in the context of high-frequency surface waves radar (HFSWR). After a short introduction to the MIMO radar technique (a technique which is not new; the RIAS developed by ONERA was probably the first MIMO radar), explores two different applications are explored. The first application aims at improving the resolution and accuracy of a coastal radar, proposed here in a bistatic configuration. Such a radar operates with a wide sparse frequency band and with an equivalent wide aperture, taking advantage of the MIMO configuration. Simulation over a congested area of targets demonstrates the benefit of MIMO over the conventional HFSWR radar, especially in terms of separation of targets. The second application consists in a more practical ship-borne HFWSR configuration compatible with space time adaptive processing (STAP) to improve the detection of slow targets. In this case, a limited number of receiving channels is considered whereas STAP uses the degrees of freedom offered by the transmitting array. The MIMO-STAP is compared with a conventional STAP, showing that theoretical performances should not be affected by the MIMO configuration even if the signals are no longer perfectly orthogonal, because of Doppler shift, once scattered by moving targets.

[14] Jian Dong; Qingxia Li; Wei Guo; ,"A Combinatorial Method for Antenna Array Design in Minimum Redundancy MIMO Radars," Antennas and Wireless Propagation Letters, IEEE , vol.8, no., pp.1150-1153, 2009

Abstract: In this letter, the antenna array design problem in minimum redundancy (MR) multiple-input-multiple-output (MIMO) radars is addressed, which seeks to maximize the virtual array aperture for a given number of transmitting and receiving (Tx/Rx) elements. Based on difference bases and cyclic difference sets (CDSs), a combinatorial method is proposed for the optimal design of Tx/Rx antenna arrays. The theoretical limits of the redundancy of MIMO virtual arrays constructed by the method for both one-dimensional and two-dimensional cases are derived. Numerical results are also presented, showing notable improvement in the spatial resolution of MIMO radar system over those reported in the literature.

[15] Jun Tang; Ning Li; Yong Wu; Yingning Peng; ,"On Detection Performance of MIMO Radar: A Relative Entropy-Based Study," Signal Processing Letters, IEEE , vol.16, no.3, pp.184-187, March 2009

Abstract: Based on Stein's lemma, the authors use relative entropy as a measure of error exponent to study detection performance of Neyman Pearson (NP) detectors for both multiple-input multiple-output (MIMO) radar and phased array radar. In high signal-to-noise ratio (SNR) region, the authors introduce the concept of diversity order to get insights of results. In low SNR region, the authors give instructive approximations for analytical results of relative entropy. Finally, the authors use relative entropy measure to study the problem of choosing the number of transmitters and receivers for MIMO radar.

[16] Feger, R.; Wagner, C.; Schuster, S.; Scheiblhofer, S.; Jager, H.; Stelzer, A.; ,"A 77-GHz FMCW MIMO Radar Based on an SiGe Single-Chip Transceiver," Microwave Theory and Techniques, IEEE Transactions on , vol.57, no.5, pp.1020-1035, May 2009

Abstract: This paper describes a novel frequency-modulated continuous-wave radar concept, where methods like nonuniform sparse antenna arrays and multiple-input multiple-output techniques are used to improve the angular resolution of the proposed system. To demonstrate the practical feasibility using standard production techniques, a prototype sensor using a novel four-channel single-chip radar transceiver in combination with differential patch antenna arrays was realized on off-the-shelf RF substrate. Furthermore, to demonstrate its practical applicability, the assembled system was tested in real world measurement scenarios in conjunction with the presented efficient signal processing algorithms.

[17] Daum, F.; Huang, J.; ,"MIMO radar: Snake oil or good idea?," Aerospace and Electronic Systems Magazine, IEEE , vol.24, no.5, pp.8-12, May 2009

Abstract: MIMO communication is theoretically superior to conventional communication under certain conditions, and MIMO communication also appears to be practical and cost-effective in the real world for some applications. It is natural to suppose that the same is true for MIMO radar, but the situation is not so clear. Researchers claim many advantages of MIMO radar relative to phased array radars (e.g., better detection performance, better angular resolution, better angular measurement accuracy, improved robustness against RFI, ECM, multipath, etc.). The authors will evaluate such assertions from a system engineering viewpoint. In particular, there are serious

trade-offs of MIMO vs. phased array radars relative to cost, system complexity, and risk considering numerous real world effects that are not included in most theoretical analyses. Moreover, in many cases one can achieve essentially the same radar system improvement with phased array radars using simpler, less expensive, and less risky algorithms. The authors evaluate roughly a dozen asserted advantages of MIMO radar relative to phased arrays.

[18] Nion, D.; Sidiropoulos, N.D.; ,"Adaptive Algorithms to Track the PARAFAC Decomposition of a Third-Order Tensor," Signal Processing, IEEE Transactions on , vol.57, no.6, pp.2299-2310, June 2009

Abstract: The PARAFAC decomposition of a higher-order tensor is a powerful multilinear algebra tool that becomes more and more popular in a number of disciplines. Existing PARAFAC algorithms are computationally demanding and operate in batch mode - both serious drawbacks for on-line applications. When the data are serially acquired, or the underlying model changes with time, adaptive PARAFAC algorithms that can track the sought decomposition at low complexity would be highly desirable. This is a challenging task that has not been addressed in the literature, and the topic of this paper. Given an estimate of the PARAFAC decomposition of a tensor at instant t, the authors propose two adaptive algorithms to update the decomposition at instant t+1, the new tensor being obtained from the old one after appending a new slice in the 'time' dimension. The proposed algorithms can yield estimation performance that is very close to that obtained via repeated application of state-of-art batch algorithms, at orders of magnitude lower complexity. The effectiveness of the proposed algorithms is illustrated using a MIMO radar application (tracking of directions of arrival and directions of departure) as an example.

[19] Adamiuk, G.; Beer, S.; Wiesbeck, W.; Zwick, T.; ,"Dual-Orthogonal Polarized Antenna for UWB-IR Technology," Antennas and Wireless Propagation Letters, IEEE , vol.8, no., pp.981-984, 2009

Abstract: This letter presents a design of a dual-orthogonal, linear polarized antenna for the UWB-IR technology in the frequency range from 3.1 to 10.6 GHz. The antenna is compact with dimensions of 40 times 40 mm of the radiation plane, which is orthogonal to the radiation direction. Both the antenna and the feeding network are realized in planar technology. The radiation principle and the computed design are verified by a prototype. The input impedance matching is better than -6 dB. The measured results show a mean gain in copolarization close to 4 dBi. The cross-polarizations suppression w.r.t. the copolarization is better than 20 dB. Due to its features, the antenna is suited for polarimetric ultrawideband (UWB) radar and UWB multiple-input-multiple-output (MIMO) applications.

[20] Kay, S.; ,"Waveform Design for Multistatic Radar Detection," Aerospace and Electronic Systems, IEEE Transactions on , vol.45, no.3, pp.1153-1166, July 2009

Abstract: The authors derive the optimal Neyman-Pearson (NP) detector and its performance, and then present a methodology for the design of the transmit signal for a multistatic radar receiver. The detector assumes a Swerling I extended target model as well as signal-dependent noise, i.e., clutter. It is shown that the NP detection performance does not immediately lead to an obvious signal design criterion so that as an alternative, a divergence criterion is proposed for signal design. A simple method for maximizing the divergence, termed the maximum marginal allocation algorithm, is presented and is guaranteed to find the global maximum. The overall

approach is a generalization of previous work that determined the optimal detector and transmit signal for a monostatic radar.

[21] Frazer, G.J.; Abramovich, Y.I.; Johnson, B.A.; ,"Multiple-input multiple-output over-thehorizon radar: experimental results," Radar, Sonar & Navigation, IET , vol.3, no.4, pp.290-303, August 2009

Abstract: Results from an experiment that applied one class of multiple-input multiple-output (MIMO) waveform techniques to over-the-horizon radar (OTHR) are reported. The experiment objective was to demonstrate that adaptive transmitter beamforming could be used in an appropriately design radar to reject spatially discrete Doppler-spread clutter. In the particular MIMO radar architecture that the authors call non-causal transmit beamforming, conventional or adaptive transmitter beamforming occurs following waveform transmission, propagation, scatter from targets and clutter sources, return propagation and finally signal reception. In the case reported herein spatially discrete clutter was successfully rejected to the noise floor of the radar return with rejection in excess of 35 dB achieved using common adaptive algorithms and straightforward training data selection. As part of the rejection algorithm the transmitted waveform direction-of-departure (DOD) from the transmitter array to the target was estimated and used as the preserved steer direction in the adaptive beamformer. The DOD estimates agree well with the geometrically determined true values. The demonstration of non-causal transmit beamforming suggests that it will be possible to create multiple simultaneous adaptive range-dependent transmitter beams with an appropriately designed OTHR. This has several applications including for the mitigation of Doppler-spread clutter.

[22] Rabideau, D.J.; ,"Non-adaptive multiple-input, multiple-output radar techniques for reducing clutter," Radar, Sonar & Navigation, IET , vol.3, no.4, pp.304-313, August 2009

Abstract: Multiple-input, multiple-output (MIMO) radars enhance performance by transmitting and receiving coded waveforms from multiple locations. This paper describes MIMO techniques that can be used to improve radar performance, especially in airborne ground moving target indicator (GMTI) applications. The authors begin by showing how MIMO techniques can lower airborne radar clutter to noise ratios (CNRs). This results in smaller losses when observing stationary or low-velocity targets. Next, the authors consider the implementation of MIMO radar modes using electronically scanned arrays (ESAs). Specifically, the authors show how MIMO techniques, applied to subarray-based ESAs, can cause high grating lobes and/or reduced search rates. To address this problem, the authors describe new space/time waveform coding techniques that can be used to improve performance. Two space/time waveform encoding approaches are proposed: (i) an overlapped virtual transmit subarray approach, and (ii) a beamspace MIMO approach. A third approach, involving conventional MIMO waveforms and irregular subarrays, is also briefly considered.

[23] Wallace, J.W.; Jensen, M.A.; ,"Sparse Power Angle Spectrum Estimation," Antennas and Propagation, IEEE Transactions on , vol.57, no.8, pp.2452-2460, Aug. 2009

Abstract: A novel method for estimating the power angle spectrum (PAS) is presented that decomposes the true PAS into a small set of basis functions. The basis coefficients for this sparse representation are found by enforcing equality to the covariance or Bartlett PAS subject to a minimum lscr1-norm constraint. The method, referred to as sparse PAS estimation (SPASE), can

be implemented conveniently using existing linear-programming (LP) solvers. Further, because only a few clusters are required in the representation, the method enables reduced-complexity stochastic models for the channel and possibly allows reduced overhead in channel feedback schemes. Application of the method to simulated channels and multiple-input multiple-output (MIMO) propagation data demonstrates the utility of the method.

[24] Godrich, H.; Haimovich, A.M.; Blum, R.S.; ,"Target localisation techniques and tools for multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.3, no.4, pp.314-327, August 2009

Abstract: This study presents a comparative study of coherent and non-coherent target localisation techniques for multiple-input multiple-output (MIMO) radar systems with widely distributed elements. Performance is evaluated based on closed-form solutions developed for the best linear unbiased estimator (BLUE) for each of the localisation methods. These estimators afford insights into the relation between radar locations, target location and localisation accuracy. In particular, the means squared error of the BLUE is factored into a term dependent on signal and processing characteristics and a term dependent on sensor locations. The latter is referred to as geometric dilution of precision (GDOP). The best achievable accuracy for the coherent case is obtained, and a comparative study with the non-coherent case is presented. MIMO radar systems with coherent processing are shown to benefit from a gain because of coherent processing among sensors. This gain is referred to as coherent localisation gain, and it is proportional to the ratio of the signal carrier frequency to the effective bandwidth (a large ratio for typical signals). The footprint of multiple transmit/receive sensors results in a gain, referred to as MIMO gain, for both processing techniques. The MIMO gain is proportional to the product of the number of transmitting and receiving sensors. Analysis of the MIMO gain through the use of GDOP contour maps demonstrates the achievable accuracy at various target locations for a given layout of sensors.

[25] Sakib, M.N.; Xiupu Zhang; Hraimel, B.; Mohamed, M.; Ke Wu; ,"Investigation of the Performance of Multiband Orthogonal Frequency Division Multiplexing Ultrawideband Over Fiber Transmission Under the Presence of In-Band Interferers," Optical Communications and Networking, IEEE/OSA Journal of , vol.1, no.3, pp.235-244, August 2009

Abstract: Multiband (MB) orthogonal frequency division multiplexing (OFDM) ultrawideband (UWB) wireless, which provides high-data-rate access, must be distributed by use of optical fiber. UWB receivers are anticipated to operate under hostile interference environments. So the study of the coexistence of various communication standards with MB-OFDM UWB over fiber is an important issue. The performance of MB-OFDM UWB over fiber transmission system is investigated, considering the effect of in-band narrowband jammers such as WiMAX, MIMO WLAN, WLAN, and marine radar. Experiments were performed to show the effect of fiber transmission under various interferer power levels. It is found that in-band interferers can cause severe degradation in system performance if any interferer to the UWB peak power ratio is not held below a certain level. The results also show that MB-OFDM UWB over fiber transmission is more vulnerable to certain interferers such as WiMAX and radar signals than to the other in-band jammers.

[26] Liu, N.; Zhang, L.-R.; Zhang, J.; Shen, D.; ,"Direction finding of MIMO radar through ESPRIT and Kalman filter," Electronics Letters , vol.45, no.17, pp.908-910, Aug. 13 2009

Abstract: A novel method employing an ESPRIT and Kalman filter is proposed for the one-dimensional direction finding problem of MIMO radar. The rotational invariance among the multiple equivalent virtual subarrays of MIMO radar is exploited to derive multiple estimates of the direction of each target through ESPRIT. The multiple estimates of each target are fused through a Kalman filter to refine the accuracy of estimation. Numerical examples demonstrate the effectiveness of the proposed method.

[27] Blum, R.S.; ,"Limiting Case of a Lack of Rich Scattering Environment for MIMO Radar Diversity," Signal Processing Letters, IEEE , vol.16, no.10, pp.901-904, Oct. 2009

Abstract: A radar system with M transmit and N receive antennas which are widely separated is employed to detect the presence of a target at a given point in space. This target is assumed to be composed of Q point scatterers which are closely spaced with respect to the waveforms transmitted by the radar system. The diversity gain for radar systems employing optimum processing (likelihood ratio tests) for detecting the presence of these targets is shown to be less than or equal to min(Q,MN).

[28] Chun-Yang Chen; Vaidyanathan, P.P.; ,"MIMO Radar Waveform Optimization With Prior Information of the Extended Target and Clutter," Signal Processing, IEEE Transactions on , vol.57, no.9, pp.3533-3544, Sept. 2009

Abstract: The concept of multiple-input multiple-output (MIMO) radar allows each transmitting antenna element to transmit an arbitrary waveform. This provides extra degrees of freedom compared to the traditional transmit beamforming approach. It has been shown in the recent literature that MIMO radar systems have many advantages. In this paper, the authors consider the joint optimization of waveforms and receiving filters in the MIMO radar for the case of extended target in clutter. A novel iterative algorithm is proposed to optimize the waveforms and receiving filters such that the detection performance can be maximized. The corresponding iterative algorithms are also developed for the case where only the statistics or the uncertainty set of the target impulse response is available. These algorithms guarantee that the SINR performance improves in each iteration step. Numerical results show that the proposed methods have better SINR performance than existing design methods.

[29] Wang, J.; Jiang, S.; He, J.; Liu, Z.; ,"Adaptive detectors with diagonal loading for airborne multi-input multi-output radar," Radar, Sonar & Navigation, IET , vol.3, no.5, pp.493-501, Oct. 2009

Abstract: The problem of adaptive target detection for airborne multi-input multi-output (MIMO) radars with space-time receivers in the presence of Gaussian interference (including clutter and noise) is studied. Previous work has assumed the interference covariance matrix to be known. The case with unknown covariance matrix is investigated here. By exploiting the low rank property of clutter subspace, generalised likelihood ratio test detector and adaptive matched filter detector with diagonal loading are suggested to improve the detection performance of MIMO radars in limited secondary data case. The closed-form detection probabilities and false alarm probabilities

of the two proposed detectors are derived and numerically evaluated. Theoretical analysis and numerical results show the advantages of the proposed detectors.

[30] Gebert, N.; Krieger, G.; ,"Azimuth Phase Center Adaptation on Transmit for High-Resolution Wide-Swath SAR Imaging," Geoscience and Remote Sensing Letters, IEEE , vol.6, no.4, pp.782-786, Oct. 2009

Abstract: Synthetic aperture radar (SAR) systems with multiple receive channels allow for high-resolution wide-swath imaging thus overcoming a fundamental limitation of conventional single-aperture SAR. By using multiple apertures in azimuth, additional samples are received for each transmitted pulse. This allows for a reduced pulse repetition frequency (PRF) thereby enabling a wider swath. However, a nonoptimum PRF is associated with a nonuniform sample spacing in azimuth and needs to be compensated by a multichannel reconstruction algorithm. For strong deviations from the optimum PRF, the inverse character of such an algorithm might result in a degraded performance. This can be overcome by an innovative advanced transmit antenna architecture which allows for a pulse-to-pulse shift of the phase center. Such an antenna enables the adaptive adjustment of the system's phase center positions to the respective PRF, thereby ensuring constant performance over a clearly extended PRF range. In particular, in combination with conventional multichannel processing strategies, this technique represents the next step toward a fully active multiple-input multiple-output (MIMO) SAR and has a great potential for future systems.

[31] Hao He; Stoica, P.; Jian Li; ,"Designing Unimodular Sequence Sets With Good Correlations---Including an Application to MIMO Radar," Signal Processing, IEEE Transactions on , vol.57, no.11, pp.4391-4405, Nov. 2009

Abstract: A multiple-input multiple-output (MIMO) radar system that transmits orthogonal waveforms via its antennas can achieve a greatly increased virtual aperture compared with its phased-array counterpart. This increased virtual aperture enables many of the MIMO radar advantages, including enhanced parameter identifiability and improved resolution. Practical radar requirements such as unit peak-to-average power ratio and range compression dictate that the authors use MIMO radar waveforms that have constant modulus and good auto- and cross-correlation properties. The authors present in this paper new computationally efficient cyclic algorithms for MIMO radar waveform synthesis. These algorithms can be used for the design of unimodular MIMO sequences that have very low auto- and cross-correlation sidelobes in a specified lag interval, and of very long sequences that could hardly be handled by other algorithms previously suggested in the literature. A number of examples are provided to demonstrate the performances of the new waveform synthesis algorithms.

[32] Hui Lv, Da-Zheng Feng, Hong-Wei Liu, Jie He, Cong Xiang, Tri-iterative least-square method for bearing estimation in MIMO radar, Signal Processing, Volume 89, Issue 12, December 2009, Pages 2686–2691

Abstract: In this paper, the authors introduce a novel tri-iterative least-square (TI-LS) method for bearing estimation in multiple-input multiple-output (MIMO) radar system. The TI-LS iteratively finds two steering matrices associated with the transmit and receive arrays, and the target's bearing can be easily obtained based on prior knowledge of the transmit and receive array manifolds. Furthermore, by jointly using the information from the transmit and receive array

responses, angular estimation accuracy can be significantly improved. Numerical examples are presented to illustrate the excellent angular estimation accuracy and computational efficiency of this new method.

[33] Wu, Y.; Tang, J.; Peng, Y.; ,"Models and performance evaluation for multiple-input multiple-output space-time adaptive processing radar," Radar, Sonar & Navigation, IET , vol.3, no.6, pp.569-582, December 2009

Abstract: Signal and clutter modelling and optimum performance evaluation for multiple-input multiple-output (MIMO)-based space-time adaptive processing radar is addressed. A signal model is developed to account for both code diverse MIMO (c-MIMO) and frequency diverse MIMO (f-MIMO), and a general framework on performance evaluation is presented to take into account various waveform configurations including phased array (PA), partially correlated MIMO and ideally orthogonal MIMO. The proposed framework evaluates the system performance through optimum processing (OP) gain and transmit array (TA) gain. The OP gain is in turn evaluated by the number of available space-time measurements (ASMs) that depends on the number of clutter degrees of freedom (clutter NDoF) relative to the system degrees of freedom (system NDoF). The waveform diversity introduced by MIMO, especially f-MIMO, could significantly enhance the OP gain by increasing the number of ASMs. Hence, in OP-gain-limited scenarios, where the overall performance significantly degrades despite the TA gains, the preferable configuration in terms of optimum performance would be ordered as f-MIMO, c-MIMO, and last, PA, that is, no MIMO.

[34] Yunhe, C.; ,"Joint estimation of angle and Doppler frequency for bistatic MIMO radar," Electronics Letters , vol.46, no.2, pp.170-172, January 21 2010

Abstract: A method of joint estimation of angle and frequency for bistatic multiple-input multiple-output (MIMO) radar based on ESPRIT using the rotational factor produced by time delay sampling is discussed. In this algorithm, transmit angles, receive angles and Doppler frequencies can be obtained simultaneously and automatically paired without array aperture loss. Simulation results confirm the effectiveness of the proposed method.

[35] Qian He; Blum, R.S.; ,"Cramer--Rao Bound for MIMO Radar Target Localization With Phase Errors," Signal Processing Letters, IEEE , vol.17, no.1, pp.83-86, Jan. 2010

Abstract: Recent research indicates the potential of MIMO radar with dispersed antennas to achieve high target localization accuracy via coherent processing. Coherent processing requires phase synchronization. Usually, perfect phase synchronization is difficult to realize. Assuming frequency synchronization, possibly through reception of a beacon, and white noise, possibly due to estimating the covariance matrix and whitening the observations, the authors consider the impact of static phase errors at the transmitters and receivers for cases with sufficiently high SNR such that the Cramer-Rao bound (CRB) provides accurate performance estimates. The authors model the phase errors as random variables and discuss the impact of these errors on target localization performance. In a few example cases the CRB is computed and compared with those in the ideal coherent and noncoherent processing cases. For these examples, using numerical results, the authors will show that at high enough signal-to-noise ratio (SNR), phase errors degrade performance only by a relatively small amount.

[36] Li, J.; Blum, R. S.; Stoica, P.; Haimovich, A. M.; Wicks, M. C.; ,"Introduction to the Issue on MIMO Radar and Its Applications," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.2-4, Feb. 2010

Abstract: The 17 papers in this special issue cover various aspects of the latest MIMO radar research and development.

[37] Roberts, W.; Stoica, P.; Jian Li; Yardibi, T.; Sadjadi, F.A; ,"Iterative Adaptive Approaches to MIMO Radar Imaging," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.5-20, Feb. 2010

Abstract: Multiple-input multiple-output (MIMO) radar can achieve superior performance through waveform diversity over conventional phased-array radar systems. When a MIMO radar transmits orthogonal waveforms, the reflected signals from scatterers are linearly independent of each other. Therefore, adaptive receive filters, such as Capon and amplitude and phase estimation (APES) filters, can be directly employed in MIMO radar applications. High levels of noise and strong clutter, however, significantly worsen detection performance of the data-dependent beamformers due to a shortage of snapshots. The iterative adaptive approach (IAA), a nonparametric and user parameter-free weighted least-squares algorithm, was recently shown to offer improved resolution and interference rejection performance in several passive and active sensing applications. In this paper, the authors show how IAA can be extended to MIMO radar imaging, in both the negligible and nonnegligible intrapulse Doppler cases, and the authors also establish some theoretical convergence properties of IAA. In addition, the authors propose a regularized IAA algorithm, referred to as IAA-R, which can perform better than IAA by accounting for unrepresented additive noise terms in the signal model. Numerical examples are presented to demonstrate the superior performance of MIMO radar over single-input multiple-output (SIMO) radar, and further highlight the improved performance achieved with the proposed IAA-R method for target imaging.

[38] Fuhrmann, D.R.; Browning, J.P.; Rangaswamy, M.; ,"Signaling Strategies for the Hybrid MIMO Phased-Array Radar," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.66-78, Feb. 2010

Abstract: The hybrid MIMO phased array radar (HMPAR) is a notional concept for a multisensor radar architecture that combines elements of traditional phased-array radar with the emerging technology of multiple-input multiple output (MIMO) radar. A HMPAR comprises a large number, MP, of T/R elements, organized into M subarrays of P elements each. Within each subarray, passive element-level phase shifting is used to steer transmit and receive beams in some desired fashion. Each of the M subarrays are in turn driven by independently amplified phase-coded signals which could be quasi-orthogonal, phase-coherent, or partially correlated. Such a radar system could be used in an airborne platform for concurrent search, detect, and track missions. This paper considers various signaling strategies which could be employed in the notional HMPAR architecture to achieve various objectives quantified by transmit beampatterns and space-time ambiguity functions. First, the authors propose a method to generate multiple correlated signals for uniform linear and rectangular arrays that achieve arbitrary rectangular transmit beampatterns in one and two dimensions, while maintaining desirable temporal properties. Examples of the range of transmit beampatterns possible with this technique are illustrated for an array of MP=900 elements, arranged using different values of M and P. Then the space-time, or MIMO, ambiguity function that is appropriate for the HMPAR radar system is

derived. Examples of ambiguity functions for our signals using a one-dimensional HMPAR architecture are given, demonstrating that one can achieve phased-array-like resolution on receive, for arbitrary transmit beampatterns.

[39] Forsythe, K.W.; Bliss, D.W.; ,"MIMO Radar Waveform Constraints for GMTI," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.21-32, Feb. 2010

Abstract: Ground moving-target indication (GMTI) provides both an opportunity and challenge for coherent multiple-input multiple-output (MIMO) radar. MIMO techniques can improve a radar's angle estimation and the minimum detectable velocity (MDV) for a target. However, the challenge of clutter mitigation places significant constraints on MIMO radar waveforms. In this paper, the loss of target return because of clutter mitigation (signal-to-noise ratio (SNR) loss) is the driving performance metric. The ideal, orthogonal repeated-pulse waveform is shown not to exist. Pulse-to-pulse time-varying waveforms, such as Doppler-division multiple access (DDMA), are shown to offer SNR loss performance approaching ideal MIMO systems.

[40] Hongbin Li; Himed, B.; ,"Transmit Subaperturing for MIMO Radars With Co-Located Antennas," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.55-65, Feb. 2010

Abstract: The authors present a transmit subaperturing (TS) approach for multiple-input multiple-output (MIMO) radars with co-located antennas. The proposed scheme divides the transmit array elements into multiple groups, each group forms a directional beam and modulates a distinct waveform, and all beams are steerable and point to the same direction. The resulting system is referred to as a TS-MIMO radar. A TS-MIMO radar is a tunable system that offers a continuum of operating modes from the phased-array radar, which achieves the maximum directional gain but the least interference rejection ability, to the omnidirectional transmission based MIMO radar, which can handle the largest number of interference sources but offers no directional gain. Tuning of the TS-MIMO system can be easily made by changing the configuration of the transmit subapertures, which provides a direct tradeoff between the directional gain and interference rejection power of the system. The performance of the TS-MIMO radar is examined in terms of the output signal-to-interference-plus-noise ratio (SINR) of an adaptive beamformer in an interference and training limited environment, where the authors show analytically how the output SINR is affected by several key design parameters, including the size/number of the subapertures and the number of training signals. Our results are verified by computer simulation and comparisons are made among various operating modes of the proposed TS-MIMO system.

[41] Yuanwei Jin; Moura, J.M.F.; O'Donoughue, N.; ,"Time Reversal in Multiple-Input Multiple-Output Radar," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.210-225, Feb. 2010

Abstract: Time reversal explores the rich scattering in a multipath environment to achieve high target detectability. Multiple-input multiple-output (MIMO) radar is an emerging active sensing technology that uses diverse waveforms transmitted from widely spaced antennas to achieve increased target sensitivity when compared to standard phased arrays. In this paper, the authors combine MIMO radar with time reversal to automatically match waveforms to a scattering channel and further improve the performance of radar detection. The authors establish a radar target model in multipath rich environments and develop likelihood ratio tests for the proposed

time-reversal MIMO radar (TR-MIMO). Numerical simulations demonstrate improved target detectability compared with the commonly used statistical MIMO strategy.

[42] Correll, B.; ,"Efficient Spotlight SAR MIMO Linear Collection Configurations," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.33-39, Feb. 2010

Abstract: The authors describe how a family of synthetic aperture radar (SAR) platforms flying linearly and transmitting mutually orthogonal waveforms at a common pulse repetition frequency (PRF) constitute a multiple-input multiple output (MIMO) radar system that reduces time spent collecting a SAR image and quantify the efficiency of such sensor configurations. The authors give efficient collection configurations for up to 15 platforms as well as asymptotically optimally efficient sequences of configurations.

[43] Abramovich, Yu.I.; Frazer, G.J.; Johnson, B.A.; ,"Noncausal Adaptive Spatial Clutter Mitigation in Monostatic MIMO Radar: Fundamental Limitations," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.40-54, Feb. 2010

Abstract: The problem of a point target detection masked by clutter distributed over range and Doppler, including the range and Doppler of the target, is considered for a multimode propagation scenario commonly encountered in quasimonostatic HF over-the-horizon radars (OTHR). Here, a clutter signal spread in Doppler frequency due to propagation via a disturbed ionospheric layer competes with a target and narrowband clutter returns propagating via a stable ionospheric layer with the same group delay (radar range). Mitigation over all ranges of spread clutter propagating via a mixed mode path with indistinguishable direction-of-arrival (DoA) relative to the target requires (potentially adaptive) transmit beamforming to exploit the direction-of-departure (DoD) difference, which varies as a function of radar range. This range-dependent beamforming can be implemented only via the use of multiple-input multiple-output radar technology. In this paper, the authors explore the fundamental limitations that exist for the maximal dimension of the area in range-Doppler space occupied by spread clutter and the required properties (cardinality) of the orthogonal waveform set for efficient spread clutter mitigation.

[44] Yao Yu; Petropulu, A.P.; Poor, H.V.; ,"MIMO Radar Using Compressive Sampling," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.146-163, Feb. 2010

Abstract: A multiple-input multiple-output (MIMO) radar system is proposed for obtaining angle and Doppler information on potential targets. Transmitters and receivers are nodes of a small scale wireless network and are assumed to be randomly scattered on a disk. The transmit nodes transmit uncorrelated waveforms. Each receive node applies compressive sampling to the received signal to obtain a small number of samples, which the node subsequently forwards to a fusion center. Assuming that the targets are sparsely located in the angle-Doppler space, based on the samples forwarded by the receive nodes the fusion center formulates an l 1 -optimization problem, the solution of which yields target angle and Doppler information. The proposed approach achieves the superior resolution of MIMO radar with far fewer samples than required by other approaches. This implies power savings during the communication phase between the receive nodes and the fusion center. Performance in the presence of a jammer is analyzed for the case of slowly moving targets. Issues related to forming the basis matrix that spans the angle-Doppler space, and for selecting a grid for that space are discussed. Extensive simulation results

are provided to demonstrate the performance of the proposed approach at difference jammer and noise levels.

[45] Qian He; Blum, R.S.; Godrich, H.; Haimovich, A.M.; ,"Target Velocity Estimation and Antenna Placement for MIMO Radar With Widely Separated Antennas," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.79-100, Feb. 2010

Abstract: This paper studies the velocity estimation performance for multiple-input multiple-output (MIMO) radar with widely spaced antennas. The authors derive the Cramer-Rao bound (CRB) for velocity estimation and study the optimized system/configuration design based on CRB. General results are presented for an extended target with reflectivity varying with look angle. Then detailed analysis is provided for a simplified case, assuming an isotropic scatterer. For given transmitted signals, optimal antenna placement is analyzed in the sense of minimizing the CRB of the velocity estimation error. The authors show that when all antennas are located at approximately the same distance from the target, symmetrical placement is optimal and the relative position of transmitters and receivers can be arbitrary under the orthogonal received signal assumption. In this case, it is also shown that for MIMO radar with optimal placement, velocity estimation accuracy can be improved by increasing either the signal time duration or the product of the number of transmit and receive antennas.

[46] Griffiths, Hugh; ,"Workshop on multistatic and MIMO radar," Aerospace and Electronic Systems Magazine, IEEE , vol.25, no.2, pp.43-45, Feb. 2010

Abstract: MIMO radar should not be regarded as a separate subject, but rather as part of a continuum of different types of diverse, networked radar sensors.

[47] Al-Ahmadi, S.; Yanikomeroglu, H.; ,"On the approximation of the generalized distribution by a gamma distribution for modeling composite fading channels," Wireless Communications, IEEE Transactions on , vol.9, no.2, pp.706-713, February 2010

Abstract: In wireless channels, multipath fading and shadowing occur simultaneously leading to the phenomenon referred to as composite fading. The use of the Nakagami probability density function (PDF) to model multipath fading and the Gamma PDF to model shadowing has led to the generalized-K model for composite fading. However, further derivations using the generalized K PDF are quite involved due to the computational and analytical difficulties associated with the arising special functions. In this paper, the approximation of the generalized-K PDF by a Gamma PDF using the moment matching method is explored. Subsequently, an adjustable form of the expressions obtained by matching the first two positive moments, to overcome the arising numerical and/or analytical limitations of higher order moment matching, is proposed. The optimal values of the adjustment factor for different integer and non-integer values of the multipath fading and shadowing parameters are given. Moreover, the approach introduced in this paper can be used to well-approximate the distribution of the sum of independent generalized-K random variables by a gamma distribution; the need for such results arises in various emerging distributed communication technologies and systems such as coordinated multipoint transmission and reception schemes including distributed antenna systems and cooperative relay networks.

[48] Schindler, J.K.; ,"Sparse, Active Aperture Imaging," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.202-209, Feb. 2010

Abstract: The authors describe an approach to radar imaging of an isolated, rotating target using coherent, sparse, or highly thinned arrays of transmit/receive elements. The array elements are assumed to be randomly positioned and accurately surveyed after placement. Further, the isolated target is assumed to occupy a limited angular sector such that there is no source of backscatter beyond the sector occupied by the target. Estimates of the resolution and image quality are provided when the array elements are widely separated and operate with coherent, multiple-input multiple-output (MIMO) signaling and inverse synthetic aperture radar (ISAR) processing at each MIMO element pair. The sparse array operation can provide superior resolution when compared to the ISAR processing and accurate estimation of scattering properties with a modest number of sparse array elements. The performance of a model-based estimator to physical optics like scattering with MIMO signaling is described. Several important issues relating to feasibility remain to be investigated. These include establishing coherence and timing among the widely separated array elements, adaptive beamforming and processing requirements and coherence of the scattering phenomena with the widely separated MIMO elements.

[49] Chin Yuan Chong; Pascal, F.; Ovarlez, J.-P.; Lesturgie, M.; ,"MIMO Radar Detection in Non-Gaussian and Heterogeneous Clutter," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.115-126, Feb. 2010

Abstract: In this paper, the generalized likelihood ratio test-linear quadratic (GLRT-LQ) has been extended to the multiple-input multiple-output (MIMO) case where all transmit-receive subarrays are considered jointly as a system such that only one detection threshold is used. The GLRT-LQ detector has been derived based on the spherically invariant random vector (SIRV) model and is constant false alarm rate (CFAR) with respect to the clutter power fluctuations (also known as the texture). The new MIMO detector is then shown to be texture-CFAR as well. The theoretical performance of this new detector is first analytically derived and then validated using Monte Carlo simulations. Its detection performance is then compared to that of the well-known Optimum Gaussian Detector (OGD) under Gaussian and non-Gaussian clutter. Next, the adaptive version of the detector is investigated. The covariance matrix is estimated using the Fixed Point (FP) algorithm which enables the detector to remain texture- and matrix-CFAR. The effects of the estimation of the covariance matrix on the detection performance are also investigated.

[50] Wenshu Zhang; Liuqing Yang; ,"Communications-Inspired Sensing: A Case Study on Waveform Design," Signal Processing, IEEE Transactions on , vol.58, no.2, pp.792-803, Feb. 2010

Abstract: Information theory, and particularly the mutual information (MI), has provided fundamental guidance for communications research. In Bell's 1993 paper, the MI was first applied to radar waveform design. Similar to its communications counterpart, the solution comes in a water-filling form. However, the practical meaning of MI in the sensing context remains unclear to date. Recently, Yang and Blum's 2007 paper shows that under the white noise assumption, the optimum water-filling scheme simultaneously maximizes the MI and minimizes the estimation minimum mean square error (MMSE). Such an equivalence, however, does not hold when the target parameter statistics are not perfectly known as shown in Yang and Blum's subsequent work. To further the understanding of the practical meaning of MI and to establish a

connection between the MI and commonly adopted MSE measures for sensing, this paper takes a fresh look at the target estimation problem. The authors consider the general colored noise, incorporate the normalized MSE (NMSE), and develop joint robust designs for both the transmitter (waveforms) and the receiver (estimator) under various target and noise uncertainty models. Our results show that i) the optimum waveform designs resulted from the MI, MMSE and NMSE criteria are all different and ii) compared to MMSE, the NMSE-based designs share more similarities with the MI-based ones, especially when the target and noise statistics are not perfectly known.

[51] Yifan Chen; Craddock, I.J.; Kosmas, P.; Ghavami, M.; Rapajic, P.; ,"Multiple-Input Multiple-Output Radar for Lesion Classification in Ultrawideband Breast Imaging," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.187-201, Feb. 2010

Abstract: This paper studies the problem of applying multiple-input multiple-output (MIMO) radar techniques for lesion classification in ultrawideband (UWB) breast imaging. Ongoing work on this topic has suggested that benign and malignant masses, which usually possess remarkable architectural differences, could be distinguished by exploiting their morphology-dependent UWB microwave backscatter. The authors have previously approached this problem by deriving the complex natural resonances of the late-time target response, where the damping factors vary with the border profiles of anomalies. In this paper, the authors investigate the potential advantage of MIMO radar to enhance the resonance scattering phenomenon in breast tissue discrimination. MIMO radar can choose freely the probing signals transmitted via its antennas to exploit the independence between signals at the array elements, thereby enhancing the performance of target classification. Based on the observed damping factors and the receiver operating characteristics at different classifiers, which correspond to various diversity paths in the MIMO radar system, two data-fusion rules are proposed for robust lesion differentiation. Finally, numerical examples are provided to demonstrate the efficacy of the proposed imaging technique.

[52] Wu, X.H.; Kishk, A.A.; Glisson, A.W.; ,"MIMO-OFDM radar for direction estimation," Radar, Sonar & Navigation, IET , vol.4, no.1, pp.28-36, February 2010

Abstract: Multiple-input-multiple-output (MIMO) radar makes use of orthogonal signals to obtain the phase delay for each transmitting/receiving antenna pair, and thus increasing the accuracy of direction estimation. The previously proposed MIMO radar assumes narrowband signals that guarantee the waveform orthogonality during the signals- transmission, propagation and reception. However, a narrowband system is unstable in target localisation because of the fluctuation of the target-s radar cross section. An MIMO-OFDM radar is proposed for target localisation. It adopts the OFDM technique to simultaneously transmit and receive a set of multiple narrowband orthogonal signals at orthogonal frequencies. A practical model accommodating a physical target is presented to simulate the MIMO-OFDM radar. As an example, a composite target composed of five infinite dielectric cylinders is localised by a four-element uniform linear array. The performance of the MIMO-OFDM radar is investigated by examining the estimation error for different numbers of sub-bands, different signal-to-noise ratios and different target directions. It is demonstrated by simulation that the MIMO-OFDM radar gives more statistically stable estimation by spreading the signal power over a wider spectrum.

[53] Guohua Wang; Yilong Lu; ,"Clutter Rank of STAP in MIMO Radar With Waveform Diversity," Signal Processing, IEEE Transactions on , vol.58, no.2, pp.938-943, Feb. 2010

Abstract: In recent years, multiple-input multiple-output (MIMO) radar systems with space-time adaptive processing (STAP) have been proposed to improve radar performance. For MIMO radars with STAP, one big concern is the clutter rank. Current studies employ the rule of time-bandwidth product to predict the clutter rank of MIMO radars using orthogonal waveforms. This paper investigates clutter rank estimation for MIMO radar systems with more flexible waveform diversity, where waveforms are not constrained to be orthogonal. Under general waveform assumption, the authors have derived the clutter covariance matrix as a function of waveform covariance matrix (WCM). The clutter rank is then found to be determined by the rank and structure of the WCM. For different waveform cases, the WCM may be either full rank or rank deficient. Rules for estimation of clutter rank in these cases are provided and demonstrated by numerical simulations.

[54] Tajer, A.; Jajamovich, G.H.; Xiaodong Wang; Moustakides, G.V.; ,"Optimal Joint Target Detection and Parameter Estimation by MIMO Radar," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.127-145, Feb. 2010

Abstract: The authors consider multiple-input multiple-output (MIMO) radar systems with widely spaced antennas. Such antenna configuration facilitates capturing the inherent diversity gain due to independent signal dispersion by the target scatterers. The authors consider a new MIMO radar framework for detecting a target that lies in an unknown location. This is in contrast with conventional MIMO radars which break the space into small cells and aim at detecting the presence of a target in a specified cell. The authors treat this problem through offering a novel composite hypothesis testing framework for target detection when 1) one or more parameters of the target are unknown and the authors are interested in estimating them, and 2) only a finite number of observations are available. The test offered optimizes a metric which accounts for both detection and estimation accuracies. In this paper, as the parameter of interest the authors focus on the vector of time-delays that the waveforms undergo from being emitted by the transmit antennas until being observed by the receive antennas. The analytical and empirical results establish that for the proposed joint target detection and time-delay estimation framework, MIMO radars exhibit significant gains over phased-array radars for extended targets which consist of multiple independent scatterers. For point targets modeled as single scatterers, however, the detection/estimation accuracies of MIMO and phased-array radars for this specific setup (joint target detection and time-delay estimation) are comparable.

[55] Ahmad, F.; Amin, M.G.; ,"Matched-Illumination Waveform Design for a Multistatic Through-the-Wall Radar System," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.177-186, Feb. 2010

Abstract: The authors present the matched illumination waveform design for improved target detection in through-the-wall radar imaging and sensing applications. The authors consider a multistatic radar system for detection of stationary targets with known impulse responses behind walls. The stationary and slowly moving nature of typical indoor targets relaxes the orthogonality requirement on the waveforms, thereby allowing sequential transmissions from each transmitter with simultaneous reception at multiple receivers. The generalization of the matched illumination waveform design concept from a monostatic to a multistatic setting casts the indoor radar sensing

problem in terms of multiple-input multiple-output (MIMO) operations and puts in context the offering of MIMO to urban sensing and imaging of targets in enclosed structures. Numerical electromagnetic modeling is used to provide the impulse response of typical behind-the-wall stationary targets, namely tables and humans, for different target orientations and at various incident and reflection angles. Simulation results depict an improvement in the signal-to-clutter-and-noise-ratio (SCNR) at the output of the matched filter receiver for multistatic radar as compared to monostatic operation.

[56] Aittomaki, T.; Koivunen, V.; ,"Performance of MIMO Radar With Angular Diversity Under Swerling Scattering Models," Selected Topics in Signal Processing, IEEE Journal of , vol.4, no.1, pp.101-114, Feb. 2010

Abstract: The performance of statistical multiple-input multiple-output (MIMO) radar configurations that use distributed antennas is analyzed in this paper. Statistical MIMO radars exploit angular diversity to mitigate the impact of radar cross section (RCS) fluctuations. The fluctuations can be modeled with the Swerling scattering model consisting of four different cases with either fast or slow target RCS fluctuations. In this paper, the performance of different statistical MIMO radar configurations is compared in the different Swerling cases. Both target detection and direction of arrival estimation tasks are considered. The authors derive the optimal test statistics for target detection for non-orthogonal waveforms in all the Swerling cases in single-pulse as well as multi-pulse scenarios. The authors derive a closed-form density function for the test statistics under null and alternate hypotheses in the Swerling cases 1 and 2. For orthogonal waveforms in cases 3 and 4, the density function is given as a convolution involving a transcendental function. A suboptimal detector having a closed-form density function in cases 3 and 4 when the waveforms are orthogonal is introduced as well. In the direction finding task, confidence bounds of the squared estimation error of the different configurations are compared. The comparison is done in terms of the confidence bounds as the Cramer-Rao bounds are not defined for all the cases and configurations. The pros and cons of the angular diversity and each radar configuration are pointed out in different fluctuation scenarios.

[57] Gogineni, S.; Nehorai, A.; ,"Polarimetric MIMO Radar With Distributed Antennas for Target Detection," Signal Processing, IEEE Transactions on , vol.58, no.3, pp.1689-1697, March 2010

Abstract: Multiple-input-multiple-output (MIMO) radar systems with widely separated antennas enable viewing the target from different angles, thereby providing spatial diversity gain. Polarimetric design of the transmit waveforms based on the properties of the target scattering matrix provides better performance than transmitting waveforms with only fixed horizontal or vertical polarizations. The authors propose a radar system that combines the advantages of both systems by transmitting polarized waveforms from multiple distributed antennas, in order to detect a point-like stationary target. The proposed system employs 2-D vector sensors at the receivers, each of which measures the horizontal and vertical components of the received electric field separately. The authors design the Neyman-Pearson detector for such systems. The authors derive approximate expressions for the probability of false alarm (PFA) and the probability of detection (PD). Using numerical simulations, the authors demonstrate that optimal design of the antenna polarizations provides improved performance over MIMO systems that transmit waveforms of fixed polarizations over all the antennas. The authors also demonstrate that having multiple widely separated antennas gives improved performance over single-input-single-output

(SISO) polarimetric radar. The authors also demonstrate that processing the vector measurements at each receiver separately gives improved performance over systems that linearly combine both the received signals to give scalar measurements.

[58] Liu, Y.; Wu, M.Y.; Wu, S.J.; ,"Fast OMP algorithm for 2D angle estimation in MIMO radar," Electronics Letters , vol.46, no.6, pp.444-445, March 18 2010

Abstract: A high-dimensional sparse signal usually should be realigned as a long 1D signal to be recovered by orthogonal matching pursuit (OMP), an efficient algorithm for compressed sensing. Clearly, however, the realigned long signal will result in a large amount of computation in OMP. If each atom in the dictionary can be expressed as the Kronecker product of two vectors, it can possible to decompose this dictionary into two sub-dictionaries. By exploiting this property, a fast OMP algorithm for 2D sparse signals of this kind is presented, and applied to 2D angle estimation in MIMO radar. Simulation results verify its good reconstruction quality approximate to that of OMP and greatly improved computational efficiency.

[59] Yang Yang; Blum, R.S.; Zishu He; Fuhrmann, D.R.; ,"MIMO Radar Waveform Design via Alternating Projection," Signal Processing, IEEE Transactions on , vol.58, no.3, pp.1440-1445, March 2010

Abstract: Waveform design is essential to unleash the performance advantages promised by multiple-input multiple-output (MIMO) radar, and this topic has attracted a lot of attention in the recent years. Revisiting an earlier examined MIMO radar waveform design problem that optimizes both minimum mean-square error estimation (MMSE) and mutual information (MI), in this correspondence the authors formulate a new waveform design problem and provide some further results, which complement the previous study. More specifically, the authors present an iterative optimization algorithm based on the alternating projection method to determine waveform solutions that can simultaneously satisfy a structure constraint and optimize the design criteria. Numerical examples are provided, which illustrate the effectiveness of the proposed approach. In particular, the authors find that the waveform solutions obtained through our proposed algorithm can achieve very close and virtually indistinguishable performance from that predicted in the previous study.

[60] T. Naghibi, M. Namvar, F. Behnia, Optimal and robust waveform design for MIMO radars in the presence of clutter, Signal Processing, Volume 90, Issue 4, April 2010, Pages 1103–1117

Abstract: Waveform design for target identification and classification in MIMO radar systems has been studied in several recent works. While the previous works assumed that the noise was independent of the transmission signals, here the authors extend the results to the signal dependent noise (clutter). The authors consider two scenarios. In the first scenario it is assumed that different transmit antennas see uncorrelated aspects of the target. In the second scenario, the authors consider the correlated target. As clutter is dependent to signal, target estimation error cannot vanish only by increasing the transmission power. It can be shown that in the second scenario, MIMO radar receiver can nullify the clutter subspace. Thus, in the second scenario, target estimation error tends to zero if the transmission power tends to infinity. The authors consider waveform design problem for these scenarios based on MMSE and MI criteria. Like previous works, the authors find that these criteria lead to the same solution. Our problems lead to

the convex optimizaton problems, which can be efficiently solved through tractable numerical methods. Closed-form solutions are also developed for this SDP problem in two cases. In the first case, target and clutter covariance matrices are jointly diagonalizable and in the second, signal to noise ratio (SNR) is assumed to be sufficiently high. The authors also present two suboptimal formulations which require less knowledge of the statistical model of the target. In the first one the robust waveforms are computed by minimizing the estimation error of the worst-case target realization and in the second, target estimation error of the scaled least square (SLS) estimator is minimized.

[61] Sang Min Lee; Taejoong Song; Jongmin Park; Changhyuk Cho; Sangjun An; Kyutae Lim; Laskar, J.; ,"A CMOS Integrated Analog Pulse Compressor for MIMO Radar Applications," Microwave Theory and Techniques, IEEE Transactions on , vol.58, no.4, pp.747-756, April 2010

Abstract: Conventional radar pulse compressors use either surface acoustic wave devices or fast convolution processing, but both solutions have significant drawbacks. To overcome these drawbacks, an integrated analog pulse compressor for a multiple-input multiple-output (MIMO) radar has been developed with an 0.18-??m CMOS process using an arbitrary waveform generator, analog correlators, and analog-to-digital converters. The proposed scheme not only has advantages over conventional methods but also adds additional flexibility to the MIMO system. The die area is 5.67 mm2, and the power consumption is 62.6 mW from the 1.8-V supply. Arbitrary waveforms such as the wavelet and the chirp signal have been demonstrated, and the average signal-to-noise ratio for the pulse compression is 18.09 dB. The identification of overlapping multiple chirp signals is successfully demonstrated.

[62] Daher, R.; Adve, R.; ,"A Notion of Diversity Order in Distributed Radar Networks," Aerospace and Electronic Systems, IEEE Transactions on , vol.46, no.2, pp.818-831, April 2010

Abstract: The authors introduce the notion of diversity order in distributed radar networks. Our goal is to analyze the tradeoff between distributed detection, using K sensors, and centralized detection, using collocated antennas. The diversity order is representative of the degrees of freedom available in the system. In contrast with the asymptotically high signal-to-noise ratio (SNR) definition in wireless communications, the authors define the diversity order of a distributed radar network as the slope of the probability of detection (PD) versus SNR curve at PD = 0.5. The authors analyze an optimal joint detection system and prove that its corresponding Neyman-Pearson (NP) test statistic follows a Gamma distribution and that, for large K, its diversity order grows. For a fully distributed system using the NP fusion rule, the authors prove that the test statistic follows a binomial distribution. In more practical systems where the fusion center uses a fixed fusion rule, the largest growth in diversity order is achieved by the OR rule, and it only grows as log(K). The authors provide the results of simulations to confirm the theory developed.

[63] Zhang, Lijie; Huanq, Jiangua; Jin, Yang; Hau, Yunshan; Jianq, Min; Zhang, Qunfei; ,"Waveform diversity based sonar system for target localization," Systems Engineering and Electronics, Journal of , vol.21, no.2, pp.186-190, April 2010

Abstract: A new monostatic array system taking advantage of diverse waveforms to improve the performance of underwater target localization is proposed. Unlike the coherent signals between different elements in common active array, the transmitted signals from different elements here are spatially orthogonal waveforms which allow for array processing in the transit mode and result in an extension of array aperture. The mathematical derivation of Capon estimator for this sonar system is described in detail. And the performance of this orthogonal-waveform based sonar is analyzed and compared with that of its phased-array counterpart by water tank experiments. Experimental results show that this sonar system could achieve 12 dB--15 dB additional array gain over its phased-array counterpart, which means a doubling of maximum detection range. Moreover, the angular resolution is significantly improved at lower SNR.

[64] Zhang, J.; Zhang, L.R.; Yang, Z.W.; Liu, N.; ,"Signal subspace reconstruction method of MIMO radar," Electronics Letters , vol.46, no.7, pp.531 -533, April 1 2010

Abstract: A novel signal subspace reconstruction method for multiple-input multiple-output (MIMO) radar is proposed. The developed method realises signal subspace resconstruction by the eigendecomposition of two low dimension matrixes. It provides lower computational complexity and fewer training samples compared to the full DOF method. Simulation results are given to demonstrate the effectiveness of the method.

[65] Dang-Wei Wang; Xiao-Yan Ma; Yi Su; ,"Two-Dimensional Imaging via a Narrowband MIMO Radar System With Two Perpendicular Linear Arrays," Image Processing, IEEE Transactions on , vol.19, no.5, pp.1269-1279, May 2010

Abstract: This paper presents a system model and method for the 2-D imaging application via a narrowband multiple-input multiple-output (MIMO) radar system with two perpendicular linear arrays. Furthermore, the imaging formulation for our method is developed through a Fourier integral processing, and the parameters of antenna array including the cross-range resolution, required size, and sampling interval are also examined. Different from the spatial sequential procedure sampling the scattered echoes during multiple snapshot illuminations in inverse synthetic aperture radar (ISAR) imaging, the proposed method utilizes a spatial parallel procedure to sample the scattered echoes during a single snapshot illumination. Consequently, the complex motion compensation in ISAR imaging can be avoided. Moreover, in our array configuration, multiple narrowband spectrum-shared waveforms coded with orthogonal polyphase sequences are employed. The mainlobes of the compressed echoes from the different filter band could be located in the same range bin, and thus, the range alignment in classical ISAR imaging is not necessary. Numerical simulations based on synthetic data are provided for testing our proposed method.

[66] Zhi-Quan Luo; Wing-Kin Ma; So, A.M.-C.; Yinyu Ye; Shuzhong Zhang; ,"Semidefinite Relaxation of Quadratic Optimization Problems," Signal Processing Magazine, IEEE , vol.27, no.3, pp.20-34, May 2010

Abstract: In this article, the authors have provided general, comprehensive coverage of the SDR technique, from its practical deployments and scope of applicability to key theoretical results. The authors have also showcased several representative applications, namely MIMO detection, BÃ‚Â¿ shimming in MRI, and sensor network localization. Another important application, namely downlink transmit beamforming, is described in [1]. Due to space limitations, the authors are unable to cover many other beautiful applications of the SDR technique, although the authors have done our best to illustrate the key intuitive ideas that resulted in those applications. The authors hope that this introductory article will serve as a good starting point for readers who would like to apply the SDR technique to their applications and to locate specific references either in applications or theory.

[67] Dang-Wei Wang; Xiao-Yan Ma; Chen, A.-L.; Yi Su; ,"High-Resolution Imaging Using a Wideband MIMO Radar System With Two Distributed Arrays," Image Processing, IEEE Transactions on , vol.19, no.5, pp.1280-1289, May 2010

Abstract: Imaging a fast maneuvering target has been an active research area in past decades. Usually, an array antenna with multiple elements is implemented to avoid the motion compensations involved in the inverse synthetic aperture radar (ISAR) imaging. Nevertheless, there is a price dilemma due to the high level of hardware complexity compared to complex algorithm implemented in the ISAR imaging system with only one antenna. In this paper, a wideband multiple-input multiple-output (MIMO) radar system with two distributed arrays is proposed to reduce the hardware complexity of the system. Furthermore, the system model, the equivalent array production method and the imaging procedure are presented. As compared with the classical real aperture radar (RAR) imaging system, there is a very important contribution in our method that the lower hardware complexity can be involved in the imaging system since many additive virtual array elements can be obtained. Numerical simulations are provided for testing our system and imaging method.

[68] Zhang, X.; Xu, D.; ,"Angle estimation in MIMO radar using reduced-dimension capon," Electronics Letters , vol.46, no.12, pp.860-861, June 10 2010

Abstract: The problem of direction of departure and direction of arrival estimation for multiple-input multiple-output (MIMO) radar is discussed, and a reduced-dimension Capon algorithm is derived. The proposed algorithm which only requires one-dimension search, can avoid the high computational cost within the two-dimension Capon (2D-Capon) algorithm. It is illustrated that the algorithm has slightly better performance than the 2D-Capon algorithm. Simulation results verify the usefulness of the algorithm.

[69] Frankford, M.T.; Johnson, J.T.; Ertin, E.; ,"Including Spatial Correlations in the Statistical MIMO Radar Target Model," Signal Processing Letters, IEEE , vol.17, no.6, pp.575-578, June 2010

Abstract: Previous studies of statistical MIMO radar detection performance have used a target model that consists of a large number of point scatterers located within a rectangular target area.

These point scatterers have scattering amplitudes that are complex random variables and are spatially uncorrelated, so that the target is a white noise process in space. Spatial correlations are introduced into the target model in this paper, and the impact of these correlations on MIMO radar system detection performance is analyzed.

[70] Sen, S.; Nehorai, A.; ,"OFDM MIMO Radar With Mutual-Information Waveform Design for Low-Grazing Angle Tracking," Signal Processing, IEEE Transactions on , vol.58, no.6, pp.3152-3162, June 2010

Abstract: The authors propose an information theoretic waveform design algorithm for target tracking in a low-grazing angle (LGA) scenario. The authors incorporate realistic physical and statistical effects, such as Earth's curvature, vertical refractivity gradient of lower atmosphere, and compound-Gaussian characteristics of sea-clutter, into our model. The authors employ a co-located multiple-input-multiple-output (MIMO) radar configuration using wideband orthogonal frequency division multiplexing (OFDM) signalling scheme. The frequency diversity of OFDM provides richer information about the target as different scattering centers resonate at different frequencies. Additionally, the authors use polarization-sensitive transceivers to resolve the multipath signals with small separation angles. Thus, the authors track the scattering coefficients of the target at different frequencies along with its position and velocity. The authors apply a sequential Monte Carlo method (particle filter) to track the target. Our tracker works in a closed-loop fashion with an integrated optimal waveform design technique based on mutual information (MI) criterion. The authors seek the optimal OFDM waveform at the current pulse duration to maximize the MI between the state and measurement vectors at the next pulse duration utilizing all the measurement history up to the current pulse. Our numerical examples demonstrate the importance of realistic physical modeling, effects of frequency diversity through OFDM MIMO configuration, and achieved performance improvements due to adaptive OFDM waveform design.

[71] Xiaodong Zhuge; Yarovoy, A.G.; Savelyev, T.; Ligthart, L.; ,"Modified Kirchhoff Migration for UWB MIMO Array-Based Radar Imaging," Geoscience and Remote Sensing, IEEE Transactions on , vol.48, no.6, pp.2692-2703, June 2010

Abstract: In this paper, the formulation of Kirchhoff migration is modified for multiple-input-multiple-output (MIMO) array-based radar imaging in both free-space and subsurface scenarios. By applying the Kirchhoff integral to the multistatic data acquisition, the integral expression for the MIMO imaging is explicitly derived. Inclusion of the Snell's law and the Fresnel's equations into the integral formulation further expends the migration technique to subsurface imaging. A modification of the technique for strongly offset targets is proposed as well. The developed migration techniques are able to perform imaging with arbitrary MIMO configurations, which allow further exploration of the benefits of various array topologies. The proposed algorithms are compared with conventional diffraction stack migration on free-space synthetic data and experimentally validated by ground-penetrating radar experiments in subsurface scenarios. The results show that the modified Kirchhoff migration is superior over the conventional diffraction stack migration in the aspects of resolution, side-lobe level, clutter rejection ratio, and the ability to reconstruct shapes of distributed targets.

[72] Liu, X.L.; Liao, G.S.; ,"Multi-target localisation in bistatic MIMO radar," Electronics Letters , vol.46, no.13, pp.945 -946, June 24 2010

Abstract: An algorithm for multi-target localisation in bistatic multiple-input multiple-output (MIMO) radar is presented. The directions of arrival (DOAs) of targets can be estimated via ESPRIT by means of the rotational factor produced from two receive subarrays with the corresponding directions of departure (DODs) being paired automatically via the signal subspace. Numerical examples show the effectiveness of the proposed method.

[73] Hassanien, A.; Vorobyov, S.A.; ,"Phased-MIMO Radar: A Tradeoff Between Phased-Array and MIMO Radars," Signal Processing, IEEE Transactions on , vol.58, no.6, pp.3137-3151, June 2010

Abstract: The authors propose a new technique for multiple-input multiple-output (MIMO) radar with colocated antennas which the authors call phased-MIMO radar. The new technique enjoys the advantages of the MIMO radar without sacrificing the main advantage of the phased-array radar which is the coherent processing gain at the transmitting side. The essence of the proposed technique is to partition the transmit array into a number of subarrays that are allowed to overlap. Then, each subarray is used to coherently transmit a waveform which is orthogonal to the waveforms transmitted by other subarrays. Coherent processing gain can be achieved by designing a weight vector for each subarray to form a beam towards a certain direction in space. Moreover, the subarrays are combined jointly to form a MIMO radar resulting in higher angular resolution capabilities. Substantial improvements offered by the proposed phased-MIMO radar technique as compared to the phased-array and MIMO radar techniques are demonstrated analytically and by simulations through analyzing the corresponding beam patterns and the achievable output signal-to-noise-plus-interference ratios. Both analytical and simulation results validate the effectiveness of the proposed phased-MIMO radar.

[74] Qian He; Blum, R.S.; Haimovich, A.M.; ,"Noncoherent MIMO Radar for Location and Velocity Estimation: More Antennas Means Better Performance," Signal Processing, IEEE Transactions on , vol.58, no.7, pp.3661-3680, July 2010

Abstract: This paper presents an analysis of the joint estimation of target location and velocity using a multiple-input multiple-output (MIMO) radar employing noncoherent processing for a complex Gaussian extended target. A MIMO radar with M transmit and N receive antennas is considered. To provide insight, the authors focus on a simplified case first, assuming orthogonal waveforms, temporally and spatially white noise-plus-clutter, and independent reflection coefficients. Under these simplifying assumptions, the maximum-likelihood (ML) estimate is analyzed, and a theorem demonstrating the asymptotic consistency, large MN , of the ML estimate is provided. Numerical investigations, given later, indicate similar behavior for some reasonable cases violating the simplifying assumptions. In these initial investigations, the authors study unconstrained systems, in terms of complexity and energy, where each added transmit antenna employs a fixed energy so that the total transmitted energy is allowed to increase as the authors increase the number of transmit antennas. Following this, the authors also look at constrained systems, where the total system energy and complexity are fixed. To approximate systems of fixed complexity in an abstract way, the authors restrict the total number of antennas employed to be fixed. Here, the authors show numerical examples which indicate a preference for receive antennas, similar to MIMO communications, but where systems with multiple transmit

antennas yield the smallest possible mean-square error (MSE). The joint Cramer-Rao bound (CRB) is calculated and the MSE of the ML estimate is analyzed. It is shown for some specific numerical examples that the signal-to-clutter-plus-noise ratio (SCNR) threshold, indicating the SCNRs above which the MSE of the ML estimate is reasonably close to the CRB, can be lowered by increasing MN. The noncoherent MIMO radar ambiguity function (AF) is developed in two different ways and illustrated by examples. It is shown for some specif- - ic examples that the size of the product MN controls the levels of the sidelobes of the AF.

[75] Abramovich, Y.I.; Frazer, G.J.; Johnson, B.A.; ,"Iterative Adaptive Kronecker MIMO Radar Beamformer: Description and Convergence Analysis," Signal Processing, IEEE Transactions on , vol.58, no.7, pp.3681-3691, July 2010

Abstract: The authors introduce an iterative procedure for design of adaptive KL-variate linear beamformers that are structured as the Kronecker product of K-variate (transmit) and L-variate (receive) beamformers. The authors focus on MIMO radar applications for scenarios where only joint transmit and receive adaptive beamforming can efficiently mitigate multi-mode propagated backscatter interference. This is because the direction-of-departure (DoD) on one interference mode, and the direction-of-arrival (DoA) on the other, coincide with those of a target, respectively. The authors introduce a Markov model for the adaptive iterative routine, specify its convergence condition, and derive final (stable) signal-to-interference-plus-noise ratio (SINR) performance characteristics. Simulation results demonstrate high accuracy of the analytical derivations. In addition, the authors demonstrate, that for the considered class of multiple-input multiple-output (MIMO) radar interference scenarios, the diagonally loaded sample matrix inversion (SMI) algorithm provides additional performance improvement and convergence rate for this iterative adaptive Kronecker beamformer.

[76] Guang Qing Duan; Dang Wei Wang; Xiao Yan Ma; Yi Su; ,"Three-Dimensional Imaging via Wideband MIMO Radar System," Geoscience and Remote Sensing Letters, IEEE , vol.7, no.3, pp.445-449, July 2010

Abstract: The 3-D inverse synthetic aperture radar imaging fast maneuvering targets is an active research area in the past decades. Planar antenna arrays are used to avoid the motion compensation algorithms but at the cost of increasing the hardware complexity. In this letter, to reduce the hardware complexity of the imaging system, a wideband multiple-input multiple-output system with two perpendicular linear arrays is suggested. In contrast to the existing 3-D imaging methods with planar antenna arrays, with the proposed method, the lower hardware complexity is achieved by many additive virtual array elements. Simulations based on synthetic data are provided for testing the proposed method.

[77] He, Qian; Lehmann, Nikolaus H.; Blum, Rick S.; Haimovich, Alexander M.; ,"MIMO Radar Moving Target Detection in Homogeneous Clutter," Aerospace and Electronic Systems, IEEE Transactions on , vol.46, no.3, pp.1290-1301, July 2010

Abstract: A multiple-input multiple-output (MIMO) radar approach employing widely dispersed transmit and receive antennas is studied for the detection of moving targets. The MIMO radar transmits orthogonal waveforms from the different transmit antennas so these waveforms can be separated at each receive antenna. For a moving target in colored Gaussian noise-plus-clutter, the authors quantify the gains from having widely dispersed antennas that allow the overall system to

"view" the target simultaneously from several different directions. The MIMO radar performance is contrasted with that of a traditional phased-array approach, which employs closely spaced antennas for this purpose. The MIMO radar approach is well suited to handle targets that have small radial velocities for scenarios in which colocated sensors cannot separate the target from the background clutter. Both a centralized processing and a simple distributed processing form of the MIMO radar approach are developed and studied, and the gains from the centralized version, which come at the price of additional complexity, are clearly demonstrated and explained intuitively. The constant false alarm rate (CFAR) property of an adaptive version of the MIMO moving target detector is also demonstrated for homogeneous clutter.

[78] Li, S.F.; Chen, J.; Zhang, L.Q.; ,"Optimisation of complete complementary codes in MIMO radar system," Electronics Letters , vol.46, no.16, pp.1157-1159, August 5 2010

Abstract: The novelty of multiple-input multiple-output (MIMO) radar is to improve the performance of radar utilising spatial diversity and waveform diversity. Proposed is the optimisation design of complete complementary sequence (CC-S) for MIMO radar based on channel capacity with the clutter statistical properties known. The method obtains the optimised CC-S through maximising the channel capacity of MIMO radar. The result shows that the optimised CC-S is a function of the clutter covariance matrix. Finally, the method from the information theoretical point of view is verified.

[79] Pal, P.; Vaidyanathan, P.P.; ,"Nested Arrays: A Novel Approach to Array Processing With Enhanced Degrees of Freedom," Signal Processing, IEEE Transactions on , vol.58, no.8, pp.4167-4181, Aug. 2010

Abstract: A new array geometry, which is capable of significantly increasing the degrees of freedom of linear arrays, is proposed. This structure is obtained by systematically nesting two or more uniform linear arrays and can provide O(N2) degrees of freedom using only N physical sensors when the second-order statistics of the received data is used. The concept of nesting is shown to be easily extensible to multiple stages and the structure of the optimally nested array is found analytically. It is possible to provide closed form expressions for the sensor locations and the exact degrees of freedom obtainable from the proposed array as a function of the total number of sensors. This cannot be done for existing classes of arrays like minimum redundancy arrays which have been used earlier for detecting more sources than the number of physical sensors. In minimum-input-minimum-output (MIMO) radar, the degrees of freedom are increased by constructing a longer virtual array through active sensing. The method proposed here, however, does not require active sensing and is capable of providing increased degrees of freedom in a completely passive setting. To utilize the degrees of freedom of the nested co-array, a novel spatial smoothing based approach to DOA estimation is also proposed, which does not require the inherent assumptions of the traditional techniques based on fourth-order cumulants or quasi stationary signals. As another potential application of the nested array, a new approach to beamforming based on a nonlinear preprocessing is also introduced, which can effectively utilize the degrees of freedom offered by the nested arrays. The usefulness of all the proposed methods is verified through extensive computer simulations.

[80] Xiufeng Song; Shengli Zhou; Willett, P.; ,"Reducing the Waveform Cross Correlation of MIMO Radar With Space--Time Coding," Signal Processing, IEEE Transactions on , vol.58, no.8, pp.4213-4224, Aug. 2010

Abstract: Multiple-input-multiple-output (MIMO) radar is attractive for target detection, parameter identification, and target classification due to diversity of waveform and perspective. However, the mutual interference among the waveforms may lead to performance degradation in resolving spatially close returns. In this paper, the authors consider the use of space-time coding (STC) to mitigate the waveform cross-correlation effects in MIMO radar. First, it turns out that a joint waveform optimization problem can be decoupled into a set of individual waveform design problems. Second, a number of monostatic waveforms can be directly used in a MIMO radar system, which offers flexibility in waveform selection. The authors provide conditions for the elimination of waveform cross correlation, and discuss four kinds of space time codes. In addition, the authors also extend the model to partial waveform cross-correlation removal based on waveform set division. Numerical results demonstrate the effectiveness of STC in MIMO radar for waveform decorrelation.

[81] Pastina, D.; Bucciarelli, M.; Lombardo, P.; ,"Multistatic and MIMO Distributed ISAR for Enhanced Cross-Range Resolution of Rotating Targets," Geoscience and Remote Sensing, IEEE Transactions on , vol.48, no.8, pp.3300-3317, Aug. 2010

Abstract: In this paper, the authors present a new technique to exploit the data acquired simultaneously by multiple radar sensors carried by multiple air platforms to increase the cross-range resolution of inverse synthetic aperture radar (ISAR) images of rotating targets. This distributed ISAR technique is devised for two different cases: 1) multiple-input-multiple-output (MIMO) case with each platform carrying an active radar that transmits and receives RF waveforms and 2) multistatic case with a single platform carrying an active radar (transmitting and receiving) and the remaining platforms equipped with passive sensors (namely, receiving only). The processing chain proposed for the distributed ISAR is shown, together with the results obtained against simulated ISAR data for both the MIMO and the multistatic cases. The performance analysis shows that the proposed technique is able to provide an increase of the cross-range resolution up to the number of platforms in the multistatic case and even higher in the MIMO case, if the platforms are properly located. This is of great benefit in applications where the target rotation angle is insufficient to guarantee the desired resolution. A typical case is the imaging of ship targets with rotation induced by the sea swell structure under low sea state conditions. To make the results appealing for practical application, the performance degradation is also analyzed arising from errors in the knowledge of both the target rotation motion and the acquisition geometry. Experimental data collected by a ground-based radar operating together with a rotating platform are processed by following the presented distributed ISAR technique to validate the proposed approach.

[82] Yutao Zhu; Yi Su; Wenxian Yu; ,"An ISAR Imaging Method Based on MIMO Technique," Geoscience and Remote Sensing, IEEE Transactions on , vol.48, no.8, pp.3290-3299, Aug. 2010

Abstract: With the inverse synthetic aperture radar (ISAR) imaging model, targets should move smoothly during the coherent processing interval (CPI). Since the CPI is quite long, fluctuations of a target's velocity and gesture will deteriorate image quality. This paper presents a multiple-

input-multiple-output (MIMO)-ISAR imaging method by combining MIMO techniques and ISAR imaging theory. By using a special M-transmitter N-receiver linear array, a group of M orthogonal phase-code modulation signals with identical bandwidth and center frequency is transmitted. With a matched filter set, every target response corresponding to the orthogonal signals can be isolated at each receiving channel, and range compression is completed simultaneously. Based on phase center approximation theory, the minimum entropy criterion is used to rearrange the echo data after the target's velocity has been estimated, and then, the azimuth imaging will finally finish. The analysis of imaging and simulation results show that the minimum CPI of the MIMO-ISAR imaging method is 1/MN of the conventional ISAR imaging method under the same azimuth-resolution condition. It means that most flying targets can satisfy the condition that targets should move smoothly during CPI; therefore, the applicability and the quality of ISAR imaging will be improved.

[83] Ithapu, V.K.; Mishra, A.K.; ,"Cooperative Multimonostatic SAR: A New SAR Configuration for Improved Resolution," Antennas and Wireless Propagation Letters, IEEE , vol.9, pp.701-704, 2010

Abstract: This letter presents a new synthetic aperture radar (SAR) configuration that has been named cooperative multimonostatic SAR (CMM SAR). CMM SAR consists of a battery of monostatic SARs whose flight paths and frequency bands are coordinated in such a way that the final system produces high-resolution images. The point spread function (PSF) of CMM SAR has been used to quantify the gain in resolution as compared to a monostatic SAR system operating under the same k-space area. Three different configurations of CMM SAR have been proposed. Evaluations of these CMM SARs are done, and the results show substantial improvement in performance compared to the conventional monostatic SAR. One of these three CMM SARs is especially the most successful in terms of both gain in performance and simplicity in implementation.

[84] Bo Tang; Jun Tang; Yingning Peng; ,"MIMO Radar Waveform Design in Colored Noise Based on Information Theory," Signal Processing, IEEE Transactions on , vol.58, no.9, pp.4684-4697, Sept. 2010

Abstract: In this paper, the authors consider multiple input multiple output (MIMO) radar waveform design in colored noise. Two information theoretic measures are used as criterions for optimal waveform design under transmitted power constraint. The first one is by maximizing the mutual information between target impulse response and target echoes; the second one is by maximizing the relative entropy between two hypotheses: in the first hypothesis the authors assume the target is not present in the echoes while in the second hypothesis the authors assume the target exists in the echoes. The authors derive optimal solutions for both cases. Interestingly, both optimal solutions require that transmitted waveform should "match" with the target and noise. However, the optimal solutions of the two problems lead to different power allocation strategies.

[85] Mohamed Laid Bencheikh, Yide Wang, Hongyang He, “Polynomial root finding technique for joint DOA DOD estimation in bistatic MIMO radar”, Signal Processing, Volume 90, Issue 9, September 2010, Pages 2723–2730

Abstract: In this paper, the authors propose a new technique to transform the 2-D direction finding in the bistatic MIMO radar into a double 1-D direction finding procedure. Firstly, a search based 2-D MUSIC method to estimate the joint DOA (direction of arrival) and DOD (direction of departure) in multi-target situation is presented. Then, the authors propose an algorithm based on double polynomial root finding procedure to estimate the DOA and DOD. The proposed method allows an efficient estimation of the target DOA and DOD with automatic pairing. The simulation results of the proposed algorithm are presented and the performances are investigated and discussed.

[86] Jindong Zhang; Haiqing Wang; Xiaohua Zhu; ,”Adaptive Waveform Design for Separated Transmit/Receive ULA-MIMO Radar," Signal Processing, IEEE Transactions on , vol.58, no.9, pp.4936-4942, Sept. 2010

Abstract: The colocated uniform linear array (ULA) multiple-input multiple-output (MIMO) radar has been demonstrated to provide enhanced performance in theory. Similar to a bistatic radar, performance of the separated transmit/receive (STR) ULA-MIMO radar is affected not only by the transmitted multiple orthogonal waveforms, but also by the position of the target. In this correspondence, the ambiguity function of the STR-ULA-MIMO radar is investigated and the corresponding range-velocity ambiguity function (RVAF) is deduced. The range and velocity resolution of RVAF for the STR-ULA-MIMO radar is discussed. Because the shape of RVAF for the STR-ULA-MIMO radar is related to the position of the target, a new algorithm for adaptively designing the orthogonal frequency-hopping waveforms according to the position of the target is proposed. This algorithm improves the range and velocity resolution and the integrated sidelobe level (ISL) of the matched filter output at the corresponding position.

[87] Akçakaya, M.; Nehorai, A.; ,”MIMO Radar Detection and Adaptive Design Under a Phase Synchronization Mismatch," Signal Processing, IEEE Transactions on , vol.58, no.10, pp.4994-5005, Oct. 2010

Abstract: The authors consider the problem of target detection for multi-input multi-output radar with widely separated antennas in the presence of a phase synchronization mismatch between the transmitter and receiver pairs. Such mismatch often occurs due to imperfect knowledge of the locations and local oscillator characteristics of the antennas. First, the authors introduce a data model using a von Mises distribution to represent the phase error terms. Then, the authors employ an expectation-maximization algorithm to estimate the error distribution parameter, target returns, and noise variance. The authors develop a generalized likelihood ratio test target detector using these estimates. Based on the mutual information between the radar measurements and received target returns (and hence the phase error), the authors propose an algorithm to adaptively distribute the total transmitted energy among the transmitters. Using Monte Carlo simulations, the authors demonstrate that the adaptive energy allocation, increase in the phase information, and realistic measurement modeling improve the detection performance.

[88] Changzheng Ma; Tat Soon Yeo; Chee Seng Tan; Yong Qiang; Tao Zhang; ,"Receiver Design for MIMO Radar Range Sidelobes Suppression," Signal Processing, IEEE Transactions on , vol.58, no.10, pp.5469-5474, Oct. 2010

Abstract: Multiple-input multiple-output (MIMO) radar transmits multiple-coded signals. In matched filter receiver, coded signals are required to have very good auto- and cross-correlation properties. These conditions are difficult to fulfill simultaneously when the lengths of the codes are short and there are many transmit antennas. In this correspondence, a receive filter matrix is designed using quadratic optimization method. The integrated correlations between the transmitted codes and the receive filter matrix in the area around zero shift are constrained under a prescribed level and the output noise power is minimized. A closed form solution is obtained. This integrated sidelobe level (ISL) method is computationally more efficient compared with the peak sidelobe level (PSL) method.

[89] Cui, G.; Kong, L.; Yang, X.; ,"Multiple-input multiple-output radar detectors design in non-Gaussian clutter," Radar, Sonar & Navigation, IET , vol.4, no.5, pp.724-732, October 2010

Abstract: This study mainly deals with the problem of multiple-input multiple-output (MIMO) radar in compound-Gaussian clutter-dominated scenario with unknown covariance matrix. The general MIMO model, with widely separated sub-arrays and co-located antennas at each sub-array, is adopted. First, the signal model is developed to compound-Gaussian clutter, and then, the generalised likelihood rate test (GLRT) and Rao detectors are derived with known covariance matrix. To make the detectors fully adaptive, the secondary with signal-free data is collected to estimate the covariance. A thorough performance assessment is also given, which considers the sense with co-located antennas configuration of transmitters and receivers array. Via several numerical examples, it is shown that the derived GLRT and Rao detectors can provide excellent detection performance in spikier clutter compared with the detector, which is derived by Jian Li in Gaussian clutter. To this end, the Rao detector outperforms best.

[90] Liu, J.; Liu, Z.; Xie, R.; ,"Low angle estimation in MIMO radar," Electronics Letters , vol.46, no.23, pp.1565 -1566, November 11 2010

Abstract: A low angle estimation method in the presence of the multipath for multiple-input multiple-output (MIMO) radar is proposed. The multipath signal model for MIMO radar is constructed with both transmitted multipath and received multipath signals being considered. To reduce the computational burden and retain estimation precision, the beam-space maximum likelihood algorithm is developed for angle estimation. This method overcomes multipath effects for low angle measurement, and only requires one one-dimension search procedure. Simulation results are presented to verify the effectiveness of the proposed method.

[91] Nion, D.; Sidiropoulos, N.D.; ,"Tensor Algebra and Multidimensional Harmonic Retrieval in Signal Processing for MIMO Radar," Signal Processing, IEEE Transactions on , vol.58, no.11, pp.5693-5705, Nov. 2010

Abstract: Detection and estimation problems in multiple-input multiple-output (MIMO) radar have recently drawn considerable interest in the signal processing community. Radar has long been a staple of signal processing, and MIMO radar presents challenges and opportunities in

adapting classical radar imaging tools and developing new ones. Our aim in this article is to showcase the potential of tensor algebra and multidimensional harmonic retrieval (HR) in signal processing for MIMO radar. Tensor algebra and multidimensional HR are relatively mature topics, albeit still on the fringes of signal processing research. The authors show they are in fact central for target localization in a variety of pertinent MIMO radar scenarios. Tensor algebra naturally comes into play when the coherent processing interval comprises multiple pulses, or multiple transmit and receive subarrays are used (multistatic configuration). Multidimensional harmonic structure emerges for far-field uniform linear transmit/receive array configurations, also taking into account Doppler shift; and hybrid models arise in-between. This viewpoint opens the door for the application and further development of powerful algorithms and identifiability results for MIMO radar. Compared to the classical radar-imaging-based methods such as Capon or MUSIC, these algebraic techniques yield improved performance, especially for closely spaced targets, at modest complexity.

[92] Jajamovich, G.H.; Lops, M.; Xiaodong Wang; ,"Space-Time Coding for MIMO Radar Detection and Ranging," Signal Processing, IEEE Transactions on , vol.58, no.12, pp.6195-6206, Dec. 2010

Abstract: Space-time coding (STC) has been shown to play a key role in the design of MIMO radars with widely spaced antennas: In particular, rank-one coding amounts to using the multiple transmit antennas as power multiplexers, while full-rank coding maximizes the transmit diversity, compromises between the two being possible through rank-deficient coding. In detecting a target at known distance and Doppler frequency, no uniformly optimum transmit policy exists, and diversity maximization turns out to be the way to go only in a (still unspecified) large signal-to-noise ratio region. The aim of this paper is to shed some light on the optimum transmit policy as the radar is to detect a target at an unknown location: To this end, at first the Cramer-Rao bounds as a function of the STC matrix are computed, and then waveform design is stated as a constrained optimization problem, where now the constraint concerns also the accuracy in target ranging, encapsulated in the Fisher Information on the range estimate. Results indicate that such accuracy constraints may visibly modify the required transmit policy and lead to rank-deficient STC also in regions where pure detection would require pursuing full transmit diversity.

[93] Xiaofei Zhang; Lingyun Xu; Lei Xu; Dazhuan Xu; ,"Direction of Departure (DOD) and Direction of Arrival (DOA) Estimation in MIMO Radar with Reduced-Dimension MUSIC," Communications Letters, IEEE , vol.14, no.12, pp.1161-1163, December 2010

Abstract: This letter discusses the problem of direction of departure (DOD) and direction of arrival (DOA) estimation for multi-input multi-output (MIMO) radar, and derives a reduced-dimension multiple signal classification (MUSIC) algorithm therein. The proposed algorithm, which only requires one-dimension search, can avoid the high computational cost within two-dimension MUSIC (2D-MUSIC) algorithm. The authors illustrate that the algorithm has better performance ESPRIT algorithm, and has very close performance to 2D-MUSIC algorithm. Further our algorithm requires no pair matching. Simulation results verify the usefulness of our algorithm.

[94] Rong Xie, Zheng Liu, Zi-jing Zhang, DOA estimation for monostatic MIMO radar using polynomial rooting, Signal Processing, Volume 90, Issue 12, December 2010, Pages 3284–3288

Abstract: A direction of the arrival (DOA) estimation method utilizing polynomial rooting is developed for monostatic MIMO radar. Utilizing the redundancy of the received data, a reduced-dimensional matrix is firstly performed to alleviate the temporal snapshots requirement and the computational burden resulting from the inversion of the covariance matrix. To further alleviate the complexity burden, a polynomial rooting method is proposed to identify the extreme values of Capon spatial spectrum. Since the target DOA lies in the set of all extreme values, DOA estimation method can be performed based only on the candidate angles around those extreme values. Numerical results verify the effectiveness of this method.

[95] Yang, M.L.; Chen, B.X.; Yang, X.Y.; ,"Conjugate esprit algorithm for bistatic mimo radar," Electronics Letters , vol.46, no.25, pp.1692 -1694, December 9 2010

Abstract: A novel conjugate ESPRIT (C-ESPRIT) algorithm is proposed to estimate the direction of arrival (DOA) and direction of departure (DOD) for bistatic MIMO radar. It employs the properties of noncircular signals to construct a new virtual array first, the virtual antenna number of which is twice that of the MIMO virtual array. It then exploits the rotational invariance property of the new virtual array to estimate DOAs and DODs of multiple targets through ESPRIT which are paired automatically in a new way. This algorithm can provide more precise angle estimation and can detect more targets than well-known classical subspace methods. Simulation results validate these conclusions.

[96] Kong, Lingjiang; Cui, Guolong; Yang, Xiaobo; Yang, Jianyu; ,"Adaptive detector design of MIMO radar with unknown covariance matrix," Systems Engineering and Electronics, Journal of , vol.21, no.6, pp.954-960, Dec. 2010

Abstract: The problem of detecting signal with multiple input multiple output (MIMO) radar in correlated Gaussian clutter dominated scenario with unknown covariance matrix is dealt with. The general MIMO model, with widely separated sub-arrays and co-located antennas at each sub-array, is adopted. Firstly, the generalized likelihood ratio test (GLRT) with known covariance matrix is obtained, and then the Rao and Wald detectors are devised, which have proved that the Rao and Wald test coincide with GLRT detector. To make the detectors fully adaptive, the secondary data with signal-free will be collected to estimate the covariance. The performance of the proposed detector is analyzed, however, it is just ancillary. A thorough performance assessment by several numerical examples is also given, which has considered the sense with co-located antennas configure of transmitters and receivers array. The results show that the performance the proposed adaptive detector is better than LJ-GLRT, and the loss can be acceptable in comparison to their non-adaptive counterparts.

[97] Cong Xiang, Da-Zheng Feng, Hui Lv, Jie He, Yang Cao, "Robust adaptive beamforming for MIMO radar," Signal Processing, Volume 90, Issue 12, December 2010, Pages 3185–3196

Abstract: In this paper, a new robust adaptive beamforming method is developed for MIMO radar in the presence of unknown mismatches of the desired signal steering vectors. Explicit models of

uncertainties in both transmitted and received signal steering vectors are considered. It is shown that the robust adaptive beamforming problem for MIMO radar can be solved by minimizing a convex quadratic cost function based on the optimization of worst-case performance when full DOFs of MIMO radar are used. Whereas, the authors reformulate the quadratic cost function into a bi-quadratic cost function by adopting a separable form for the weight vector and the minimum point of the new cost function can be efficiently found by combining bi-iterative algorithm (BIA) with second-order cone programming (SOCP). The proposed beamformer has lower computational complexity and faster convergence rate comparable with that of the traditional robust adaptive beamforming algorithms with full DoFs, while, at the same time, it provides better robustness to the non-ideal cases and reduces the training samples required. Numerical experiments with the frequently encountered types of signal steering vector mismatches are provided to demonstrate the effectiveness of the proposed robust adaptive beamforming algorithm as compared with the other robust adaptive beamforming algorithms.

[98] Xiaodong Zhuge; Yarovoy, A.G.; ,"A Sparse Aperture MIMO-SAR-Based UWB Imaging System for Concealed Weapon Detection," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.1, pp.509-518, Jan. 2011

Abstract: A high-resolution imaging system based on the combination of ultrawideband (UWB) transmission, multiple-input-multiple-output (MIMO) array, and synthetic aperture radar (SAR) is suggested and studied. Starting from the resolution requirements, spatial sampling criteria for nonmonochromatic waves are investigated. Exploring the decisive influence of the system's fractional bandwidth (instead of previously claimed aperture sparsity) on the imaging capabilities of sparse aperture arrays, a MIMO linear array is designed based on the principle of effective aperture. For the antenna array, an optimized UWB antenna is designed allowing for distortionless impulse radiation with more than 150% fractional bandwidth. By combining the digital beamforming in the MIMO array with the SAR in the orthogonal direction, a high-resolution 3-D volumetric imaging system with a significantly reduced number of antenna elements is proposed. The proposed imaging system is experimentally verified against the conventional 2-D SAR under different conditions, including a typical concealed-weapon-detection scenario. The imaging results confirm the correctness of the proposed system design and show a strong potential of the MIMO-SAR-based UWB system for security applications.

[99] Wang, J.; Jiang, S.; He, J.; Liu, Z.; Baker, C.J.; ,"Adaptive subspace detector for multi-input multi-output radar in the presence of steering vector mismatch," Radar, Sonar & Navigation, IET , vol.5, no.1, pp.23-31, January 2011

Abstract: This study studies the problem of adaptive target detection by multi-input multi-output (MIMO) radar with multiple antennas at each of the receiver sites. MIMO radar has been postulated to have a number of advantages over its monostatic counterpart. However, many previous publications have not necessarily made valid assumptions in assessing performance potential. Here, the authors consider the issue of the overall MIMO radar system steering vector which should be aligned with the desired pointing direction. However, misalignment can occur because of calibration errors, receiver channel imperfections and beam pointing errors. To account for this misalignment, the steering vector is assumed to belong to a known linear subspace. At the design stage, the authors resort to a generalised likelihood ratio principle and Rao test criterion. Subsequently, MIMO versions of the subspace generalised likelihood ratio test (MIMO-SGLRT), the subspace adaptive beam-former orthogonal rejection test (MIMO-SABORT) and the subspace Rao (MIMO-SRao) detector are developed to improve the robustness

of MIMO radar detection performance for the case of steering vector mismatch. The constant false alarm rate properties of the three detectors are demonstrated. Finally, the performance of the MIMO-SGLRT, MIMO-SABORT and MIMO-SRao detectors in both the matched and mismatched steering vector cases are numerically evaluated. The results show the robustness of the proposed detectors to steering vector mismatch.

[100] Jin, M.; Liao, G.; Li, J.; ,"Target localisation for distributed multiple-input multiple-output radar and its performance analysis," Radar, Sonar & Navigation, IET , vol.5, no.1, pp.83-91, January 2011

Abstract: This study considers the problem of target localisation with a coherent processing technique for distributed multiple-input multiple-output radar systems. To enable the coherent processing technique, dual-frequency transmitters are employed to eliminate the stochastic phases of complex fading coefficients, which are caused by target angular fluctuations. And then a two-step procedure is introduced to accomplish the target localisation. In the first step, the amplitudes of the complex fading coefficients are estimated. In the second step, the target position is obtained using the MUSIC algorithm with modified target steering vector. With the amplitudes estimated, the target localisation performance is improved. The Cramer-Rao bound (CRB) for target localisation accuracy is derived with precise knowledge of radar positions. The CRB is shown to be inversely proportional to the frequency difference between the transmitted signals. With the radar positions uncertainty, the average asymptotic performance of the proposed method is given. Finally, numerical examples are given to validate the proposed method and the theoretical analyses.

[101] Gogineni, S.; Nehorai, A.; ,"Monopulse MIMO Radar for Target Tracking," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.1, pp.755-768, January 2011

Abstract: The authors propose a multiple input multiple output (MIMO) radar system with widely separated antennas that employs monopulse processing at each of the receivers. The authors use Capon beamforming to generate the two beams required for the monopulse processing. The authors also propose an algorithm for tracking a moving target using this system. This algorithm is simple and practical to implement. It efficiently combines the information present in the local estimates of the receivers. Since most modern tracking radars already use monopulse processing at the receiver, the proposed system does not need much additional hardware to be put to use. The authors simulated a realistic radar-target scenario to demonstrate that the spatial diversity offered by the use of multiple widely separated antennas gives significant improvement in performance when compared with conventional single input single output (SISO) monopulse radar systems. The authors also show that the proposed algorithm keeps track of rapidly maneuvering airborne and ground targets under hostile conditions like jamming.

[102] Wang, G.; Lu, Y.; ,"Designing single/multiple sparse frequency waveforms with sidelobe constraint," Radar, Sonar & Navigation, IET , vol.5, no.1, pp.32-38, January 2011

Abstract: Sparse frequency waveform with narrow stopbands sparsely distributed over a wide spectrum band is preferred for many radar and communication systems operating in a highly congested spectrum environment. In this paper, a new method for designing sparse frequency waveform with low range side lobes are proposed. The basic idea is to achieve waveform total performance improvement by minimising a new effective penalty function based on both

requirements for the power spectrum density and the range side lobe through an iterative algorithm. The proposed approach is efficient in computation and flexible in designing sparse frequency waveform. Several design examples are also presented to show the validity of the proposed method. An extension to design multiple waveforms for multiple-input multiple-output radar is also presented.

[103] Cristallini, D.; Pastina, D.; Lombardo, P.; ,"Exploiting MIMO SAR Potentialities With Efficient Cross-Track Constellation Configurations for Improved Range Resolution," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.1, pp.38-52, Jan. 2011

Abstract: In this paper, an innovative technique is presented for synthetic aperture radar (SAR) ground range resolution improvement using multiple transmit and receive platforms with adequate cross-track displacement. Using orthogonal waveforms, which occupy the same bandwidth in the range frequency domain, for the different platforms of the constellation, a multiple-input-multiple-output SAR system is configured. The proposed technique allows one to achieve a maximum theoretical range resolution improvement factor that is significantly greater than the number of operating SAR sensors by jointly exploiting both mono- and bistatic acquisitions. This can be exploited to obtain a ground range resolution that is much higher than the resolution corresponding to the frequency bandwidth transmitted by the single platform. After illustrating the proposed technique and its system requirements, a simulated data set is used to show the effectiveness of the proposed approach.

[104] Zheng, Z.D.; Zhang, J.Y.; ,"Fast method for multi-target localisation in bistatic MIMO radar," Electronics Letters , vol.47, no.2, pp.138-139, January 2011

Abstract: A computationally efficient method for multi-target localisation in bistatic MIMO radar is presented. The key idea is to apply the propagator method which requires only linear operation but does not involve any eigendecomposition of the sample covariance matrix. Compared with the ESPRIT method, it has lower computational complexity and gives better performance, particularly when the ratio of the product of transmitter and receiver array size to the number of targets is large. Simulation results are presented to verify the effectiveness of the proposed method.

[105] Belmega, E.V.; Lasaulce, S.; ,"Energy-Efficient Precoding for Multiple-Antenna Terminals," Signal Processing, IEEE Transactions on , vol.59, no.1, pp.329-340, Jan. 2011

Abstract: The problem of energy-efficient precoding is investigated when the terminals in the system are equipped with multiple antennas. Considering static and fast-fading multiple-input multiple-output (MIMO) channels, the energy-efficiency is defined as the transmission rate to power ratio and shown to be maximized at low transmit power. The most interesting case is the one of slow fading MIMO channels. For this type of channels, the optimal precoding scheme is generally not trivial. Furthermore, using all the available transmit power is not always optimal in the sense of energy-efficiency [which, in this case, corresponds to the communication-theoretic definition of the goodput-to-power (GPR) ratio]. Finding the optimal precoding matrices is shown to be a new open problem and is solved in several special cases: 1. when there is only one receive antenna; 2. in the low or high signal-to-noise ratio regime; 3. when uniform power allocation and the regime of large numbers of antennas are assumed. A complete numerical analysis is provided

to illustrate the derived results and stated conjectures. In particular, the impact of the number of antennas on the energy-efficiency is assessed and shown to be significant.

[106] Belfiori, F.; van Rossum, W.; Hoogeboom, P.; ,"Coherent MIMO Array Design With Periodical Physical Element Structures," Antennas and Wireless Propagation Letters, IEEE , vol.10, no., pp.1341-1344, 2011

Abstract: Multiple-input-multiple-output (MIMO) processing is a consolidated technique in communication systems thanks to the benefits that it offers in multipath fading environments. In recent years, studies have shown how the performances of conventional phased-array radar can be improved by using the same approach. This letter illustrates how the digital beamforming (DBF) theory can be extended to include MIMO arrays. In particular, the general description of a MIMO pattern is retrieved; accordingly, two different designs are described, which are aimed at obtaining optimal angular resolution and at controlling the sidelobes of the synthetic array pattern. An experimental result of a pattern synthesis is presented in the last section of the letter.

[107] Rabideau, D.J.; ,"Multiple-input multiple-output radar aperture optimisation," Radar, Sonar & Navigation, IET , vol.5, no.2, pp.155-162, Feb. 2011

Abstract: The authors describe a process for designing low-cost, light-weight antenna apertures for use in multiple-input multiple-output (MIMO) radars. In a MIMO radar system, two or more transmitters emit independent waveforms, with the resulting reflections received by an array of receivers. Recently, MIMO radar has become a subject of great interest. In part, this interest is due to the potential for MIMO techniques to reduce radar weight and cost, while maintaining performance (as compared with conventional radar approaches). However, the size of these reductions has not yet been quantified. Here, the authors describe a process for designing optimal radar apertures. This process treats the design problem as one of minimising an objective function under performance constraints. The objective function is based upon a first-order model for the relationship between cost (or weight) and performance, and is derived for systems employing active, element-digitised arrays. A systematic process for optimising the aperture's design with respect to this objective function is presented, and equations describing the optimal aperture are derived. These equations provide insight into the optimal relationship between various aperture characteristics, such as the number of transmitters, number of receivers, module power level and virtual array length.

[108] Hao He; Stoica, P.; Jian Li; ,"Wideband MIMO Systems: Signal Design for Transmit Beampattern Synthesis," Signal Processing, IEEE Transactions on , vol.59, no.2, pp.618-628, Feb. 2011

Abstract: The usage of multi-input multi-output (MIMO) systems such as a MIMO radar allows the array elements to transmit different waveforms freely. This waveform diversity can lead to flexible transmit beampattern synthesis, which is useful in many applications such as radar/sonar and biomedical imaging. In the past literature most attention was paid to receive beampattern design due to the stringent constraints on waveforms in the transmit beampattern case. Recently progress has been made on MIMO transmit beampattern synthesis but mainly only for narrowband signals. In this paper the authors propose a new approach that can be used to efficiently synthesize MIMO waveforms in order to match a given wideband transmit beampattern, i.e., to match a transmit energy distribution in both space and frequency. The

synthesized waveforms satisfy the unit-modulus or low peak-to-average power ratio (PAR) constraints that are highly desirable in practice. Several examples are provided to investigate the performance of the proposed approach.

[109] Zhang, X.; Xu, D.; ,"Low-complexity ESPRIT-based DOA estimation for colocated MIMO radar using reduced-dimension transformation," Electronics Letters , vol.47, no.4, pp.283-284, February 17 2011

Abstract: Direction of arrival (DOA) estimation for colocated multiple-input multiple-output (MIMO) radar is considered. An estimation of signal parameters via rotational invariance techniques (ESPRIT)-based DOA estimation for the MIMO radar using reduced-dimension transformation is proposed to reduce the complexity. The proposed algorithm has very close angle estimation performance to conventional ESPRIT; also it has slightly better performance than conventional ESPRIT for low SNR. Simulation results verify the usefulness of the proposed algorithm.

[110] Chao, S.Y.; Chen, B.X.; ,"FDGLRT detector of MIMO radar in non-homogeneous clutter," Electronics Letters , vol.47, no.6, pp.403-404, March 17 2011

Abstract: Recently, an adaptive generalised likelihood ratio test-linear quadratic (AGLRT_LQ) detector has been proposed for MIMO radar in the presence of non-homogeneous clutter. However, this method suffers a large performance loss when the amount of secondary data available is small. In this reported work, a full data GLRT detector is derived by utilising not only the primary data but also the secondary data in the design process and the covariance matrix estimation process to decrease this loss.

[111] Qian He; Blum, R.S.; ,"Diversity Gain for MIMO Neyman--Pearson Signal Detection," Signal Processing, IEEE Transactions on , vol.59, no.3, pp.869-881, March 2011

Abstract: For a multiple-input multiple-output (MIMO) system adopting the Neyman-Pearson (NP) criterion, the authors initially derive the diversity gain for a signal-present versus signal-absent scalar hypothesis test statistic and also for a vector signal-present versus signal-absent hypothesis testing problem. For a MIMO radar system with M transmit and N receive antennas, used to detect a target composed of Q random scatterers with possibly non-Gaussian reflection coefficients in the presence of possibly non-Gaussian clutter-plus-noise, the authors consider a class of test statistics, including the optimum test for Gaussian reflection coefficients and Gaussian clutter-plus-noise, and apply the previously developed results to compute the diversity gain. It is found that the diversity gain for the MIMO radar system is dependent on the cumulative distribution function (cdf) of the reflection coefficients while being invariant to the cdf of the clutter-plus-noise under some reasonable conditions requiring certain moments of the magnitude of the processed clutter-plus-noise be bounded. If the noise-free received waveforms, due to target reflection, at each receiver span a space of dimension M'×M, the largest possible diversity gain is controlled by the value of min(NM', Q) and the lowest order power in an expansion, about zero, of the cdf of the magnitude squared of a linear transformed version of the reflection coefficient vector. It is shown that the maximum possible diversity gain in any given scenario can be achieved without employing orthogonal waveforms.

[112] Moo, P.W.; ,"Multiple-input multiple-output radar search strategies for high-velocity targets," Radar, Sonar & Navigation, IET , vol.5, no.3, pp.256-265, March 2011

Abstract: The radar detection of high-velocity targets with a multiple-element antenna array is considered. The detection performance of multiple-input multiple-output (MIMO) radar with orthogonal waveforms is compared with that of a radar using a directed beam. An analytical expression for the probability of detection for a radar with a multiple-element array is derived. For high-velocity targets, the decrease in probability of detection because of the longer integration time required for MIMO radar is quantified. It is shown that for lower-velocity targets, sector search using orthogonal waveforms results has similar detection range performance to that of scanning directed beams. For higher-velocity targets, the use of scanning directed beams yields larger detection range.

[113] Guo, Y.D.; Zhang, Y.S.; Tong, N.N.; ,"Central angle estimation of coherently distributed targets for bistatic MIMO radar," Electronics Letters , vol.47, no.7, pp.462-463, March 31 2011

Abstract: It is shown that the steering vectors of coherently distributed targets for bistatic MIMO radar possess a property called Hadamard product rotational invariance, and a novel central angle estimation algorithm is derived by using this property. The proposed algorithm need not search and can pair the estimated angles easily. Furthermore, it can deal with different coherently distributed targets with different angular distribution functions or unknown angular distribution functions. The effectiveness of the proposed method is verified by simulation result.

[114] Zhou, S.H.; Liu, H.W.; ,"Signal fusion-based target detection algorithm for spatial diversity radar," Radar, Sonar & Navigation, IET , vol.5, no.3, pp.204-214, March 2011

Abstract: Signal fusion-based radar target detection algorithms are studied in this article for spatial diversity multiple input multiple output (MIMO) radar based on the generalised likelihood ratio test (GLRT) algorithm, under the assumption that covariance matrices of clutter signals received by different radar sites are different. Two signal fusion-based target detection algorithms are proposed, which can be applied in signal fusion networks (SFNs) with typical structures, at a low communication and computation cost. Simulation experiments in several scenarios indicate that two proposed signal fusion algorithms have better detection performances than decision fusion algorithms.

[115] Xing Tan; Roberts, W.; Jian Li; Stoica, P.; ,"Sparse Learning via Iterative Minimization With Application to MIMO Radar Imaging," Signal Processing, IEEE Transactions on , vol.59, no.3, pp.1088-1101, March 2011

Abstract: Through waveform diversity, multiple-input multiple-output (MIMO) radar can provide higher resolution, improved sensitivity, and increased parameter identifiability compared to more traditional phased-array radar schemes. Existing methods for target estimation, however, often fail to provide accurate MIMO angle-range-Doppler images when there are only a few data snapshots available. Sparse signal recovery algorithms, including many l1-norm based approaches, can offer improved estimation in that case. In this paper, the authors present a regularized minimization approach to sparse signal recovery. Sparse learning via iterative minimization (SLIM) follows an lq-norm constraint (for $0 < q <= 1$), and can thus be used to

provide more accurate estimates compared to the l1-norm based approaches. The authors herein compare SLIM, through imaging examples and examination of computational complexity, to several well-known sparse methods, including the widely used CoSaMP approach. The authors show that SLIM provides superior performance for sparse MIMO radar imaging applications at a low computational cost. Furthermore, the authors will show that the user parameter q can be automatically determined by incorporating the Bayesian information criterion.

[116] Boyer, R.; ,"Performance Bounds and Angular Resolution Limit for the Moving Colocated MIMO Radar," Signal Processing, IEEE Transactions on , vol.59, no.4, pp.1539-1552, April 2011

Abstract: To identify a target, the moving noncoherent colocated multiple-input multiple-output (MIMO) radar system takes advantage of multiple antennas in transmission and reception which are close in space. In this paper, the authors study the estimation performance and the resolution limit for this scheme in which each array geometry is described by the sample-variance of the sensor distribution. So, our analysis encompasses any sensor distributions, including varying intersensors distances or/and lacunar (missing sensors) configuration. As in the space-time MIMO model considered here the radar is moving, the target Doppler frequency cannot be assumed invariant to the target position/angle. The first part of this paper derives and analyzes closed form (nonmatrix) expressions of the deterministic Cramer-Rao lower bound (CRB) for the direction and the velocity of a moving target contaminated by a structured noise (clutter echoes) and a background noise, including the cases of the clutter-free environment and the high signal-to-noise ratio (SNR) regime. The analysis of the proposed expressions of the CRB allows to better understand the characterization of the target. In particular, the authors prove the coupling between the direction parameter and the velocity of the target is linear with the radar velocity. In the second part, the authors focus our study on the analytical (closed form) derivation and the analysis of the angular resolution limit (ARL). Based on the resolution of an equation involving the CRB, the ARL can be interpreted as the minimal separation to resolve two closely spaced targets. Consequently, the ARL is a key quantity to evaluate the performance of a radar system. The authors show that the ARL is in fact quasi-invariant to the movement of the MIMO radar.

[117] Naghibi, T.; Behnia, F.; ,"MIMO Radar Waveform Design in the Presence of Clutter," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.2, pp.770-781, April 2011

Abstract: Waveform design for target identification and classification in multiple-input multiple-output (MIMO) radar systems has been studied in several recent works. In previous works, optimal signals for an estimation algorithm are found assuming that only signal- independent noise exists. This work extends previous research by studying the case where clutter is also present. The authors develop a procedure to design the optimal waveform which minimizes estimation error at the output of the minimum mean squared error (MMSE) estimators in two scenarios. In the first one different transmit antennas see uncorrelated aspects of the target, and the authors consider the correlated target aspects in the second one. Estimation error in the first case will not zero even if the transmit power tends to infinity. This value of this error is referred to as the lower estimation error bound ε-BOUND. It can be shown that since the MIMO radar receiver can null out the clutter subspace, ε-BOUND is zero in the second scenario. Waveform design for MMSE estimator under the uncorrelated target aspects assumption, leads to the semi-definite programming (SDP) problem, a convex optimization problem which can be efficiently

solved through numerical methods. An explicit solution is developed for this SDP problem in two cases. In the first case target and clutter covariance matrices are jointly diagonalizable, and in the second one the signal-to-noise ratio (SNR) is sufficiently high. Finding optimal transmit signals for the correlated target aspects scenario also results in an SDP problem.

[118] Pratt, T.G.; Yih-Fang Huang; Zhenhua Gong; Lemmon, M.; ,"Subspace Optimization in Centralized Noncoherent MIMO Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.2, pp.1230-1240, April 2011

Abstract: The authors consider the problem of subspace optimization for centralized noncoherent multiple input-multiple output (MIMO) radar based on various measures such as capacity, diversity, and probability of detection. In subspace centralized noncoherent MIMO radar (SC-MIMO), a subset of stations is selected based on channel knowledge or channel statistics to reduce system complexity while simultaneously attempting to optimize the performance of the reduced-dimension centralized MIMO radar system. The radar transmitters are assumed to be sufficiently separated (e.g., at different locations) to yield spatially white channel transfer gains and are assumed to operate on a noninterference basis through time-division or frequency-division multiplexing. Detection optimization for the SC-MIMO system in a Neyman Pearson (NP) sense is found to be equivalent to selecting the subspace that maximizes the Frobenius norm of the corresponding channel matrix. Information-theoretic measures for capacity and diversity are also applied to the problem of subspace selection. Channels with temporal coherence times that are long relative to the radar system's latencies and channels with coherence times that are short relative to the radar system's latencies are considered. In the former case, metrics are based upon instantaneous channel estimates, whereas in the latter case, average channel estimates are used. Numerical analyses are conducted to illustrate the use of the metrics for optimizing system performance.

[119] Wen-Qin Wang; ,"Near-space vehicles: Supply a gap between satellites and airplanes for remote sensing," Aerospace and Electronic Systems Magazine, IEEE , vol.26, no.4, pp.4-9, April 2011

Abstract: Near-space is defined as the atmospheric region from about 20 kilometer (km) to 100 km above the Earth's surface; near-space vehicles offer several advantages to Low Earth Orbit (LEO) satellites and airplanes because near-space vehicles are not constrained by orbital mechanics and fuel consumption. Some of the near-space vehicle advantages include their potential for some specific radar applications that require persistentiy monitoring or fast-revisiting frequency which are explained herein. The role of near-space vehicles is reviewed in supplying a gap between satellites and airplanes for microwave remote sensing applications. Several potential applications such as passive surveillance, reconnaissance, and high resolution wide swath imaging are described. The novel multiple-input and multiple-output (MIMO)-based multi-aperture in elevation and space-time coding (STC) synthetic aperture radar (SAR) are presented for high resolution wide swath imaging. Therefore, given their operational flexibility, near-space vehicle-borne radars may supply the gap between space-borne and airborne radars which is the reason the authors appeal to the systems engineering community for more publications and more support on the research and development of near-space vehicle-borne radars.

[120] Zhang, W.; Li, J.; Lin, H.; He, Z.; ,"Estimation of clutter rank of MIMO radar in case of subarraying," Electronics Letters , vol.47, no.11, pp.671-673, May 26 2011

Abstract: A simple formula for estimation of clutter rank of MIMO radar in the case of transmitting subarraying is derived. With the help of the time-bandwidth product rule, the estimation of clutter rank of MIMO radar is extended to the case of subarraying, this would be useful to design an optimal subaraying technique. The rule for estimation of clutter rank in this case is provided and demonstrated by numerical simulations.

[121] Zeng, Xiangneng; Zhang, Yongshun; Guo, Yiduo; ,"Polyphase coded signal design for MIMO radar using MO-MicPSO," Systems Engineering and Electronics, Journal of , vol.22, no.3, pp.381-386, June 2011

Abstract: A novel modified optimization technique known as the multi-objective micro particle swarm optimization (MO-MicPSO) is proposed for polyphase coded signal design. The proposed MO-MicPSO requires only a small population size compared with the standard particle swarm optimization that uses a larger population size. This new method is guided by an elite archive to finish the multi-objective optimization. The orthogonal polyphase coded signal (OPCS) can fundamentally improve the multiple input multiple output (MIMO) radar system performance, with which the radar system has high resolution and abundant signal channels. Simulation results on the polyphase coded signal design show that the MO-MicPSO can perform quite well for this high-dimensional multi-objective optimized problem. Compared with particle swarm optimization or genetic algorithm, the proposed MO-MicPSO has a better optimized efficiency and less time consumption.

[122] Jindong, Z.; Kerang, W.; Xiaohua, Z.; ,"Spatial-dependent waveform design for colocated uniform linear array multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.5, no.5, pp.545-550, June 2011

Abstract: Multiple-input multiple-output (MIMO) radars have attracted considerable attention for their ability to transmit multiple waveforms. These waveforms affect the range, Doppler and spatial performance. Recently, the concept of ambiguity function, which is an important mathematical tool for analysing and designing radar signals, has been extended to the MIMO radar case. In this study, the authors investigate the range and spatial properties of colocated MIMO radar based on range-spatial ambiguity function. Owing to spatial dependence of the matched filter output of MIMO radar, the spatial detection region is divided into multiple sections by spatial resolution. A new algorithm for designing orthogonal frequency-hopping waveforms according to the spatial section where the target may appear is proposed. This algorithm improves the peak sidelobe level of the matched filter output.

[123] Hassanien, A.; Vorobyov, S.A.; ,"Transmit Energy Focusing for DOA Estimation in MIMO Radar With Colocated Antennas," Signal Processing, IEEE Transactions on , vol.59, no.6, pp.2669-2682, June 2011

Abstract: In this paper, the authors propose a transmit beamspace energy focusing technique for multiple-input multiple-output (MIMO) radar with application to direction finding for multiple targets. The general angular directions of the targets are assumed to be located within a certain spatial sector. The authors focus the energy of multiple (two or more) transmitted orthogonal

waveforms within that spatial sector using transmit beamformers which are designed to improve the signal-to-noise ratio (SNR) gain at each receive antenna. The subspace decomposition-based techniques such as MUSIC can then be used for direction finding for multiple targets. Moreover, the transmit beamformers can be designed so that matched-filtering the received data to the waveforms yields multiple (two or more) data sets with rotational invariance property that allows applying search-free direction finding techniques such as ESPRIT or parallel factor analysis (PARAFAC). Unlike previously reported MIMO radar ESPRIT/PARAFAC-based direction finding techniques, our method achieves the rotational invariance property in a different manner combined also with the transmit energy focusing. As a result, it achieves better estimation performance at lower computational cost. The corresponding Cramer-Rao bound is derived and its dependence on the number of waveforms used is discussed. Simulation results also show the superiority of the proposed technique over the existing techniques.

[124] Xuan Hui Wu; Kishk, A.A.; Glisson, A.W.; ,"Antenna Effects on a Monostatic MIMO Radar for Direction Estimation, a Cramèr-Rao Lower Bound Analysis," Antennas and Propagation, IEEE Transactions on , vol.59, no.6, pp.2388-2395, June 2011

Abstract: Antenna effects on a monostatic multiple-input-multiple-output (MIMO) Radar for direction estimation are studied by analyzing the Cramer-Rao lower bound (CRLB). The CRLB is derived for a multi-band MIMO Radar system, and is in a form that incorporates the characteristics of a practical antenna array. Two different uniform linear antenna arrays, one narrowband and the another wideband, are investigated by exploring the CRLB. The estimation performance for the real antenna array is compared to that for an ideal array composed of isotropic antenna elements. It is found out that the mutual coupling between antenna elements alters the radiation patterns a lot, and therefore tremendously affects the estimation performance. Furthermore, the study demonstrates that by distributing the transmitted power over several frequency bands, more accurate estimation can be achieved due to frequency diversity, and the negative effects of radiation pattern deviation can be alleviated.

[125] Blum, R.S.; ,"Ordering for Estimation and Optimization in Energy Efficient Sensor Networks," Signal Processing, IEEE Transactions on , vol.59, no.6, pp.2847-2856, June 2011

Abstract: A discretized version of a continuous optimization problem is considered for the case where data is obtained from a set of dispersed sensor nodes and the overall metric is a sum of individual metrics computed at each sensor. An example of such a problem is maximum-likelihood estimation based on statistically independent sensor observations. By ordering transmissions from the sensor nodes, a method for achieving a saving in the average number of sensor transmissions is described. While the average number of sensor transmissions is reduced, the approach always yields the same solution as the optimum approach where all sensor transmissions occur. The approach is described first for a general optimization problem. A maximum-likelihood target location and velocity estimation example for a multiple node noncoherent multiple-input multiple-output (MIMO) radar system is later described. In particular, for cases with N good quality sensors with ideal signals and sufficiently large signal-to-interference-plus-noise ratio (SINR), the average percentage of transmissions saved approaches 100% as the number of discrete grid points in the optimization problem Q becomes significantly large. In these same cases, the average percentage of transmissions saved approaches (Q-1)/ Q × 100 % as the number of sensors N in the network becomes significantly large. Similar savings are

illustrated for general optimization (or estimation) problems with some sufficiently well-designed sensors. Savings can be even larger in some cases for systems with some poor quality sensors.

[126] Akcakaya, M.; Nehorai, A.; ,"Adaptive MIMO Radar Design and Detection in Compound-Gaussian Clutter," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.3, pp.2200-2207, July 2011

Abstract: Multiple-input multiple-output (MIMO) radars with widely separated transmitters and receivers are useful to discriminate a target from clutter using the spatial diversity of the scatterers in the illuminated scene. The authors consider the detection of targets in compound-Gaussian clutter, describing heavy-tailed clutter distributions fitting high-resolution and/or low-grazing-angle radars in the presence of sea or foliage clutter. First the authors introduce a data model using the inverse gamma distribution to represent the clutter texture. Then the authors apply the parameter-expanded expectation-maximization (PX-EM) algorithm to estimate the clutter texture and speckle as well as the target parameters. The authors develop a statistical decision test using these estimates and demonstrate its statistical characteristics. Based on the statistical characteristics of this test, the authors propose an algorithm to adaptively distribute the transmitted energy among the transmitters and maximize the detection performance. The authors demonstrate the advantages of the MIMO setup and adaptive energy allocation in target detection in the presence of compound-Gaussian clutter using Monte Carlo (MC) simulations.

[127] Zhang, X.; Xu, Z.; Xu, L.; Xu, D.; ,"Trilinear decomposition-based transmit angle and receive angle estimation for multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.5, no.6, pp.626-631, July 2011

Abstract: In this study, the authors address the problem of angle estimation in a bistatic multiple-input multiple-output (MIMO) radar. This study links the problem to the trilinear model, and then the authors derive a trilinear decomposition-based angle estimation algorithm, which can obtain automatically paired 2D angle estimation. The proposed algorithm requires no spectral peak searching or pair matching, and it has better angle estimation performance than conventional algorithms such as the estimation of signal parameters via rotational invariance technique (ESPRIT) algorithm and the root multiple signal classification (MUSIC) algorithm. Simulation results illustrate performance of the proposed algorithm.

[128] Jiang, M.; Niu, R.; Blum, R.S.; ,"Bayesian target location and velocity estimation for multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.5, no.6, pp.666-670, July 2011

Abstract: For a non-coherent multiple-input multiple-output radar system, the minimum mean square error (MMSE) estimator and maximum a posteriori (MAP) estimator of the target location and velocity, considered random unknown parameters, are formulated and the corresponding posterior Cramer-Rao lower bound (PCRLB) is derived. Moreover, numerical solutions for the proposed MMSE estimator and the PCRLB are obtained by using Monte-Carlo methods because of the absence of closed-form solutions. The numerical results show that the mean square errors (MSEs) of the MMSE estimate and the MAP estimate converge to the corresponding PCRLB as the signal-to-noise ratio (SNR) increases when the number of transmit and receive antennas is sufficiently large. A linear approximation can be used to simplify the MMSE estimation. It is shown in some simulations that the linear approximation of the MMSE estimate is accurate at

high SNR values and the SNR needed for accurate approximation can be reduced by increasing the number of antennas employed.

[129] Akcakaya, M.; Nehorai, A.; ,"MIMO Radar Sensitivity Analysis for Target Detection," Signal Processing, IEEE Transactions on , vol.59, no.7, pp.3241-3250, July 2011

Abstract: The authors consider the effect of imperfect separability in the received signals on the detection performance of multi-input multi-output (MIMO) radar with widely separated antennas. The mutual orthogonality among the received signals is often assumed but cannot be achieved in practice for all Doppler and delay pairs. The authors introduce a data model considering the correlation among the data from different transmitter-receiver pairs as unknown parameters. Based on the expectation maximization algorithm, the authors propose a method to estimate the target, correlation, and noise parameters. The authors then use the estimates of these parameters to develop a statistical decision test. Employing the asymptotic statistical characteristics and the numerical performance of the test, the authors analyze the sensitivity of the MIMO radar with respect to changes in the cross-correlation levels of the measurements. The authors demonstrate the effect of the increase in the correlation among the received signals from different transmitters on the detection performance.

[130] Godrich, H.; Petropulu, A.P.; Poor, H.V.; ,"Power Allocation Strategies for Target Localization in Distributed Multiple-Radar Architectures," Signal Processing, IEEE Transactions on , vol.59, no.7, pp.3226-3240, July 2011

Abstract: Widely distributed multiple radar architectures offer parameter estimation improvement for target localization. For a large number of radars, the achievable localization minimum estimation mean-square error (MSE), with full resource allocation, may extend beyond the predetermined system performance goals. In this paper, performance driven resource allocation schemes for multiple radar systems are proposed. All available antennas are used in the localization process. For a predefined estimation MSE threshold, the total transmitted energy is minimized such that the performance objective is met, while keeping the transmitted power at each station within an acceptable range. For a given total power budget, the attainable localization MSE is minimized by optimizing power allocation among the transmit radars. The Cramer-Rao bound (CRB) is used as an optimization metric for the estimation MSE. The resulting nonconvex optimization problems are solved through relaxation and domain decomposition methods, supporting both central processing at the fusion center and distributed processing. It is shown that uniform or equal power allocation is not necessarily optimal and that the proposed power allocation algorithms result in local optima that provide either better localization MSE for the same power budget, or require less power to establish the same performance in terms of estimation MSE. A physical interpretation of these conclusions is offered.

[131] Guo, Y.D.; Zhang, Y.S.; Tong, N.N.; ,"Beamspace ESPRIT algorithm for bistatic MIMO radar," Electronics Letters , vol.47, no.15, pp.876 -878, July 21 2011

Abstract: A novel beamspace ESPRIT (B-ESPRIT) algorithm is proposed to estimate the direction of departures (DODs) and direction of arrivals (DOAs) for bistatic MIMO radar. It restores the rotational invariance structure lost in the beamspace transformation for both the transmit array and the receive array, and then the DODs and DOAs can be estimated through ESPRIT. The proposed algorithm can achieve a significant computational saving over the

element-space ESPRIT (E-ESPRIT) algorithm for bistatic MIMO radar. Simulation results validate these conclusions.

[132] Grossi, E.; Lops, M.; Venturino, L.; ,"Robust Waveform Design for MIMO Radars," Signal Processing, IEEE Transactions on , vol.59, no.7, pp.3262-3271, July 2011

Abstract: The problem of robust waveform design for multiple-input, multiple-output radars equipped with widely spaced antennas is addressed here. Robust design is needed as a number of parameters may be unknown, e.g., the target scattering covariance matrix and the disturbance covariance matrix. Following a min-max approach, the code matrix is designed to minimize the worst-case cost over all possible target (or target and disturbance) covariance matrices. The same min-max solution applies to many commonly adopted performance measures, such as the average signal-to-disturbance ratio, the linear minimum mean square error in estimating the target response, the mutual information between the received signal echoes and the target response, and the approximation of the detection probability in the high- and low-signal regimes for a fixed probability of false alarm. Examples illustrating the behavior of the min-max codes are provided.

[133] Willsey, M.S.; Cuomo, K.M.; Oppenheim, A.V.; ,"Quasi-Orthogonal Wideband Radar Waveforms Based on Chaotic Systems," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.3, pp.1974-1984, July 2011

Abstract: Many radar applications, such as those involving multiple-input, multiple-output (MIMO) radar, require sets of waveforms that are orthogonal, or nearly orthogonal. As shown in the work presented here, a set of nearly orthogonal waveforms with a high cardinality can be generated using chaotic systems, and this set performs comparably to other waveform sets used in pulse compression radar systems. Specifically, the nearly orthogonal waveforms from chaotic systems are shown to possess many desirable radar properties including a compact spectrum, low range sidelobes, and an average transmit power within a few dB of peak power. Moreover, these waveforms can be generated at essentially any practical time length and bandwidth. Since these waveforms are generated from a deterministic process, each waveform can be represented with a small number of system parameters. Additionally, assuming these waveforms possess a large time-bandwidth product, a high number of nearly orthogonal chaotic waveforms exist for a given time and bandwidth. Thus the proposed generation procedure can potentially be used to generate a new transmit waveform on each pulse.

[134] Zhou, S.H.; Liu, H.W.; ,"Target statistical correlation characteristic for spatial-frequency jointly diversity multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.5, no.6, pp.638-649, July 2011

Abstract: In diversity multiple-input multiple-output (MIMO) radar system, the mutual correlation of target echo signals in its diversity channels is an important concern for designing signal processing algorithms. The target temporal, spatial and frequency correlation characteristic is studied at the background of a diversity MIMO radar with multiple widely separated radar sites all capable of working at multiple carrier frequencies. With a two-dimensional round-shaped scatterers centre target model, the correlation coefficient of target echo signals in any type of diversity channel pair (DCP) is proved to be a function of the target size and the equivalent frequency interval. The theoretical correlation coefficient is verified by numerical experiments.

The correlation coefficient of target echo signals often depends on the target location, which is shown for two typical DCP types.

[135] Caicai LI, Guisheng Liao, Shengqi Zhu, Sunyong Wu, An ESPRIT-like algorithm for coherent DOA estimation based on data matrix decomposition in MIMO radar, Signal Processing,Volume 91, Issue 8, August 2011, Pages 1803–1811

Abstract: A direction-of-arrival (DOA) estimation method for coherent sources is presented for MIMO radar. It uses symmetrical array mode for both the transmit and receive arrays and reconstructs a special data matrix from the range-compressed receive data. In the reconstructed matrix, the signal term is a Toeplitz matrix with the rank only related to the DOAs of the signals and independent with their coherency. Taking the noise term into account, the average method of multiple pulses is utilized to obtain the signal and noise subspaces. And then the DOA can be resolved via the SVD-based ESPRIT algorithm. Furthermore, the presented method is also useful in spatial colored noise scenario for MIMO radar. Theoretical and numerical simulations show the effectiveness of the proposed algorithm.

[136] Hongyan Wang, Guisheng Liao, Yong Wang, Xiangyang Liu, "On parameter identifiability of MIMO radar with waveform diversity," Signal Processing, Volume 91, Issue 8, August 2011, Pages 2057–2063

Abstract: Parameter identifiability is one of the most interesting issues in multiple-input multiple-output (MIMO) radar systems. Previous works have presented conditions for parameter identifiability of the systems with uncorrelated waveforms. In this paper, under general waveform assumptions, the authors investigate conditions for of MIMO radar systems with more flexible waveform diversity, where the transmitted waveforms are not restricted to be uncorrelated. The conditions specify the maximum number of targets that can be uniquely localized, which are obtained based on the rule of time-bandwidth product. Moreover, it is found that the conditions are in terms of the rank and structure of the waveform covariance matrix (WCM) and the geometry of MIMO radar systems. Numerical examples are provided to verify the effectiveness of the conditions.

[137] Guo, Y.D.; Zhang, Y.S.; Tong, N.N.; ,"ESPRIT-like angle estimation for bistatic MIMO radar with gain and phase uncertainties," Electronics Letters , vol.47, no.17, pp.996-997, August 18 2011

Abstract: Gain and phase uncertainties would destroy the invariance property of both the transmit array and the receive array in bistatic MIMO radar, so the computationally efficient ESPRIT algorithm cannot be applied directly. Proposed is a novel ESPRIT-like algorithm, which uses the instrumental sensors method (ISM), to estimate the direction of departures and direction of arrivals. The ESPRIT-like algorithm is able to achieve favourable and unambiguous angle estimation without any information of the gain and phase uncertainties. The effectiveness of the proposed algorithm is verified by simulation results.

[138] Lung-Sheng Tsai; Wei-Ho Chung; Da-shan Shiu; ,"Lower Bounds on the Correlation Property for OFDM Sequences with Spectral-Null Constraints," Wireless Communications, IEEE Transactions on , vol.10, no.8, pp.2652-2659, August 2011

Abstract: Sequences with specific autocorrelation (AC) and cross-correlation (CC) properties are crucial components in radar and wireless communications. In this paper, the authors derive the theoretical bounds on the AC and CC for OFDM sequences with constraints of spectral nulls, e.g., the mandatory nulls on the DC sub-carrier and guardbands in OFDM systems. The bounds and trade-off limits are provided for the properties of sequences, including the peak AC and CC levels, the cardinality of the sequence set, the sequence length, and the temporal length of the low correlation zone. The authors also investigate the trade-offs of correlations among sequence sets. The presented trade-off limits can serve as guidelines for applications where the performance measures or design criteria are related to the peak AC and CC levels.

[139] Ahmed, S.; Thompson, J.S.; Petillot, Y.R.; Mulgrew, B.; ,"Unconstrained Synthesis of Covariance Matrix for MIMO Radar Transmit Beampattern," Signal Processing, IEEE Transactions on , vol.59, no.8, pp.3837-3849, Aug. 2011

Abstract: Multiple-input multiple-output (MIMO) radars have many advantages over their phased-array counterparts: improved spatial resolution; better parametric identifiably and greater flexibility to design the transmit beampattern. The design of the transmit beampatterns generally requires the waveforms to have arbitrary auto- and cross-correlation properties. The correlation/covariance matrix, R, of the waveforms must be positive semidefinite, therefore synthesis of a desired beampattern is usually a constrained optimization problem. In this paper, to simplify the constrained optimization problem, two algorithms are proposed to synthesize the waveform covariance matrix for the desired beampattern. In the first proposed algorithm the elements of a square-root matrix of the covariance matrix R are parameterized using the coordinates of a hypersphere that implicitly fulfil the constraints. This yields an iterative algorithm, whose convergence speed can be increased significantly by providing good initial values. In the second algorithm the constraints and redundant information in the covariance matrix R are exploited to find a closed-form solution. The drawback of the second algorithm is that it may yield a pseudocovariance matrix (pseudo-CM) that is not guaranteed to be positive semidefinite. However, the pseudo-CM can be easily converted into a covariance matrix using eigenvalue decomposition and/or shrinkage methods. Moreover, a pseudo-CM can also be used to provide good initial values for the first algorithm to enable faster convergence.

[140] Changzheng Ma; Tat Soon Yeo; Chee Seng Tan; Zhoufeng Liu; ,"Three-Dimensional Imaging of Targets Using Colocated MIMO Radar," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.8, pp.3009-3021, Aug. 2011

Abstract: Conventional inverse synthetic aperture radar image is a 2-D range-Doppler projection of a target and does not provide 3-D information. Its formation also requires complex motion compensation when the target is uncooperative and maneuvering. On the other hand, multiple-input and multiple-output (MIMO) radar, in addition to having a wide virtual aperture and high cross-range resolution, could also obtain a target's 3-D image in one snapshot and thus have avoided the complex motion compensation needed. In this paper, the authors propose a 3-D imaging algorithm using three MIMO configurations. The signal model is derived based on a

modified zero correlation zone code. A strong scatterer selection criterion is also proposed for the construction of the target profile.

[141] Wen-Qin Wang; ,"Space-Time Coding MIMO-OFDM SAR for High-Resolution Imaging," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.8, pp.3094-3104, Aug. 2011

Abstract: Multiple-input and multiple-output (MIMO) radar has received renewed attention in recent years, but little work on MIMO synthetic aperture radar (SAR) remote sensing has been reported. This paper presents a scheme of space-time coding MIMO orthogonal frequency division multiplexing (OFDM) SAR for high-resolution imaging. This system employs MIMO configuration in the elevation direction and the Alamouti space-time coding scheme in the azimuth direction, along with the use of OFDM waveform diversity and displaced phase center antenna (DPCA) techniques. As an orthogonal transmission waveform is required for this novel space-time coding MIMO-OFDM SAR system, one kind of OFDM linearly frequency modulated waveforms is investigated. The matched filtering and multibeam forming in the elevation direction are detailed. Additionally, the corresponding mathematical relations and signal models for high-resolution imaging are formed. In this way, efficient spatial diversity gain and improved range resolution are obtained by the MIMO configuration, and the requirement of pulse repeated frequency for wide-swath remote sensing is reduced by the DPCA technique. The feasibility is validated by numerical simulation results.

[142] Tariq R. Qureshia, Michael D. Zoltowskia, Robert Calderbankb, Ali Pezeshkic, "Unitary design of radar waveform diversity sets," Digital Signal Processing, Volume 21, Issue 5, September 2011, Pages 552–567

Abstract: In this work, multiple radar waveforms are simultaneously transmitted, emitted from different antennas. The goal is to process the returns in such a way that the overall ambiguity function is a sum of individual ambiguity functions, such that the sum better approximates the ideal thumbtack shape. A unitary design for the illustrative 4×4 example prescribes the scheduling of the waveforms over four transmit antennas over four PRIs. Further, it dictates how the matched filtering of the returns over four PRIs is combined in such a way so as to achieve both perfect separation (of the superimposed returns) AND perfect reconstruction. Perfect reconstruction implies that the sum of the time-autocorrelations associated with each of the four waveforms is a delta function. The net result of the processing of four PRIs over four virtual antennas yields 16 cross-correlations all of which ideally exhibit a sharp peak at the target delay. Conditions for both perfect separation and perfect reconstruction are developed, and a variety of waveform sets satisfying both are presented. Doppler compensation is achieved by a data-dependent weighting of the different PRI matched-filtered outputs prior to summing. Simulations are presented verifying the efficacy of the proposed unitary waveform matrix designs in conjunction with the proposed Doppler compensation technique.

[143] Douglas A. Gray, Rowan Fry, "Noise MIMO radar – co-array cross-spectral and cross-covariance matrices," Digital Signal Processing, Volume 21, Issue 5, September 2011, Pages 586–592

Abstract: An expression for the cross-spectral matrix of the co-array of an element space noise MIMO radar is derived and then used to determine the output power in various noise fields using

both conventional and MVDR beamforming. Theoretical and numerical results are presented to show that beamforming using an intuitive form of the cross-spectral matrix of the co-array for noise MIMO radar provides no benefit over receive-only beamforming in the presence of any combination of scatterers, jammers and white noise when constant scattering coefficients are assumed. A time domain formulation is considered and theoretical and simulation results are presented to demonstrate its ability to realize the full gains of the co-array when a sufficient number of samples is used in the temporal component of the MIMO matched filter.

[144] Patwari, N.; Wilson, J.; ,"Spatial Models for Human Motion-Induced Signal Strength Variance on Static Links," Information Forensics and Security, IEEE Transactions on , vol.6, no.3, pp.791-802, Sept. 2011

Abstract: A wireless network can use the variance of measured received signal strength (RSS) on the links in a network to infer the locations of people or objects moving in the network deployment area. This paper provides a statistical model for the RSS variance as a function of a person's position with respect to the transmitter (TX) and receiver (RX) locations. The authors show that the ensemble mean of the RSS variance has an approximately linear relationship with the expected value of total affected power (ETAP), for a range of ETAP. The authors derive approximate expressions for the ETAP as a function of the person's position, for scattering and reflection, which are tested via simulation. Counterintuitively, the authors show that reflection, not scattering, causes the RSS variance contours to be shaped similar to Cassini ovals. Results reported in past literature and from a new experiment reported in this paper are shown to be as predicted by the analysis.

[145] Jia Xu; Xi-Zeng Dai; Xiang-Gen Xia; Li-Bao Wang; Yu, J.; Peng, Y.; ,"Optimizations of Multisite Radar System with MIMO Radars for Target Detection," Aerospace and Electronic Systems, IEEE Transactions on , vol.47, no.4, pp.2329-2343, OCTOBER 2011

Abstract: This paper proposes a novel multisite radar system (MSRS) with multiple-input and multiple-output (MIMO) radars, i.e., MIMO-MSRS system, to improve the detection performance of fluctuating targets. The proposed MIMO-MSRS system increases the local signal-to-noise ratio (SNR) by using digital beamforming (DBF) among all transmitting and receiving channels in a single site. Then it smoothes the target's fluctuation via spatial diversity among the DBF outputs of different sites. For the MIMO-MSRS system, the authors derive the likelihood ratio test (LRT) detector at first based on the proposed signal model and spatial diversity conditions. Furthermore, with the derived statistics of the LRT detector in the fixed noise background, three optimization problems are discussed on the MIMO-MSRS system configurations, i.e., the numbers of sites and collocated channels in different sites. The first problem is to detect the lowest SNR target with a given probability of false alarm (PF), probability of detection (PD) and total system degrees of freedom (DOF). The second is to detect a target with the highest PD for a given PF, target SNR, and system DOF. The third is on the minimal system DOF to detect a target with a given PF, PD, and target SNR. For the uniform MIMO-MSRS system, both the standard optimal site number, i.e., the diversity DOF, and its closed-form approximation of the above three problems are obtained. Finally, some numerical results are also provided to demonstrate the effectiveness of the proposed MIMO-MSRS systems.

[146] Gumbmann, F.; Schmidt, L.; ,"Millimeter-Wave Imaging With Optimized Sparse Periodic Array for Short-Range Applications," Geoscience and Remote Sensing, IEEE Transactions on , vol.49, no.10, pp.3629-3638, Oct. 2011

Abstract: This paper presents a multiple-input-multiple-output imaging system on the basis of a hybrid concept with synthetic aperture radar and digital beam forming. By moving a multistatic linear array perpendicularly to the array dimension, a 2-D aperture is sampled. The scope of application is concealed weapon detection in conjunction with the imaging of humans and, alternatively, nondestructive testing (NDT). The frequency range of 75-90 GHz was chosen because of the inherent high lateral resolution. For NDT, it seems to be a good compromise between lateral resolution and penetration depth as well. A moderate number of transmit and receive channels are achieved by a sparse periodic array (SPA) design. Since this is a far-field approach, ambiguities are not well suppressed in the near-field point spread function of the sparse array. An extension of the SPA concept for short-range applications on the basis of an optimized array design and an optimized beamforming algorithm is presented in this paper.

[147] Zhuge, X.; Yarovoy, A.G.; ,"Sparse multiple-input multiple-output arrays for high-resolution near-field ultra-wideband imaging," Microwaves, Antennas & Propagation, IET , vol.5, no.13, pp.1552-1562, October 2011

Abstract: This study investigates the utilisation of a multiple-input multiple-output (MIMO) array technique for high-resolution near-field ultra-wideband (UWB) imaging. Using this technique, a classical array can be replaced with an MIMO array with a similar resolution and beam pattern but using a smaller number of elements. A deterministic approach to factorise a desired effective array topology into topologies of transmit and receive sub-arrays is suggested. Based on it, an MIMO array design procedure is proposed. A few examples of linear array topologies are suggested and their performances in the near-field are compared for different values of the operational bandwidth. The experimental results verify the correctness and effectiveness of the proposed design procedure for UWB near-field imaging.

[148] Pu Wang; Hongbin Li; Himed, B.; ,"Moving Target Detection Using Distributed MIMO Radar in Clutter With Nonhomogeneous Power," Signal Processing, IEEE Transactions on , vol.59, no.10, pp.4809-4820, Oct. 2011

Abstract: In this paper, the authors consider moving target detection using a distributed multiple-input multiple-output (MIMO) radar on stationary platforms in nonhomogeneous clutter environments. Our study is motivated by the fact that the multistatic transmit-receive configuration in a distributed MIMO radar causes nonstationary clutter. Specifically, the clutter power for the same test cell may vary significantly from one transmit-receive pair to another, due to azimuth-selective backscattering of the clutter. To account for these issues, a new nonhomogeneous clutter model, where the clutter resides in a low-rank subspace with different subspace coefficients (and hence different clutter power) for different transmit-receive pair, is introduced and the relation to a general clutter model is discussed. Following the proposed clutter model, the authors develop a generalized-likelihood ratio test (GLRT) for moving target detection in distributed MIMO radar. The GLRT is shown to be a constant false alarm rate (CFAR) detector, and the test statistic is a central and noncentral Beta variable under the null and alternative hypotheses, respectively. Simulations are provided to demonstrate the performance of the proposed GLRT in comparison with several existing techniques.

[149] Ofer Bar-Shalom, Anthony J. Weis, "Direct positioning of stationary targets using MIMO radar, Signal Processing," Volume 91, Issue 10, October 2011, Pages 2345–2358

Abstract: MIMO radar is a new concept that has recently been proposed as an extension to the multi-static radar systems. The authors apply the direct position determination (DPD) approach to MIMO radar and obtain maximum likelihood algorithms for a location estimation of a stationary target. It is shown that under low signal to noise ratio DPD improves the estimation accuracy with respect to the traditional location methods.

[150] Hongyan Wang, Guisheng Liao, Jun Li, Hui Lv, "Waveform optimization for MIMO-STAP to improve the detection performance?," Signal Processing, Volume 91, Issue 11, November 2011, Pages 2690–2696

Abstract:In this letter, the authors address the problem of waveform optimization for multi-input multi-output (MIMO) space-time adaptive processing (STAP) in the presence of colored Gaussian disturbance. A novel diagonal loading (DL) based method is proposed to optimize the waveform covariance matrix (WCM) for maximizing the output signal-interference-noise ratio (SINR) of MIMO-STAP such that the detection performance can be maximized. The resultant nonlinear optimization problem is reformulated as a semidefinite programming (SDP) one, which can be solved very efficiently. Simulation results show that the output SINR of MIMO-STAP can be improved considerably by the proposed method, as compared to that of uncorrelated waveforms.

[151] Yang Yang; Blum, R.S.; ,"Phase Synchronization for Coherent MIMO Radar: Algorithms and Their Analysis," Signal Processing, IEEE Transactions on , vol.59, no.11, pp.5538-5557, Nov. 2011

Abstract: Multiple-input multiple-output (MIMO) radar can achieve improved localization performance by employing a coherent processing approach with proper antenna positioning. Coherent processing, however, entails the challenge of ensuring phase coherence of the carrier signals from different distributed radar elements. In this work, the authors aim to address such a challenge by providing a systematic treatment of the phase synchronization problem in coherent MIMO radar systems. The authors propose and study three different approaches for reaching a common notion of phase in coherent MIMO radar, namely, the master-slave closed-loop algorithm, the round-trip algorithm and the broadcast consensus based algorithm. These algorithms range from centralized to distributed types, and include both noniterative and iterative approaches. They do not require a priori establishment of the time synchronization, and thus are all time asynchronous in nature. Under a similar analytical framework, the authors mathematically characterize each of these algorithms, and further derive and study the statistical properties of a few relevant figures of merit including the resulting phase synchronization error. Simulation results are presented to validate our theoretical analysis.

[152] Yao Yu; Petropulu, A.P.; Poor, H.V.; ,"Measurement Matrix Design for Compressive Sensing--Based MIMO Radar," Signal Processing, IEEE Transactions on , vol.59, no.11, pp.5338-5352, Nov. 2011

Abstract: In colocated multiple-input multiple-output (MIMO) radar using compressive sensing (CS), a receive node compresses its received signal via a linear transformation, referred to as a

measurement matrix. The samples are subsequently forwarded to a fusion center, where an l1-optimization problem is formulated and solved for target information. CS-based MIMO radar exploits target sparsity in the angle-Doppler-range space and thus achieves the high localization performance of traditional MIMO radar but with significantly fewer measurements. The measurement matrix affects the recovery performance. A random Gaussian measurement matrix, typically used in CS problems, does not necessarily result in the best possible detection performance for the basis matrix corresponding to the MIMO radar scenario. This paper considers optimal measurement matrix design with the optimality criterion depending on the coherence of the sensing matrix (CSM) and/or signal-to-interference ratio (SIR). Two approaches are proposed: the first one minimizes a linear combination of CSM and the inverse SIR, and the second one imposes a structure on the measurement matrix and determines the parameters involved so that the SIR is enhanced. Depending on the transmit waveforms, the second approach can significantly improve the SIR, while maintaining a CSM comparable to that of the Gaussian random measurement matrix (GRMM). Simulations indicate that the proposed measurement matrices can improve detection accuracy as compared to a GRMM.

[153] Gogineni, S.; Nehorai, A.; ,"Target Estimation Using Sparse Modeling for Distributed MIMO Radar," Signal Processing, IEEE Transactions on , vol.59, no.11, pp.5315-5325, Nov. 2011

Abstract: Multiple-input multiple-output (MIMO) radar systems with widely separated antennas provide spatial diversity by viewing the targets from different angles. In this paper, the authors use a novel approach to accurately estimate properties (position, velocity) of multiple targets using such systems by employing sparse modeling. The authors also introduce a new metric to analyze the performance of the radar system. The authors propose an adaptive mechanism for optimal energy allocation at the different transmit antennas. The authors show that this adaptive energy allocation mechanism significantly improves in performance over MIMO radar systems that transmit fixed equal energy across all the antennas. The authors also demonstrate accurate reconstruction from very few samples by using compressive sensing at the receivers.

[154] Salmi, J.; Molisch, A.F.; ,"Propagation Parameter Estimation, Modeling and Measurements for Ultrawideband MIMO Radar," Antennas and Propagation, IEEE Transactions on , vol.59, no.11, pp.4257-4267, Nov. 2011

Abstract: Ultrawideband (UWB) radar is a promising method for reliable remote monitoring of vital signs. The use of multiple antennas at transmitter and receiver (MIMO) allows not only improved reliability, but also better accuracy in localization and tracking of humans and their various types of movement. This paper describes an experimental demonstration of localizing a test subject and tracking his breathing under ideal conditions. The UWB MIMO channel, which includes the test subject as well as other objects, is modeled as a superposition of multipath components (MPCs). From the measured data one can extract the parameters of the MPCs, including their directions and delays, which allows localization of the test subject as well as tracking the breathing motion. Since the breathing pattern of the test subject induces delay variations of the diaphragm-reflected MPC that are much smaller than the Fourier resolution limits, the high-resolution RIMAX algorithm (iterative maximum-likelihood estimation scheme) is employed together with a path detection scheme for determining and tracking the MPC parameters. Furthermore, it is illustrated that with a wideband array model, the requirements for antenna spacing are not as limited as for conventional narrowband array processing. Through

controlled experiments with a vector network analyzer and a virtual antenna array observing both an artificial "breathing" object as well as a human subject, it is shown that one can accurately estimate the small scale movement from human respiratory activity. This is achieved both for line-of-sight between transmitter, receiver, and objects, as well as for non-line-of sight.

[155] Wei-Jen Chen; Narayanan, R.M.; ,"Antenna Placement for Minimizing Target Localization Error in UWB MIMO Noise Radar," Antennas and Wireless Propagation Letters, IEEE , vol.10, no., pp.135-138, 2011

Abstract: An iterative approach is applied to estimate target location in an ultrawideband multiple-input-multiple-output noise radar system, and the lower bound of its performance is analyzed. The analysis clearly shows that target location estimation accuracy depends on the antenna locations. An approach to efficiently deploy the antennas is proposed. Simulations demonstrate that the root mean square error in target location estimation is inversely proportional to the square root of the product of the number of transmit and receive antennas numbers, and it is able to achieve the derived lower bound at high signal-to-noise ratios.

[156] Ahmed, S.; Thompson, J.S.; Petillot, Y.R.; Mulgrew, B.; ,"Finite Alphabet Constant-Envelope Waveform Design for MIMO Radar," Signal Processing, IEEE Transactions on , vol.59, no.11, pp.5326-5337, Nov. 2011

Abstract: The design of waveforms with specified auto- and cross-correlation properties has a number of applications in multiple-input multiple-output (MIMO) radar beampattern design. In this work, two algorithms are proposed to generate finite alphabet constant-envelope (CE) waveforms with required cross-correlation properties. The first-algorithm proposes a closed-form solution to find the finite alphabet CE waveforms to realize the given covariance matrix. Here, Gaussian random-variables (RV's) are mapped onto binary-phase shift keying (BPSK) and quadrature-phase shift keying (QPSK) symbols using nonlinear functions, and the cross-correlation relationship between the Gaussian RV's and BPSK/QPSK RV's is established. This cross-correlation relationship is exploited to convert the problem of finding the BPSK/QPSK waveforms to realize the covariance matrix, corresponding to the given beampattern, into finding the Gaussian RV's to realize another covariance matrix that can be easily found. In the second-algorithm, by exploiting the results of first-algorithm, a generalized algorithm to generate BPSK waveforms to approximate the given beampattern is proposed. Simulation results show that proposed finite alphabet CE waveforms outperform the existing algorithms to approximate the desired beampattern.

[157] Gierlich, R.; Huttner, J.; Ziroff, A.; Weigel, R.; Huemer, M.; ,"A Reconfigurable MIMO System for High-Precision FMCW Local Positioning," Microwave Theory and Techniques, IEEE Transactions on , vol.59, no.12, pp.3228-3238, Dec. 2011

Abstract: In this paper, a highly accurate local positioning system is presented that is based on linear frequency-modulated continuous-wave signals in the 5.8-GHz industrial-scientific-medical band. The developed system allows for much higher operating distances than leading ultra-wideband local positioning systems, while it provides the same or even better accuracy. This is achieved by a novel multiple-input multiple-output (MIMO) measurement concept that enables the receiving unit to control the beam patterns of the receiving and the transmitting antenna arrays by a coherent combination of the received signals. In this way, interfering multipath components

are suppressed, leading to a significantly reduced ranging error. Furthermore, the angle of arrival and the angle of departure are determined from the MIMO datasets using super-resolution direction-finding techniques. For position determination, both range and angle information are exploited. Extensive measurements with the MIMO system in different indoor environments show that the position error can be reduced by up to 80% compared to an equivalent single-antenna setup.

[158] Chen, W.-J.; Narayanan, R.M.; ,"Comparison of the estimation performance of coherent and non-coherent ambiguity functions for an ultrawideband multi-input-multi-output noise radar," Radar, Sonar & Navigation, IET , vol.6, no.1, pp.49-59, January 2012

Abstract: The authors start by analysing the mean square error (MSE) of target velocity and location estimation in ultrawideband (UWB) multi-input-multi-output (MIMO) noise radar. In the authors- system architecture, transmit antennas are illuminated by UWB-independent noise waveforms to meet the requirement of MIMO spatial diversity. The ambiguity function (AF) formulation is applied to implement the estimations. Since the maximum value of the AF is attained when the time-delay and Doppler stretch of replica signals are exactly matched with the ones corresponding to the reflections, this estimation is also a peak localisation problem. When noise is added, the peak may be located in a different place causing error. In this study, the authors formulate probability density functions (pdfs) to approximate the distributions of coherent and non-coherent ambiguity functions (CAFs and NCAFs) that are then applied to analyse MSE of their estimates. The pdfs are also applied to analyse the detection performance based on different AF approaches. Based on the analyses, the authors demonstrate that the NCAF-based estimation is a better approach in spatial diversity MIMO radars.

[159] Godrich, H.; Petropulu, A.P.; Poor, H.V.; ,"Sensor Selection in Distributed Multiple-Radar Architectures for Localization: A Knapsack Problem Formulation," Signal Processing, IEEE Transactions on , vol.60, no.1, pp.247-260, Jan. 2012

Abstract: Widely distributed multiple radar architectures offer parameter estimation improvement for target localization. For a large number of radars, with full resource allocation, the achievable localization minimum estimation mean-square error (MSE) may extend beyond the system predetermined performance goals. In this paper, performance driven resource allocation schemes for multiple radar systems are proposed. Two operational policies are considered. In the first, the number of transmit and receive antennas employed in the estimation process is minimized by effectively selecting a subset of active antennas such that the required MSE performance threshold is attained. In the second, an optimal subset of active antennas of predetermined size is selected such that the localization MSE is minimized. These problems are formulated in a combinatorial optimization framework as a knapsack problem (KP), where the goal is to obtain a performance level with the lowest cost, in terms of active system elements. The Cramer-Rao bound (CRB) is used as a performance metric. Cost parameters, representing operational cost or any other utilization constraints on the antennas, are associated with each of the radars. These are incorporated in the KP formulation, integrating decision making factors in the selection process. Antenna subset selection is implemented through a heuristic algorithm, by successively selecting antennas so as to minimize the performance gap between the temporal CRB and a given MSE goal or a given subset size. The proposed approximate algorithms offer considerable reduction in computational complexity when compared with an exhaustive search. By minimizing the number

of operational antennas needed to complete the task, this concept introduces savings in both communication link needs and central processing load, in addition to the operational ones.

[160] Xiufeng Song; Willett, P.; Shengli Zhou; Luh, P.B.; ,"The MIMO Radar and Jammer Games," Signal Processing, IEEE Transactions on , vol.60, no.2, pp.687-699, Feb. 2012

Abstract: The interaction between a smart target and a smart MIMO radar is investigated from a game theory perspective. Since the target and the radar form an adversarial system, their interaction is modeled as a two-person zero-sum game. The mutual information criterion is used in formulating the utility functions. The unilateral, hierarchical, and symmetric games are studied, and the equilibria solutions are derived.

[161] Chen, H.; Yang, J.; Zhou, W.; Wang, H.; Li, X.; ,"On Unique Localization of Multiple Targets by MIMO Radars," Antennas and Wireless Propagation Letters, IEEE , vol.11, no., pp.949-952, 2012

Abstract: In this letter, the authors investigate the number of targets that can be uniquely localized by a direction-finding (DF) multiple-input--multiple-output (MIMO) radar system, often referred to as the parameter identification capacity (PIC), regardless of any certain DF algorithm. Using the dimension theory, the authors derive the PIC from a general measurement model. The authors show that the PIC of DF MIMO radar is determined not only by the antenna geometry configuration, but also by the number of independent processing intervals, unknown noise level, and the targets' reflection coefficients. Finally, the PICs of four representative antenna geometries are investigated and compared.

[162] Naghsh, M.M.; Modarres-Hashemi, M.; ,"Exact theoretical performance analysis of optimum detector in statistical multi-input multi-output radars," Radar, Sonar & Navigation, IET , vol.6, no.2, pp.99-111, February 2012

Abstract: This study is concerned with the performance analysis of detection problem in statistical multiple-input multiple-output radars for Gaussian interference. This subject has been addressed in some publications for such special cases as white Gaussian noise and orthogonal transmission. However, theoretical performance analysis of optimum detector for general case including coloured Gaussian interference and arbitrary transmission signal has not been reported yet. In the present study, after developing the optimum detector for a general case, exact closed-form expressions are derived for the probability of detection and false alarm. As the derived expressions have complicated form, their interpretation is not tractable in the general case. Therefore lower and upper Chernoff bounds are obtained to provide better insight into the detector performance. Furthermore, the effect of various parameters on the detector performance is investigated by Monte-Carlo simulations. Numerical analysis shows a high degree of consistency between the theoretical and Monte-Carlo simulation results.

[163] Jiang, Min; Huang, Jianguo; Jin, Yong; Han, Jing; ,"Target estimation using MIMO radar with multiple subcarriers," Systems Engineering and Electronics, Journal of , vol.23, no.1, pp.57-62, Feb. 2012

Abstract: This paper analyzes the effect of waveform parameters on the joint target location and velocity estimation by a noncoherent multiple input multiple output (MIMO) radar transmitting

multiple subcarriers signals. How the number of subcarriers influences the estimation accuracy is illustrated by considering the joint Cramer-Rao bound and the mean square error of the maximum likelihood estimate. The noncoherent MIMO radar ambiguity function with multiple subcarriers is developed and investigated by changing the number of subcarriers, the pulse width and the frequency spacing between adjacent subcarriers. The numerical results show that more subcarriers mean more accurate estimates, higher localization resolution, and larger pulse width results in a worse performance of target location estimation, while the frequency spacing affects target location estimation little.

[164] El Korso, M.N.; Boyer, R.; Renaux, A.; Marcos, S.; ,"Statistical Resolution Limit for Source Localization With Clutter Interference in a MIMO Radar Context," Signal Processing, IEEE Transactions on , vol.60, no.2, pp.987-992, Feb. 2012

Abstract: During the last decade, multiple-input multiple-ouput (MIMO) radar has received an increasing interest. One can find several estimation schemes in the literature related to the direction of arrivals and/or direction of departures, but their ultimate performance in terms of the statistical resolution limit (SRL) have not been fully investigated. In this correspondence, the authors fill this lack. Particulary, the authors derive the SRL to resolve two closely spaced targets in clutter interference using a MIMO radar with widely separated antennas. Toward this end, the authors use a hypothesis test formulation based on the generalized likelihood ratio test (GLRT). Furthermore, the authors investigate the link between the SRL and the minimum signal-to-noise ratio (SNR) required to resolve two closely spaced targets for a given probability of false alarm and for a given probability of detection. Finally, theoretical and numerical analysis of the SRL are given for several scenarios (with/without clutter interference, known/unknown parameters of interest and known/unknown noise variance).

[165] Guimei Zheng; Baixiao Chen; Minglei Yang; ,"Unitary ESPRIT algorithm for bistatic MIMO radar," Electronics Letters , vol.48, no.3, pp.179-181, February 2 2012

Abstract: A new Unitary ESPRIT algorithm for joint direction of departure (DOD) and direction of arrival (DOA) estimation in bistatic MIMO radar is proposed. The properties of centro-Hermitian matrices are utilised to transform the complex-valued data matrix into a real-valued data matrix. Then the real-valued rotational invariance equations for signal subsapce are figured out to estimate DOAs and DODs which are paired automatically in a new way. The proposed algorithm provides increased estimation accuracy with reduced computational complexity owing to real-valued processing and double the number of data samples inherently in unitary ESPRIT. Simulation results are presented to verify the effectiveness of the proposed algorithm.

[166] Bo Tang; Jun Tang; Yingning Peng; ,"Waveform Optimization for MIMO Radar in Colored Noise: Further Results for Estimation-Oriented Criteria," Signal Processing, IEEE Transactions on , vol.60, no.3, pp.1517-1522, March 2012

Abstract: Previous work on multiple-input multiple-output (MIMO) radar waveform design in colored noise based on minimizing minimum mean-square error (MMSE) and normalized mean-square error (NMSE) only considered the optimization of the singular value of the waveform matrix, while the optimization of singular vectors, which forms a basis of singular value optimization, was not stressed enough. In this correspondence, the authors revisit the waveform design problem for MIMO radar in colored noise based on MMSE and NMSE respectively.

Further results for the optimal solutions under both criteria are derived. The authors prove the optimality of "matching" with the target and colored noise for the singular vectors of the transmitted waveform. Moreover, to obtain minimum MMSE/NMSE, the pairing of the eigenvectors of the target and noise should be carefully designed, where the optimal pairing of the eigenvectors based on MMSE is fixed while the optimal pairing based on NMSE changes according to the transmitted power, the strength of the target, and noise.

[167] Radmard, M.; Karbasi, S.M.; Khalaj, B.H.; Nayebi, M.M.; ,"Data association in multi-input single-output passive coherent location schemes," Radar, Sonar & Navigation, IET , vol.6, no.3, pp.149-156, March 2012

Abstract: Efficient combination of multiple input multiple output (MIMO) and passive coherent location (PCL) ideas is expected to improve performance of localisation schemes. While using multiple antennas at transmit and receive sides provides spatial diversity, it is possible to obtain similar performance by using multiple transmitters, already transmitting standard signals (such as digital TV) in the environment (also known as illuminators of opportunity). However, in this case, it is not always possible to ensure that signals of different transmitters are orthogonal to each other. In such cases, resolving signals of multiple transmitters reflected from multiple objects is not a trivial problem. One such scenario arises when transmitters of a single frequency network (SFN) are used. Consequently, in order to obtain the desired diversity gain, it is necessary to develop proper techniques to assign each echo arriving at the receiver to a given transmitter and a specific object to be localised. In this paper, the authors propose a scheme that addresses the association problem in an efficient way. Also, the authors consider the case of multiple antennas only at the transmit side while using a single receiver, which is the case of a multi-input single-output (MISO) system, a subset of MIMO systems, in general.

[168] Wilcox, D.; Sellathurai, M.; ,"On MIMO Radar Subarrayed Transmit Beamforming," Signal Processing, IEEE Transactions on , vol.60, no.4, pp.2076-2081, April 2012

Abstract: Multiple-input-multiple-output (MIMO) radar schemes whereby the transmit array is partitioned into subarrays have recently been proposed in the literature to combine advantages of phased array and MIMO radar technology. In this work, the authors utilize this architecture to significantly simplify a transmit procedure in which the covariance matrix across the MIMO radar array is optimized to improve the Cramer-Rao bound (CRB) on target parameter estimation. The MIMO effective array for regular subarrayed transmit apertures is studied, and necessary conditions to obtain a filled effective aperture are presented, which is important for maintaining nonambiguous, low sidelobe beampatterns. The performance of the subarrayed transmit approach is evaluated in terms of the CRB on target parameter estimation, and the optimisation of the beamformer applied to the subarrays to minimize the CRB is considered. The subarrayed transmit scheme is found to have a CRB which is suboptimal to the full diversity transmission, as expected, but is solvable in a small fraction of the time using an iterative beamspace algorithm developed here.

[169] Friedlander, B.; ,"Effects of Model Mismatch in MIMO Radar," Signal Processing, IEEE Transactions on , vol.60, no.4, pp.2071-2076, April 2012

Abstract: The current literature on MIMO radar commonly uses a signal model that assumes that the Doppler and delay parameters of the scatterers lie on a discrete grid. The Doppler and delay of

actual scatterers take on arbitrary values causing a mismatch between this model and reality. Here, the authors develop a signal model that takes into account this mismatch and shows that it causes a distortion of the array manifold. This distortion, which is unique to MIMO radar, impacts the results of array processing functions such as beamforming, null steering, and direction finding. The degree of performance degradation caused by this is illustrated by numerical examples.

[170] Sammartino, P.F.; Tarchi, D.; Fortuny-Guasch, J.; Oliveri, F.; Giuliani, R.; ,"Phase compensation and processing in multiple-input-multiple-output radars," Radar, Sonar & Navigation, IET , vol.6, no.4, pp.222-232, April 2012

Abstract: In this study, the issue of phase discontinuity in multiple-input-multiple-output (MIMO) radar systems is analysed and described in detail, together with an efficient way for processing MIMO radar data by means of discrete-time Fourier transform (DFT) fast Fourier transform (FFT). In particular, here it is shown that the phase history of a point target illuminated by an MIMO radar shows a number of discontinuities because of the geometry of the antennas. It is also shown that these become negligible in the far range, whereas they represent an issue in the short range if not compensated properly because, in turn, they prevent DFT-based algorithms correctly focusing the received signals. It is shown that data from MIMO radars have to be pre-processed in order to allow an efficient DFT-based focalisation. For this purpose, together with a theoretical description of the problem, a sub-optimal algorithm is presented, discussed and tested against real data gathered by the Joint Research Centre (JRC) MIMO radar system.

[171] Rabideau, D.J.; ,"MIMO Radar Waveforms and Cancellation Ratio," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.2, pp.1167-1178, APRIL 2012

Abstract: The performance of adaptive multiple-input multiple-output (MIMO) radar waveforms is examined. The authors begin by defining a metric, called "MISO cancellation ratio", for numerically screening MIMO waveforms so as to assess their clutter cancellation performance. Next, the authors evaluate the MISO cancellation ratio levels provided by a number of MIMO waveform classes. Finally, the authors describe a new MIMO waveform approach, called "dithered DDMA" (Doppler division multiple access), which enables high performance clutter cancellation over a large range-Doppler region without introducing ambiguous ranges or blind speeds, and without increasing the computational load on the MIMO processor.

[172] Yao Yu; Petropulu, A.P.; Poor, H.V.; ,"CSSF MIMO RADAR: Compressive-Sensing and Step-Frequency Based MIMO Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.2, pp.1490-1504, APRIL 2012

Abstract: A new approach is proposed, namely CSSF MIMO radar, which applies the technique of step frequency (SF) to compressive sensing (CS) based multiple-input multiple-output (MIMO) radar. The proposed approach enables high resolution range, angle and Doppler estimation, while transmitting narrowband pulses. For the case of slowly moving targets, a technique is proposed that achieves significant complexity reduction by successively estimating angle-range and Doppler in a decoupled fashion.

[173] Chen, Haowen; Chen, Yiping; Yang, Zhaocheng; Li, Xiang; ,"Extended ambiguity function for bistatic MIMO radar," Systems Engineering and Electronics, Journal of , vol.23, no.2, pp.195-200, April 2012

Abstract: This paper derives the extended ambiguity function for a bistatic multiple-input multiple-output (MIMO) radar system, which includes the whole radar system parameters: geometric sensor configuration, waveforms, range, range rate, target scattering and noise characteristics. Recent research indicates the potential parameter estimate performance of bistatic MIMO radars. And this ambiguity function can be used to analyze the parameter estimate performance for the relationship with the Cramer-Rao bounds of the estimated parameters. Finally, some examples are given to demonstrate the good parameter estimate performance of the bistatic MIMO radar, using the quasi-orthogonal waveforms based on Lorenz chaotic systems.

[174] Ruixin Niu; Blum, R.S.; Varshney, P.K.; Drozd, A.L.; ,"Target Localization and Tracking in Noncoherent Multiple-Input Multiple-Output Radar Systems," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.2, pp.1466-1489, APRIL 2012

Abstract: For a noncoherent multiple-input multiple-output (MIMO) radar system, the maximum likelihood estimator (MLE) of the target location and velocity, as well as the corresponding Cramer-Rao lower bound (CRLB) matrix, is derived. MIMO radar's potential in localization and tracking performance is demonstrated by adopting simple Gaussian pulse waveforms. Due to the short duration of the Gaussian pulses, a very high localization performance can be achieved, even when the matched filter ignores the Doppler effect by matching to zero Doppler shift. This leads to significantly reduced complexities for the matched filter and the MLE. Further, two interactive signal processing and tracking algorithms, based on the Kalman filter and the particle filter (PF), respectively, are proposed for noncoherent MIMO radar target tracking. For a system with a large number of transmit/receive elements and a high signal-to-noise ratio (SNR) value, the Kalman filter (KF) is a good choice; while for a system with a small number of elements and a low SNR value, the PF outperforms the KF significantly. In both methods, the tracker provides predictive information regarding the target location, so that the matched filter can match to the most probable target locations, reducing the complexity of the matched filter and improving the tracking performance. Since tracking is performed without detection, the presented approach can be deemed as a track-before-detect approach. It is demonstrated through simulations that the noncoherent MIMO radar provides significant tracking performance improvement over a monostatic phased array radar with high range and azimuth resolutions. Further, the effects of coherent integration of pulses are investigated for both the phased array radar and a hybrid MIMO radar, where only the pulses transmitted and received by colocated transceivers are coherently integrated and the other pulses are combined noncoherently. It is shown that the hybrid MIMO radar achieves significa- t tracking performance improvement when compared with the phased array radar, by using the extra Doppler information obtained through coherent pulse integration.

[175] Guolong Cui, Lingjiang Kong, Xiaobo Yang, Jianyu Yang, "Distributed target detection with polarimetric MIMO radar in compound-Gaussian clutter," Digital Signal Processing, Volume 22, Issue 3, May 2012, Pages 430–438

Abstract: This paper mainly deals with distributed targets detection with a polarimetric MIMO radar against compound-Gaussian clutter dominated scenario with unknown covariance matrix. First, the general polarimetric detecting problem of the distributed targets is developed to the

MIMO radar, and then, the fully adaptive Generalized Likelihood Ratio Test (GLRT) is devised according to the well known two-step design procedure. Three covariance matrix estimation strategies using the secondary data are introduced to make derived receiver fully adaptive. A thorough performance assessment is given, and via several numerical examples, the results highlight that the spatial and polarization diversities can be exploited to improve the detection performance of the distributed targets in compound-Gaussian background, and it outperforms the phased-array counterpart, the adaptive loss is completely acceptable in practical applications. Meanwhile, the fixed-point estimation strategy is more suitable to implement the adaptive detection algorithm.

[176] Sandeep Gogineni, Arye Nehorai, “Game theoretic design for polarimetric MIMO radar target detection,” Signal Processing, Volume 92, Issue 5, May 2012, Pages 1281–1289

Abstract: Polarimetric radar systems allow the flexibility of transmitting arbitrarily polarized waveforms that match the scattering profiles of the target. Since different types of targets have varying profiles, the advantages of a polarimetric radar system can fully be exploited only when the type of target is accurately estimated. However, accurate estimation requires a significant amount of training data, which can be expensive. The authors propose a polarimetric design scheme for distributed multiple input multiple output (MIMO) radar target detection. The authors formulate the selection of transmit polarizations using a game theoretic framework by examining the impact of all possible transmit schemes on the detection performance with different available target profiles (see also Gogineni and Nehorai, 2011 [1]). This approach does not require training data, and the authors show a significant performance improvement due to the polarimetric design. Other radar design problems can also be solved using this game theoretic approach.

[177] Levitin, G.; Yuanshun Dai; ,”k-out-of-n sliding window systems," Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on , vol.42, no.3, pp.707-714, May 2012

Abstract: This paper proposes a new model that generalizes the linear multistate sliding window system to the case of multiple failures. In this model, the system consists of independent linearly ordered multistate elements. Each element can have different states: from complete failure up to perfect functioning. A performance rate is associated with each state. The system fails if, at least in groups of consecutive elements (windows), the sum of the performance rates of elements belonging to the group is less than a minimum allowable level. An algorithm for system reliability evaluation is suggested which is based on an extended universal moment generating function. Examples of evaluating system reliability and elements' reliability importance indices are presented.

[178] Hassanien, A.; Vorobyov, S.A.; Gershman, A.B.; ,”Moving Target Parameters Estimation in Noncoherent MIMO Radar Systems," Signal Processing, IEEE Transactions on, vol.60, no.5, pp.2354-2361, May 2012

Abstract: The problem of estimating the parameters of a moving target in multiple-input multiple-output (MIMO) radar is considered and a new approach for estimating the moving target parameters by making use of the phase information associated with each transmit-receive path is introduced. It is required for this technique that different receive antennas have the same time reference, but no synchronization of initial phases of the receive antennas is needed and,

therefore, the estimation process is noncoherent. The authors model the target motion within a certain processing interval as a polynomial of general order. The first three coefficients of such a polynomial correspond to the initial location, velocity, and acceleration of the target, respectively. A new maximum likelihood (ML) technique for estimating the target motion coefficients is developed. It is shown that the considered ML problem can be interpreted as the classic "overdetermined" nonlinear least-squares problem. The proposed ML estimator requires multidimensional search over the unknown polynomial coefficients. The Cramer-Rao bound (CRB) for the proposed parameter estimation problem is derived. The performance of the proposed estimator is validated by simulation results and is shown to achieve the CRB.

[179] Yuanbing Cheng; Hong Gu; Weimin Su; ,"Joint 4-D Angle and Doppler Shift Estimation via Tensor Decomposition for MIMO Array," Communications Letters, IEEE , vol.16, no.6, pp.917-920, June 2012

Abstract: A joint 4-dimensional (4-D) angle and Doppler shift estimation method is proposed for bistatic multiple-input multiple-output (MIMO) uniform rectangular array (URA). The key idea behind the proposed approach is to use tensor decomposition to estimate the target parameter matrices, and use Vandermonde structure enforcing strategy to regress the parameters. This algorithm can effectively estimate all the parameters simultaneously, and requires neither parameter pairing nor multi-dimensional nonlinear peak searching.

[180] Emanuele Grossi, Marco Lops, Luca Venturino, "Min–max waveform design for MIMO radars under unknown correlation of the target scattering," Signal Processing, Volume 92, Issue 6, June 2012, Pages 1550–1558

Abstract: The authors address the problem of robust waveform design for MIMO radars when the target scattering covariance matrix is unknown at both the transmit and receive sides. Following a min–max approach, the code matrix is designed to minimize the worst-case cost under all possible target covariance matrices. Differently from previous works the authors include the choice of the codeword's length in the design problem. For a large class of cost functions, the min–max solution has a simple and intuitive structure which the authors explain. In particular, the codeword's length must be chosen as large as possible in order to provide the transmitter with the largest degrees of freedom. Examples illustrating the behavior of the min–max codes are provided for different case studies.

[181] Gogineni, S.; Nehorai, A.; ,"Frequency-Hopping Code Design for MIMO Radar Estimation Using Sparse Modeling," Signal Processing, IEEE Transactions on , vol.60, no.6, pp.3022-3035, June 2012

Abstract: The authors consider the problem of multiple-target estimation using a colocated multiple-input multiple-output (MIMO) radar system. The authors employ sparse modeling to estimate the unknown target parameters (delay, Doppler) using a MIMO radar system that transmits frequency-hopping waveforms. The authors formulate the measurement model using a block sparse representation. The authors adaptively design the transmit waveform parameters (frequencies, amplitudes) to improve the estimation performance. Firstly, the authors derive analytical expressions for the correlations between the different blocks of columns of the sensing matrix. Using these expressions, the authors compute the block coherence measure of the dictionary. The authors use this measure to optimally design the sensing matrix by selecting the

hopping frequencies for all the transmitters. Secondly, the authors adaptively design the amplitudes of the transmitted waveforms during each hopping interval to improve the estimation performance. To perform this amplitude design, the authors initialize it by transmitting constant-modulus waveforms of the selected frequencies to estimate the radar cross section (RCS) values of all the targets. Next, the authors make use of these RCS estimates to optimally select the waveform amplitudes. The authors demonstrate the performance improvement due to the optimal design of waveform parameters using numerical simulations. Further, the authors employ compressive sensing to conduct accurate estimation from far fewer samples than the Nyquist rate.

[182] Wei-Jen Chen; Narayanan, R.M.; ,"CGLRT plus TDL Beamforming for Ultrawideband MIMO Noise Radar," Aerospace and Electronic Systems, IEEE Transactions on, vol.48, no.3, pp.1858-1869, JULY 2012

Abstract: The authors consider the estimation of target directions in ultrawideband (UWB) multi-input-multi-output (MIMO) noise radar. The authors apply the tapped-delay-line (TDL) based beamforming technique to concentrate on receiving signals from a certain direction and to suppress interference from others. The conditional generalized likelihood ratio test (CGLRT) is applied for detecting target given the target impulse responses estimated by the CLEAN algorithm. Then, the authors propose the iterative CGLRT (ICGLRT) to determine their directions by implementing these two techniques iteratively.

[183] Gorji, A.A.; Tharmarasa, R.; Blair, W.D.; Kirubarajan, T.; ,"Multiple Unresolved Target Localization and Tracking using Colocated MIMO Radars," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.3, pp.2498-2517, JULY 2012

Abstract: In this paper localization and tracking of multiple unresolved targets using a colocated multiple input multiple output (MIMO) radar is addressed. The commonly-used model for colocated MIMO radars is modified in order to guarantee the observability in received measurements. Then, a maximum likelihood estimator is derived for localizing multiple targets falling within a certain resolution cell. The Cramer-Rao lower bound (CRLB) for localization with the new model is also derived. For the tracking part, a multiple-hypothesis-based approach is used to deal with the uncertainty in target state estimation. In addition, an unscented Kalman filter (UFK) based estimator is used to tackle the nonlinearity in the measurement model. Finally, the posterior CRLB (PCRLB) is derived to evaluate the consistency of tracking results. Simulation results confirm the superiority of the proposed approach in resolving multiple targets over using the standard localization results for tracking.

[184] Bencheikh, M.L.; Wang, Y.; ,"Joint DOD-DOA estimation using combined ESPRIT-MUSIC approach in MIMO radar," Electronics Letters , vol.46, no.15, pp.1081-1083, July 22 2010

Abstract: A new method for joint direction of arrival (DOA)-direction of departure (DOD) estimation in bistatic MIMO radar is proposed. This method, based on the decomposition of the 2D direction finding into double 1D direction finding, uses the ESPRIT method to estimate the DOD and the Root-MUSIC for the DOA estimation. Some simulation results are presented to verify the efficiency of this approach.

[185] Chaoran Du; Thompson, J.S.; Petillot, Y.R.; ,"Detector and Waveform Design for MIMO Radar System with Noisy Channel Estimation," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.3, pp.2332-2348, JULY 2012

Abstract: It has been shown that time-reversal (TR), which was developed in the acoustics domain, can also improve the detection performance of a radar system. However, the TR technique is no longer a good choice when the noise level is high since the retransmitted signal contains significant noise components. The authors investigate a multiple-input multiple-output (MIMO) detection process similar to TR detection, during which a waveform designed using the estimated channel and a parameter indicating the quality of the estimation is retransmitted, and the detector determines the presence or absence of a target. The authors develop three detectors, whose theoretical thresholds and probabilities of detection are derived. Three schemes are proposed to design the retransmitted waveform with constraints on signal power. The designed detectors require different amounts of a priori information, whose performance is compared and analyzed. Numerical results show that all the three designed waveforms can improve the system performance significantly compared with the TR approach, but such enhancement is gained at the price of knowing the quality of channel estimation a priori.

[186] Lei Xu; Qilian Liang; ,"Zero Correlation Zone Sequence Pair Sets for MIMO Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.3, pp.2100-2113, JULY 2012

Abstract: Inspired by recent advances in multiple-input multiple-output (MIMO) radar, the authors apply orthogonal phase coded waveforms to MIMO radar system in order to gain better range resolution and target direction finding performance. The authors provide and investigate a generalized MIMO radar system model using orthogonal phase coded waveforms. In addition, the authors slightly modify the system model to improve the system performance. Accordingly, the authors propose the concept and the design methodology for a set of ternary phase coded waveforms that is the optimized punctured zero correlation zone (ZCZ) sequence-pair set (ZCZPS). The authors also study the MIMO radar ambiguity function of the system using phase coded waveforms, based on which the authors analyze the properties of our proposed phase coded waveforms which show that better range resolution could be achieved. In the end, the authors apply our proposed codes to the two MIMO radar system models and simulate their target direction finding performances. The simulation results show that the first MIMO radar system model could obtain ideal target direction finding performance when the number of transmit antennas is equal to the number of receive antennas. The second MIMO radar system model is more complicated but could improve the direction finding performance of the system.

[187] Haowen Chen; Xiang Li; Zhaowen Zhuang; ,"Antenna Geometry Conditions for MIMO Radar With Uncoupled Direction Estimation," Antennas and Propagation, IEEE Transactions on , vol.60, no.7, pp.3455-3465, July 2012

Abstract: The authors mainly focus on the role played by the antenna geometry in the direction estimation performance for a direction finding (DF) bistatic multiple-input multiple-output (MIMO) radar. First, the authors introduce the signal and the noise models which satisfy the space-time separability conditions. Then, the authors derive an expression of the Cramer-Rao lower bound (CRLB) on target parameters with the antenna locations for a single point target in the far-field scenario. The authors show that, under the space-time separability conditions, the

temporal dimension parameters (range and range rate) and spatial dimension parameters are uncoupled. The authors also show that DOD and DOA are uncoupled because of their spatial independence. In addition, the authors derive a set of the necessary and sufficient geometrical constraints for the uncoupled direction estimation which is based on the diagonal Fisher information matrix (FIM). The authors present that, when both the transmit and the receive antenna location parameters have equivalent auto-moment-of-inertia tensors of x and y axes, and zero cross-moment-of-inertia tensors of x, y and z axes, the bistatic MIMO radar system with uncoupled direction estimation can be obtained. The corresponding conditions are extended to monostatic MIMO radar case for their commonness of the colocated antenna geometry. In numerical example section, the authors show several representative antenna geometries to illustrate the antenna geometry conditions derived in this paper.

[188] Cao, Y.; Zhang, Z.; Dai, F.; Xie, R.; ,"Direction of arrival estimation for monostatic multiple-input multiple-output radar with arbitrary array structures," Radar, Sonar & Navigation, IET , vol.6, no.7, pp.679-686, August 2012

Abstract: Compared with other systems with a single transmit antenna, multiple-input multiple-output (MIMO) radar systems have additional degrees of freedom that can enhance space resolution, improve parameter identifiability and enhance flexibility for transmit beam pattern design. The computational complexity for direction of arrival (DOA) estimation using sensor arrays increases very rapidly with the number of channels. The polynomial-rooting version of multiple signal classification algorithm (root-MUSIC) is computationally more efficient than spectral MUSIC. However, this algorithm can only be applied to uniform linear arrays. The manifold separation technique allows arrays of any geometry to be used with fast DOA estimators designed for linear arrays. In this study, a DOA estimation method that uses manifold separation and polynomial rooting technique is presented for monostatic MIMO radar with arbitrary array configuration. The algorithm offers a low computation complexity and an improved resolution capability for closely spaced sources as compared to conventional spectral MUSIC. Moreover, the wavefield modelling for monostatic MIMO radar and the number of mode selection of the proposed method are also analysed in the study. Finally, the simulation results are presented and the performances of the proposed algorithm are investigated and discussed.

[189] Radmard, M.; Khalaj, B.H.; Chitgarha, M.M.; Majd, M.N.; Nayebi, M.M.; ,"Receivers positioning in multiple-input multiple-output digital video broadcast-terrestrial-based passive coherent location," Radar, Sonar & Navigation, IET , vol.6, no.7, pp.603-610, August 2012

Abstract: Using multiple illuminators of opportunity at the transmit side and multiple antennas at the receiver side in a passive coherent location (PCL) scheme is expected to improve the detection performance. However, in such multiple-input multiple-output (MIMO) configuration choosing the position of the receivers is an obstacle that can have significant influence on the resulting performance. In this study, the authors consider the case of digital video broadcast (DVB)-T stations as non-cooperative transmitters and introduce a procedure based on the probability of missed detection to properly place receive antennas in a MIMO digital video broadcasting (DVB)-T based PCL configuration.

[190] Changzheng Ma; Tat Soon Yeo; Chee Seng Tan; Jian-Ying Li; Yong Shang; ,"Three-Dimensional Imaging Using Colocated MIMO Radar and ISAR Technique," Geoscience and Remote Sensing, IEEE Transactions on , vol.50, no.8, pp.3189-3201, Aug. 2012

Abstract: A conventional inverse synthetic aperture radar image is a 2-D range-Doppler projection of a target and does not provide 3-D information. Three-dimensional imaging using an interferometric technique cannot separate scatterers that have been projected onto the same range-Doppler unit. Multiple-input-multiple-output (MIMO) radar, however, in addition to having a wide virtual aperture and a high cross-range resolution, could also obtain a target's 3-D image in one snapshot. The authors discuss in this paper the use of time-domain information to improve MIMO radar's imaging quality. A 3-D image alignment algorithm and a rotation vector estimation method are discussed. Simulation results show that image SNR is improved and cross-range sidelobes are mitigated.

[191] Yong-Chao Wang; Xu Wang; Hongwei Liu; Zhi-Quan Luo; ,"On the Design of Constant Modulus Probing Signals for MIMO Radar," Signal Processing, IEEE Transactions on , vol.60, no.8, pp.4432-4438, Aug. 2012

Abstract: Probing signal waveforms play a central role in the signal processing performance of a multiple-input multiple-output (MIMO) radar. In practice, for a given desired beam pattern, the authors need to design a probing signal waveform whose beam pattern closely matches the desired one and whose autocorrelation and cross-correlation sidelobes are kept low. The latter properties are important to mitigate undesirable interference caused by multiple targets or scatterers. In this correspondence, the authors present an efficient optimization method to design a constant modulus probing signal which can synthesize a desired beam pattern while maximally suppressing both the autocorrelation and cross-correlation sidelobes at/between given spacial angles. The authors formulate this problem as an unconstrained minimization of a fourth order trigonometric polynomial and propose an efficient quasi-Newton iterative algorithm to solve it. Besides, the authors provide an analysis of the local minima of the fourth-order trigonometric polynomial and prove that any local minima is a 1/2-approximation of its global optimal solution. Numerical examples show that the proposed approach compares favorably with the existing approach.

[192] Brennan, P.V.; Narayanan, A.; Benjamin, R.; ,"Grating lobe control in randomised, sparsely populated MIMO radar arrays," Radar, Sonar & Navigation, IET , vol.6, no.7, pp.587-594, August 2012

Abstract: Randomisation of element positions in a sparsely populated, non-uniform antenna array is a well-known approach in communication systems for controlling grating lobes and allowing improved spatial resolution for a given number of antenna elements. MIMO array techniques have been applied more recently to radar systems with a view to improving the versatility and performance, particularly angular resolution, of a system with a given number of elements. A sparsely populated, non-uniform MIMO array would therefore seem a logical and attractive combination, though its performance is rather more difficult to predict and less easy to control because of geometrical constraints. This study sets out to examine the spatial sidelobe performance and potential for grating lobe control of a sparsely populated MIMO radar array architecture using antenna position randomisation to suppress grating lobes.

[193] Xiaodong Zhuge; Yarovoy, A.G.; ,"Study on Two-Dimensional Sparse MIMO UWB Arrays for High Resolution Near-Field Imaging," Antennas and Propagation, IEEE Transactions on , vol.60, no.9, pp.4173-4182, Sept. 2012

Abstract: A novel generic topology for two-dimensional (2-D) sparse multiple-input-multiple-output (MIMO) ultrawideband (UWB) arrays is suggested. Based on the proposed topology, a 2-D MIMO UWB array for high-resolution short-range imaging is developed. The focusing properties of this array are studied both theoretically and experimentally and are shown to be superior to those of arrays with a similar number of antennas and based on known topologies such as Mills Cross, rectangular, and spiral configurations. Decisive impact of a large operational bandwidth and short focusing distance on MIMO array performance is shown. Imaging capabilities of the proposed array are experimentally demonstrated for distributed targets.

[194] Friedlander, B.; ,"On Transmit Beamforming for MIMO Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.4, pp.3376-3388, October 2012

Abstract: Methods for transmit beamforming in multiple-input multiple-output (MIMO) radar based on the design of multiple correlated waveforms have been proposed. This paper points out that this approach couples the spatial (beamformer) and temporal (waveform) parts of the problem, significantly complicating the design. It is shown here that the most general form of transmit beamforming can be achieved in a decoupled form, using orthogonal (uncorrelated) waveforms and a multi-rank transmit beamformer. This formulation allows the use of standard beamformer design procedures. Examples are provided to illustrate the design of multi-rank beamformers for search and tracking applications. The examples include single and multiple beamformers, adaptive beamformers, and wide beams for illumination. These examples are illustrated by simulation results.

[195] Zheng, Zhidong; Zhang, Jianyun; Wu, Yuebo; ,"Multi-target localization for bistatic MIMO radar in the presence of unknown mutual coupling," Systems Engineering and Electronics, Journal of , vol.23, no.5, pp.708-714, Oct. 2012

Abstract: A decoupling-estimation signal parameters via rotarional invariance technique (ESPRIT) method is presented for multi-target localization with unknown mutual coupling in bistatic multiple-input multiple-output (MIMO) radar. Two steps are carried out in this method. The decoupling operation between angle and mutual coupling estimates is realized by choosing the auxiliary elements on both sides of the transmit and receive uniform linear arrays (ULAs). Then the ESPRIT method is resilient against the unknown mutual coupling matrix (MCM) and can be directly utilized to estimate the direction of departure (DOD) and the direction of arrival (DOA). Moreover, the mutual coupling coefficient is estimated by finding the solution of the linear constrained optimization problem. The proposed method allows an efficient DOD and DOA estimates with automatic pairing. Simulation results are presented to verify the effectiveness of the proposed method.

[196] Zhang, X.; Huang, Y.; Chen, C.; Li, J.; Xu, D.; ,"Reduced-complexity Capon for direction of arrival estimation in a monostatic multiple-input multiple-output radar," Radar, Sonar & Navigation, IET , vol.6, no.8, pp.796-801, October 2012

Abstract: In this study, the authors consider the direction of arrival (DOA) estimation problem for a monostatic multiple-input multiple-output (MIMO) radar. A DOA estimation algorithm for the monostatic MIMO radar using Capon and the reduced-dimension transformation is proposed. The proposed algorithm can achieve lower computational complexity than the Capon algorithm, while not debasing the performance of the angle estimation. The proposed algorithm has better angle estimation performance than the Capon algorithm and estimation of signal parameters via rotational invariance techniques algorithm, and it has close angle estimation performance to the Cramer-Rao bound (CRB). The variance of the estimation error and the CRB of the DOA estimation are derived. Simulation results present the usefulness of the proposed algorithm.

[197] Friedlander, B.; ,"On Signal Models for MIMO Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.4, pp.3655-3660, October 2012

Abstract: A detailed model for the signal received by a multiple-input multiple-output (MIMO) radar from point scatterers is derived and compared with a simplified model frequently used in the literature. The simplified model assumes discretization of the scatterer delays and Dopplers and a particular way of handling the out-of-bin radar returns. It is argued that these assumptions may cause results derived from the simplified model to deviate, possibly significantly, from corresponding results observed in a real radar.

[198] Chen, H.; Zhou, W.; Yang, J.; Peng, Y.; Li, X.; ,"Manifold studies on fundamental limits of direction-finding multiple-input multiple-output radar systems," Radar, Sonar & Navigation, IET , vol.6, no.8, pp.708-718, October 2012

Abstract: In this study, the authors extend Manikas's array bound theory using differential geometry to direction-finding (DF) multiple-input multiple-output (MIMO) radar, and investigate the ultimate DF accuracy, detection and resolution capabilities via the manifold studies on MIMO virtual arrays. The authors derive the expression of the asymptotic normalised mean-square angular error, which is based on Cramer'Rao bounds of azimuth and elevation angles, to explore the ultimate DF accuracy both for one- and two-target cases. Furthermore, in two-target case, the authors derive the expressions of detection and resolution thresholds of directional parameters, respectively. They find that all fundamental limits above are highly dependent on the antenna geometry of DF MIMO radar systems. At last, the fundamental limits of four representative antenna geometries of DF MIMO radars, which are used in most of the current literature, are investigated and compared.

[199] Tian Jin; Jun Lou; Zhimin Zhou; ,"Extraction of Landmine Features Using a Forward-Looking Ground-Penetrating Radar With MIMO Array," Geoscience and Remote Sensing, IEEE Transactions on , vol.50, no.10, pp.4135-4144, Oct. 2012

Abstract: A vehicle-mounted forward-looking ground-penetrating radar (GPR) with multiple-input and multiple-output (MIMO) array can obtain the high-resolution image of its front area to perform the standoff detection of landmines. The major challenge for the GPR landmine detection over wide areas is the very high false alarm rate when maintaining a high detection probability. In

this paper, a novel feature extraction method is proposed to obtain the bistatic scattering information from the MIMO array image to discriminate landmines from clutter. To realize the goal, an imaging model of the MIMO array is firstly developed. Based on the imaging model, the bistatic scattering function of a suspected object is estimated from its MIMO array image using the space-wavenumber processing. Images of different incident angles and bistatic angles at some resonance frequencies are selected from the estimated bistatic scattering function to represent the scattering characteristics. In order to obtain the scale, rotation, and translation invariant feature vector, Hu moment invariants of the selected images are calculated to form the low-dimensional feature vector. The experimental results show that the proposed method can offer an efficient feature vector for the landmine discriminator to improve the detection performance.

[200] Haowen Chen; Wei Zhou; Jin Yang; Peng You; Xiang Li; ,"Manifold Sensitivity Analysis for MIMO Radar," Geoscience and Remote Sensing Letters, IEEE , vol.9, no.5, pp.999-1003, Sept. 2012

Abstract: The purpose of this letter is to investigate the sensitivity relative to the antenna position uncertainties (APUs) for multiple-input multiple-output (MIMO) radar with colocated antennas. Manifold study is introduced to MIMO radar virtual array as an analyzing tool. To assess the importance of each antenna in a MIMO radar system, the authors extend Manikas's sensor importance function to MIMO radar. Furthermore, to compare the robustness to APUs of different antenna geometries, the authors extend the overall-system-sensitivity criterion to MIMO radar system. The authors show that, with the same sensor geometry, MIMO radar has better robustness performance than the corresponding phased array because of waveform diversity.

[201] Wen-Qin Wang; Jingye Cai; ,"MIMO SAR using Chirp Diverse Waveform for Wide-Swath Remote Sensing," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.4, pp.3171-3185, October 2012

Abstract: Synthetic aperture radar (SAR) is a well-proven remote sensing technique; however, current single-antenna SAR systems cannot fulfill the increasing demands of future remote sensing in high-resolution and wide-swath imaging performance. This paper presents a scheme of multiple-input and multiple-output (MIMO) SAR using chirp diverse waveform for wide-swath remote sensing. This approach employs MIMO antenna configuration in elevation which is divided into multiple subpertures. In this way, multiple pairs of transmit-receive virtual beams directing to different subswathes are formed simultaneously. Equivalently a large swath is synthesized. The corresponding system scheme, chirp diverse waveform design, multi-beam forming algorithm and range ambiguity performance are investigated. A chirp-scaling-based image formation algorithm is presented to focus the MIMO SAR simulation data. Comprehensive numerical simulation examples are performed. It is shown that the proposed method enables the SAR systems to operate with high flexibility and reconfigurability which is particularly attractive for next generation remote sensing technique.

[202] Jianxin Wu; Tong Wang; Lifeng Zhang; Zheng Bao; ,"Range-Dependent Clutter Suppression for Airborne Sidelooking Radar using MIMO Technique," Aerospace and Electronic Systems, IEEE Transactions on , vol.48, no.4, pp.3647-3654, October 2012

Abstract: Range-dependent clutter suppression is an important issue in airborne bistatic radar moving target detection. Range-dependent clutter suppression using the multiple-input multiple-

output (MIMO) technique is investigated. By employing the MIMO technique, the clutter ridges of all range bins are located in the same plane of the three-dimensional (3D) space. Moreover as long as the sum of the target radial velocities relative to the transmitter and the receiver is unequal to zero, the target will not be located in this plane. Thus clutter suppression can be realized by a 3D linear constrained minimum variance (LCMV) filter. In high clutter-to-noise (CNR) cases, the presented technique yields better performance than the conventional bistatic sidelooking phased-array radar. Numerical examples are given to demonstrate the effectiveness of the presented technique.

[203] Li, N.; Cui, G.; Kong, L.; Yang, X.; ,"Rao and Wald tests design of multiple-input multiple-output radar in compound-Gaussian clutter," Radar, Sonar & Navigation, IET , vol.6, no.8, pp.729-738, October 2012

Abstract: This study considers the detection problem of multiple-input multiple-output (MIMO) radar in the presence of a compound-Gaussian clutter. Two new detectors based on the Rao and Wald criteria are devised under the known covariance matrix. The theoretical expression for the probability of false alarm is developed and constant false alarm (CFA) rate behaviour is remarked on. Furthermore, the fully adaptive approximated Rao and Wald tests are investigated in place of the exact covariance matrix with a suitable estimator using secondary data. Finally, several numerical simulations with typical parameters are provided and discussed.

[204] Haowen Chen; Xiang Li; Weidong Jiang; Zhaowen Zhuang; ,"MIMO Radar Sensitivity Analysis of Antenna Position for Direction Finding," Signal Processing, IEEE Transactions on , vol.60, no.10, pp.5201-5216, Oct. 2012

Abstract: Sensitivity analysis plays an integral role in many engineering design problems. The purpose of this paper is to investigate the direction finding sensitivities (DFSs) with respect to antenna position uncertainties (APUs) for multiple-input multiple-output (MIMO) radar with colocated antennas. These uncertainties cause differences between the MIMO radar virtual array manifold used by direction finding (DF) algorithms and the true array manifold, which is named as "calibrated errors." To evaluate the effects of such errors on DF, the DFSs relative to APUs are considered from two following approaches. First, the authors use the first-order sensitivity analysis for MIMO radar. For a given arbitrary antenna geometry, the formulas of DFSs using maximum likelihood (ML) algorithm are developed for relatively small APUs. In addition, the formula for computing the ambiguity thresholds of the ML algorithm as a function of target separation and other DF system parameters are derived for relatively large APUs. Alternatively, the DFSs are only concerned with antenna geometry, i.e., the virtual array manifold, being regardless of any certain DF algorithm. Herein, the authors extend Manikas's method to MIMO radar. To assess the importance of each antenna in a given MIMO radar system, the authors derive the antenna importance function (AIF) which is defined as the amount of varieties of manifold vectors from the APUs. Furthermore, to compare the robustness to APUs for different antenna geometries, the authors derive the overall system sensitivity (OSS) for MIMO radar systems. In numerical example section, the authors show the previous DFS analysis results by several representative MIMO radar antenna geometries. The presented sensitivity analysis could be as the guideline of MIMO radar system analysis and design.

[205] Bobin Yao; Wenjie Wang; Qinye Yin; ,"DOD and DOA Estimation in Bistatic Non-Uniform Multiple-Input Multiple-Output Radar Systems," Communications Letters, IEEE , vol.16, no.11, pp.1796-1799, November 2012

Abstract: This letter investigates the joint estimation of the direction of departure (DOD) and direction of arrival (DOA) for multi-input multi-output (MIMO) radar systems. A novel estimation method based on non-uniform array configuration is proposed and the practical identifiability of the corresponding parameter is analyzed. The key idea is to use the Doppler diversity to construct a virtual MIMO array. Through the theoretical proof, the authors demonstrate that the proposed method can provide much stronger parameter identifiability than the conventional ones, and also can improve the parameter estimation performance. Numerical simulations verify the effectiveness of the proposed algorithm.

[206] Cao, Y.; Feng, D.-Z.; Shui, P.-L.; Xiang, C.; ,"Two-dimensional pulse-to-pulse canceller applied in multiple-input-multiple-output radar," Radar, Sonar & Navigation, IET , vol.6, no.9, pp.945-955, December 2012

Abstract: Since the spectrum of the ground clutter in the ground-based pulse radar is spatially-temporally decoupled, a simple pulse-to-pulse canceller is often used as a moving target indication filter for suppressing the ground clutter near the zero-Doppler frequency. In contrast, in the airborne phased-array radar, which is a typical single-input-multiple-output radar, the spectrum of the ground clutter is spatially-temporally coupled each other, and the two-dimensional pulse-to-pulse canceller (TDPC) for ground clutter cancellation has been developed by using the ground clutter model in the spatial-temporal domain. Based on the ground clutter model of multiple-input-multiple-output (MIMO) radar, the authors can extend the existing TDPC to more general form that can suppress the ground clutter in the MIMO radar. As the MIMO TDPC can be calculated offline by utilising the geometry knowledge of the ground clutter of MIMO radar, it can be used as an efficient and convenient ground clutter pre-filtering tool.

[207] B. Friedlander, "On the role of waveform diversity in MIMO radar," Digital Signal Processing, Available online 20 December 2012

Abstract: MIMO radar employs multiple antennas to simultaneously transmit diverse waveforms, as well as multiple antennas to receive the radar returns. This paper studies the role of waveform diversity in MIMO radar as separate and distinct from the role of the multiple transmit antennas. This is done by comparing a MIMO radar system to a scanning phased array radar which uses the same transmit and receive arrays but only a single waveform. The performance characteristics of the two systems, in terms of the ambiguity function and the spatial response, are compared for single pulse operation as well as multi-pulse operation with coherent integration. Both element-space and beam-space systems are considered.

[208] Yingbo Hua; Ping Liang; Yiming Ma; Cirik, A.C.; Qian Gao; ,"A Method for Broadband Full-Duplex MIMO Radio," Signal Processing Letters, IEEE , vol.19, no.12, pp.793-796, Dec. 2012

Abstract: The authors present a time-domain transmit beamforming (TDTB) method for self-interference cancelation (SIC) at the radio frequency (RF) frontend of the receivers on broadband full-duplex MIMO radios. It is shown that the conventional frequency-domain transmit beamforming (FDTB) method along with the orthogonal frequency division multiplexing

(OFDM) framework does not generally perform SIC in the prefix region of a transmitted frame. A hardware based test of the TDTB method shows a 50 dB SIC over a bandwidth of 30 MHz.

[209] Tarchi, D.; Oliveri, F.; Sammartino, P.F.; ,"MIMO Radar and Ground-Based SAR Imaging Systems: Equivalent Approaches for Remote Sensing," Geoscience and Remote Sensing, IEEE Transactions on , vol.51, no.1, pp.425-435, Jan. 2013

Abstract: Currently there is an increasing interest in multiple-input multiple-output (MIMO) radars, because MIMO technology is able to provide a level of performance similar to that of a conventional antenna array, while also providing hardware and cost-related benefits. In this paper, the authors describe an upgrade of an existing ground-based synthetic aperture radar system (which is used for landslide monitoring) to a low-cost MIMO system. The authors also describe the associated low-cost/high-performance remote sensing benefits that this new configuration provides and present the results gathered by the new system. The authors conclude by outlining two configurations of the MIMO system with particular emphasis on antenna positioning, which has a key role in the overall performance.

[210] Sammartino, Pier Francesco; Baker, Christopher J.; Griffiths, Hugh D.; ,"Frequency Diverse MIMO Techniques for Radar," Aerospace and Electronic Systems, IEEE Transactions on , vol.49, no.1, pp.201-222, Jan. 2013

Abstract: It has been shown over several decades of radar research that the exploitation of diversity in a number of domains (space, frequency, time, polarization, and, recently, waveform) can provide increased agility, flexibility, robustness, and capabilities to the radar system. However this is often achieved either through efforts in system design, increased hardware complexity, or by employing additional resources. A conventional antenna array is considered with the intention of introducing, not major, but minor mismatches, in particular in the carrier frequencies and, eventually in the codes at the element level. The starting point of this analysis is the frequency diverse array (FDA), which has been demonstrated to generate a range-angle pattern. Through a reconsideration of the organization of the array, which the authors have termed the wavelength array (WA), a new pattern,"orthogonal" to that of the standard phased array, can be achieved. The bistatic combination of a WA and a receiver leads to the frequency diverse bistatic system (FDBS), which can be a significant application of this concept. In a second stage the analysis focuses on the effects of introducing waveform diversity in such a system. In particular, if the elements of an electronically steered array (ESA) simultaneously transmit a number of pseudonoise (PN) codes at slightly different carrier frequencies, the coherent summation of the codes gives rise to a waveform whose shape is a function of both angle and range. In fact this is the consequence of applying the multiple-input multiple-output (MIMO) technique to the FDA, which has the result of associating a waveform to each point range/angle of the space, with the possibility of recovering this information in receive after appropriate processing.

[211] Honghui Yan; Guowei Shen; Zetik, R.; Hirsch, O.; Thoma, R.S; ,"Ultra-Wideband MIMO Ambiguity Function and Its Factorability," Geoscience and Remote Sensing, IEEE Transactions on , vol.51, no.1, pp.504-519, Jan. 2013

Abstract: Ambiguity function (AF) provides an effective way for analysis of the resolving performance of a radar system. With the development of ultra-wideband (UWB) and multiple-

input-multiple-output (MIMO) radio techniques, recently, the combination of them-the concept of UWB MIMO radar has been proposed and received much attention. For a UWB MIMO radar, first, the signal waveform with an exponential expression which is widely adopted in narrowband cases is not appropriate anymore. Second, the MIMO radar sensors are typically organized in a certain spatial topology, which greatly impacts the performance of the MIMO system. In addition, for a typical MIMO radar application scenario, generally, there are relative motions existing between the radar sensors and the targets. The presence of the relative motions would further complicate the performance analysis of the system. In fact, for a MIMO radar, the overall performance of the system is jointly determined by the parameters, such as the signal waveform, the topology, and the relative motions. Each of the parameters impacts the resolving performance in a particular way. In order to evaluate the contribution of each individual parameter of interest, in this paper, a UWB MIMO AF is developed and factorized into several factors. By this means, each individual parameter can be evaluated via the corresponding factor to examine a certain specific characteristic of the system, instead of via the complicated whole MIMO AFs.

[212] Jung-Hyo Kim; Younis, M.; Moreira, A.; Wiesbeck, W.; ,"A Novel OFDM Chirp Waveform Scheme for Use of Multiple Transmitters in SAR," Geoscience and Remote Sensing Letters, IEEE , vol.10, no.3, pp.568-572, May 2013

Abstract: In this letter, the authors present a new waveform technique for the use of multiple transmitters in synthetic aperture radar (SAR) data acquisition. This approach is based on the principle of the orthogonal-frequency-division-multiplexing technique. Unlike multiple subband approaches, the proposed scheme allows the generation of multiple orthogonal waveforms on common spectral support and thereby enables to exploit the full bandwidth for each waveform. This letter introduces the modulation and the demodulation processing in regard to typical spaceborne SAR receive signals. The proposed processing techniques are verified by a simulation for the case of pointlike targets.

3.2 Conference papers published in 2008, since September

[213] X. Zhuge, T.G. Savelyev, A.G. Yarovoy, and L.P. Ligthart. Uwb array-based radar imaging using modified kirchhoff migration. In *Ultra-Wideband, 2008. ICUWB 2008. IEEE International Conference on*, volume 3, pages 175 –178, sept. 2008.^

Abstract: This paper presents a new modification of Kirchhoff migration algorithm for ultra-wideband (UWB) array-based radar imaging. The developed algorithm is evolved from traditional Kirchhoff migration which is based on the classical integral theorem of Helmholtz and Kirchhoff. The new algorithm is designed for array-based radar imaging with arbitrary multiple input multiple output (MIMO) configuration. The developed algorithm is compared with conventional diffraction stack migration using both synthetic data from numerical simulation and measurement data from landmine detection. The results have shown promising improvements in the aspects of beamwidth, side-lobe rejection ratio and the ability to reconstruct shapes of distributed targets.

[214] G.J. Frazer, Y.I. Abramovich, and B.A. Johnson. Use of adaptive non-causal transmit beamforming in othr: Experimental results. In *Radar, 2008 International Conference on*, pages 311 –316, sept. 2008.

Abstract: We report results from an experiment that applied multiple-input multiple-output (MIMO) waveform techniques to over-the-horizon radar (OTHR). The experiment objective was to demonstrate that adaptive transmitter beamforming could be used to reject spatially discrete radar clutter. In MIMO radar architectures, conventional or adaptive transmitter beamforming occurs following waveform transmission, propagation, scatter from targets and clutter sources, return propagation and finally signal reception. We have successfully rejected spatially discrete clutter to the noise floor of the radar return with rejection in excess of 35 dB achieved using common adaptive algorithms and straightforward training data selection. As part of this we estimated the transmitted waveform direction-of-departure from the transmitter array to the target and used the estimate as the preserved steer direction in the adaptive beamformer. The direction-of-departure estimates agreed well with the true values.

[215] Juan Chen, Dazhi Zeng, and Teng Long. A study of multiple-input multiple-output radar. In *Radar, 2008 International Conference on*, pages 416 –420, sept. 2008.

Abstract: In this paper, the present MIMO radar concepts are summarized, and MIMO radar performance is analysed. Next an example of using spatial information to improve the resolution of SAR system is given, and it helps us to understand the spatial information correctly. Then the diversity technique in wireless communication and the MIMO radar technique are compared and analysed, and the pattern diversity is proposed to be used in MIMO radar. Moreover the comparability between the array pattern and the ambiguity function of the periodic signal is analysed, and some waveform design methods can be used in removing the angle ambiguity in array antenna.

[216] B.A. Johnson and Y.I. Abramovich. Low training volume adaptive processing in hf skywave radar. In *Radar, 2008 International Conference on*, pages 616 –621, sept. 2008.

Abstract: Adaptive processing in the HF radar environment suffers from the paucity of appropriate training data relative to the dimension of the required spatial filters. We review the applicability of a number of reduced-rank/reduced-order adaptive filtering methods to HF radar and point out the need for several key developments. These developments including properly normalized likelihood ratio for under-sampled scenarios, parametric order estimation based on minimization of both deterministic and stochastic losses, and application of time-varying autoregressive (TVAR) parametric models to the spatially and temporally varying HF radar case.

[217] Fa Foster Dai and Luong Howard. Session 5 - broadband circuit techniques for emerging wireless communications. In *Custom Integrated Circuits Conference, 2008. CICC 2008. IEEE*, pages xxxiii –xxxiv, sept. 2008.

Abstract: This session focuses on circuit design techniques for emerging broadband wireless applications, including multiple-input multiple-output (MIMO), software-defined radios (SDR), radar, vehicles, and space communications. The session is slit into two sub-sessions with three papers presented in the morning from 10:00 am to 11:40am and two papers presented in the afternoon from 2:00pm to 3:20pm.

[218] Hongping Hu and Bo Liu. Genetic algorithm for designing polyphase orthogonal code. In *Wireless Communications, Networking and Mobile Computing, 2008. WiCOM '08. 4th International Conference on*, pages 1 –4, oct. 2008.

Abstract: Successful design of orthogonal polyphase code sets is one of crucial for implementing multiple input multiple output (MIMO) radar and orthogonal Netted radar systems (ONRS). A genetic algorithm (GA) is presented to numerically optimize orthogonal code sets design. The simulation results show that the proposed algorithm are feasible and effective for the design of polyphase code sets used in MIMO radar and ONRS radar. Computational results are compared with simulated annealing (SA). In some cases, GA outperforms SA.

[219] Min Jiang, Jianguo Huang, and Yunshan Hou. Esprit method for multiple-target localization using mimo array. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 84 –87, oct. 2008.

Abstract: A subspace-based method for multiple-target localization by multi-input multi-output (MIMO) array is presented in this paper. Because the covariance matrix of reflected signals from targets at different locations is always nonsingular as a result of mutual orthogonality among the signals transmitted by MIMO array, estimation of signal parameters via rotational invariance technique (ESPRIT) algorithm can be directly applied to the direction of arrival (DOA) estimation problem of the MIMO array without spatial smoothing (SS) techniques beforehand. Simulation results verify the effectiveness of the proposed method.

[220] Jianguo Huang, Lijie Zhang, Yunshan Hou, and Yong Jin. Modified subspace algorithms for doa estimation using mimo array. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 195 –198, oct. 2008.

Abstract: This paper proposes two subspace algorithms, named S-MUSIC and S-SSMUSIC, based on the MUSIC and SSMUSIC algorithms for direction finding in MIMO array systems, which achieve improved performance by exploiting the waveform information about the transmitted signals. Numerical results show that the proposed algorithms outperform their traditional counterparts at low SNR.

[221] Guohua Wang and Yilong Lu. High resolution mimo-hfswr using sparse frequency waveform. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2238 –2241, oct. 2008.

Abstract: In this paper, we propose a concept of multiple-input multiple-output high frequency surface wave radar (MIMO-HFSWR) system with widely separated antennas transmitting and receiving the sparse frequency waveforms. The proposed concept obtains several advantages over the conventional HFSWR system such as finer resolutions and better flexibility. The ambiguity function (AF) was derived in detail to assess the proposed system. The impacts of Doppler effect and the geometry configuration factor are also studied.

[222] Zhao Zhao and Xiang quan Shi. Doppler compensation for orthogonal netted radar systems. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2246 –2249, oct. 2008.

Abstract: Orthogonal netted radar systems (ONRS) can fundamentally improve radar performance by using a group of specially designed orthogonal polyphase code signals. However, the existing numerical solutions only address autocorrelation and cross-correlation properties with the result that the signals degrade severely in the presence of small Doppler shifts. In the context of these problems, a new hybrid polyphase code set which combines single frequency pulse with the designed orthogonal polyphase signal, is presented to implement Doppler compensation and keep ONRS a good resilience to Doppler shifts. Doppler frequency of the target is firstly estimated based on interpolated FFT in the time span of single frequency pulse and the Doppler compensated signal can be constructed to maintain Doppler tolerance. The construction of Doppler compensated signals is illustrated. Simulation results show that the proposed hybrid polyphase code set is effective for moving target detection in ONRS.

[223] Xiao-Yan Ma, Dang-Wei Wang, and Yi Su. High-resolution imaging using a narrowband mimo radar system. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2263 –2266, oct. 2008.

Abstract: This paper presents a system model and method for the two-dimensional (2-D) imaging application via a narrowband multiple-input multiple-output (MIMO) radar system with two perpendicular linear arrays. The proposed method utilities the spatial parallel procedure sampling the scattered echoes during a single snapshot illumination, instead of the spatial sequential one sampling the scattered echoes during multiple snapshot illuminations in inverse synthetic aperture radar (ISAR) imaging. Consequently, the complex motion compensation in ISAR imaging can be avoided. Furthermore, in our array configuration, multiple narrowband shared-spectrum

waveforms coded with orthogonal polyphase sequences are employed to illuminate a target. The mainlobe of the compressed echoes from the different filter band for all scatterers could be located in the same range bin, and thus, complex range alignment in classical ISAR imaging is not necessary. Numerical simulations based on synthetic data are provided for testing our proposed method.

[224] Shu feng Li, Jie Chen, Lv qian Zhang, and Yin qing Zhou. Construction of quadri-phase complete complementary pairs applied in mimo radar systems. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2298 –2301, oct. 2008.

Abstract: Multiple input multiple output (MIMO) radar systems employ the orthogonal signals to improve the system performance. Some results show that there are no complete orthogonal signals in the single code field, even refer to the binary, polyphase and the plural sequences, the maximum of both the auto-correlation function (ACF) and the cross-correlation function (CCF) can not equal to zero at the all delays. The paper utilizes the recursive algorithm to construct a class complete complementary pairs (CC-pairs) based on complementary pair in the dual codes field. The conclusion implies that the CC-pairs satisfy the complete orthogonality required for MIMO radar systems and open a new direction in orthogonal signal design.

[225] Changzheng Ma, Tat Soon Yeo, Guoxiong Xu, and Hwee Siang Tan. Range and cross range joint processing of mimo radar using ds-cdma signal. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2356 –2359, oct. 2008.

Abstract: It has been shown that Multiple-Input Multiple-Output radar can dramatically improve the performance of a radar. In this paper, the Direct Sequence Code Division Multiple Access(DS-CDMA) sequence are used as transmitting waveforms for the different antennas. Due to the high sidelobe of the code correlation, conventional code correlation range compression methods cannot provide a proper range profile of the targets. In this paper, we find that range and cross range joint Capon beamforming provide a higher angle resolution but also suppress the range sidelobe.

[226] Changzheng Ma, Tat Soon Yeo, Junjie Feng, and Hwee Siang Tan. Two dimensional imaging of extended targets by mimo radar using hopped frequency signal. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2360 –2363, oct. 2008.

Abstract: Multiple input multiple output (MIMO) radar transmits orthogonal or non-coherent waveforms which greatly improve the array aperture. Works published generally only consider narrow band signal and/or point targets located in one range cell. In this paper, the study of range and azimuth angle imaging of extended targets employing wideband hopped frequency signals is discussed. Hopped frequency signal are sensitive to a targetpsilas speed. A kurtosis based criterion is presented for doing motion compensation. In order to mitigate the high side lobe of the hopped frequency signal, a ldquoCLEANrdquo based signal processing procedure is also presented.

[227] Qi Zhu and Yunneng Yuan. A method of mimo system for synthetic aperture radar imaging. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2404 –2408, oct. 2008.

Abstract: Inspired by recent advances in multiple-input multiple-output (MIMO) radar, this paper introduces a method of synthetic aperture radar imaging utilizing MIMO technique based on the most important characteristic of MIMO system: spatial diversity and multiple transmitters and receivers antenna elements configuration, this method can achieve high resolution of SAR image. The performances of the proposed method have been compared with conventional SAR in simulation. The result shows the superiority of the MIMO technique for SAR in high resolution imaging.

[228] Yu Zhang and Jianxin Wang. Ofdm-coded signals design for mimo radar. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2442 –2445, oct. 2008.

Abstract: A novel method is proposed to designed OFDM-coded signals for multiple input multiple output(MIMO) radar systems. The proposed method can fundamentally improve radar performance by using a group of specially designed OFDM-coded signals. The genetic algorithms (GA) is used to numerically optimize such OFDM-coded code sets. Some of the designed results are presented and they indicate that the proposed algorithm is effective for OFDM-coded signals design.

[229] Huaijun Wang and Yi Su. Narrowband mimo radar imaging with two orthogonal linear t/r arrays. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2513 –2516, oct. 2008.

Abstract: Based on the spatial convolution principle of multi-input multi-output (MIMO) radar, the distribution of two orthogonal linear transmit/receive (T/R) arrays is designed. With this array structure, a two-dimensional (2-D) imaging method for narrowband MIMO radar is proposed. The simulation shows that this array can provide about the same imaging resolution but uses fewer antennas compared with a planar receive-only array.

[230] Shenghua Zhou, Hui Xu, Liangbing Hu, and Hongwei Liu. Research for scattering properties of spatial and frequency diversity mimo radar targets. In *Signal Processing, 2008. ICSP 2008. 9th International Conference on*, pages 2533 –2537, oct. 2008.

Abstract: In this paper, for the problem of spatial correlation and frequency correlation of targets echoes in receiving channels of diversity MIMO radar, based on two-dimensional scatter model in polar coordination system, correlation coefficient and independent condition of radar target echoes in spatial and frequency diversity receiving channels are developed, indicating that for round shaped scatter model targets with scatters intensity isotropic and i.i.d zero-mean distributed, its spatial correlation and frequency correlation are unified. Therefore in view point of target detection, spatial diversity technique and frequency technique in MIMO radar are equivalent. The correlation coefficient is rectified by numerical experiment.

[231] E. Conte, S. Tomasin, and N. Benvenuto. Scheduling strategies for multiuser mimo ofdm systems with limited feedback. In *Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008. IEEE 19th International Symposium on*, pages 1 –5, sept. 2008.

Abstract: In a cellular system with partial channel state information, i.e. with limited feedback, and multiple antennas, we consider scheduling of downlink transmissions at the base station using beamforming and orthogonal frequency division multiplexing. As the complexity of optimal scheduling for throughput maximization under quality of service constraints grows exponentially with the number of subcarriers, in this paper we propose two low complexity suboptimal techniques. The first is a greedy iterative strategy that at each step selects one user with the aim of maximizing the weighted sum rate (WSR), without the need of recomputing the beamformer. We next propose a pre-selection strategy that removes from the selection process users that do not provide an increase in the WSR, thus speeding the search. Both complexity and performance of the proposed techniques are evaluated and compared with existing solutions in a long-term evolution 3GPP scenario.

[232] G. Shingu, K. Takizawa, and T. Ikegami. Human body detection using mimo-uwb radar sensor network in an indoor environment. In *Parallel and Distributed Computing, Applications and Technologies, 2008. PDCAT 2008. Ninth International Conference on*, pages 437 –442, dec. 2008.

Abstract: Recently, UWB (ultra wide band) signal that has frequency bandwidth of 500 MHz or more is considered to be using high precision radar because of a very high resolution. The UWB is considered to have fewer influences on human being because of low transmitting power. And, MIMO (multiple-input multiple-output) radar refers to an architecture that employs multiple, spatially distributed transmitters and receivers. In this paper, sensor network made up of MIMO-UWB radar with widely separated antennas to estimate distance and to detect human being existence is studied. Detection performances are evaluated from the computer simulation by using the real propagation measurement result with the network analyzer. The positioning accuracy of the human body and the effectiveness of MIMO-UWB radar are shown.

[233] O. Bar-Shalom and A.J. Weiss. Direct position determination using mimo radar. In *Electrical and Electronics Engineers in Israel, 2008. IEEEI 2008. IEEE 25th Convention of*, pages 575 –579, dec. 2008.

Abstract: MIMO radar is a new concept that has recently been proposed as an extension to the multi-static radar concept. In the following paper we apply the concept of direct position determination (DPD) to MIMO radar in order to explore the effect of the transmit diversity on the target position determination accuracy. It is shown that under low signal to noise ratio (SNR) conditions the results of the MIMO radar DPD improve the estimation accuracy by more than an order of magnitude with respect to conventional, geolocation method.

[234] Yijia Yang, Zishu He, and Wei Xia. Waveform design for mimo radar using kronecker structured matrix estimation. In *Communication Systems, 2008. ICCS 2008. 11th IEEE Singapore International Conference on*, pages 431 –435, nov. 2008.

Abstract: The multiple-input multiple-output (MIMO) radar system is a new kind of radar technology. It can choose flexibly the probing signals transmitted via its antennas or increase the

inter-element distance to reduce the cross-correlation of the signals, so that the spatial diversity gain can be obtained. Waveform design is one of the important topics of the MIMO radar. We discuss here the waveform design method for extended radar targets using Kronecker structured matrix estimation. Simulation results are provided to validate the proposed solutions.

[235] Wei Xia and Zishu He. Active direction finding in imaging sensor nets. In *Communication Systems, 2008. ICCS 2008. 11th IEEE Singapore International Conference on*, pages 1359 –1363, nov. 2008.

Abstract: We consider herein the problem of active direction finding in imaging the massively scalable sensor networks in which the active sensor nodes reflect electronically the beacon transmitted by a collector node. Very large number of randomly deployed sensor nodes with limited computational capability have no knowledge of their locations, while the location estimation is accomplished by the collector node. The collector node is equipped with noncoherent collections of coherent subarrays at the transmit and receive arrays to achieve both the coherent gain and spatial diversity simultaneously. In this configuration, the transmit and receive spatial diversity can be jointly or independently exploited. The performance of the proposed scheme is validated by the simulation results.

[236] T. Naghibi and F. Behnia. Convex optimization and mimo radar waveform design in the presence of clutter. In *Signals, Circuits and Systems, 2008. SCS 2008. 2nd International Conference on*, pages 1 –6, nov. 2008.

Abstract: Waveform design for target identification and classification in MIMO radar systems has been studied in several recent works. While the previous works considered signal independent noise and found optimal signals for an estimation algorithm, here we extend the results to the case where clutter is also present and then we will find the optimum waveform for several estimators differing in the assumptions on the given statistics. Several different approaches to the optimal waveform design are proposed, including minimizing the error of MMSE estimator, minimizing the maximum error of the covariance shaping least square (CSLS) estimator and minimizing the MSE error of scaled least square (SLS) estimator. Choosing optimal waveform for MMSE estimator leads to the semi-definite programming (SDP) problem. Finding the optimal transmit signals for CSLS estimator results in a minimax eigenvalue problem. Finally it is shown that equal power waveforms are the best transmit signals for the SLS estimator.

[237] T. Naghibi and F. Behnia. Optimal signals for mimo radar in the presence of clutter. In *Signals, Circuits and Systems, 2008. SCS 2008. 2nd International Conference on*, pages 1 –6, nov. 2008.

Abstract: Waveform design for target identification and classification in MIMO radar systems has been studied in several recent works. While the previous works considered signal independent noise and found optimal signals, here we extend the results to the case where clutter is also present and then we will find the optimum waveform for MMSE estimator. Choosing optimal waveform for MMSE estimator leads to the Semi-definite programming (SDP)problem, a convex optimization problem which can be efficiently solved through numerical methods. Explicit solution is developed for this SDP problem in two cases. In the first case, target and clutter covariance matrices are jointly diagonalizable and in the second one, signal to noise ratio (SNR)is sufficiently high.

[238] B. Yang, X. Zhuge, A.G. Yarovoy, and L.P. Ligthart. Uwb mimo antenna array topology design using pso for through dress near-field imaging. In *Microwave Conference, 2008. EuMC 2008. 38th European*, pages 1620 –1623, oct. 2008.

Abstract: In this paper two novel MIMO UWB antenna arrays have been proposed for through dress imaging radar application. The advantage of using MIMO array is that the number of elements can be reduced and the element spacing can be sparser than that of SIMO array, while the performance will be almost the same. Particle swarm optimization (PSO) method is used to determine the optimum antenna array topologies for different scenarios that can provide sufficient cross-range resolution and an acceptable mainlobe to side lobe level. The results demonstrated that by properly design the fitness function, we can trade off the cross-range resolution and mainlobe to sidelobe ratio and find proper array topologies for different scenarios.

[239] B. Correll. Efficient spotlight sar mimo linear collection geometries. In *Radar Conference, 2008. EuRAD 2008. European*, pages 21 –24, oct. 2008.

Abstract: We describe and quantify how a family of SAR platforms transmitting mutually orthogonal waveforms at a common PRF constitute a MIMO radar system that reduces the need for conventional SAR imaging. We give efficient linear collection configurations for up to 15 platforms and an asymptotically optimally efficient sequence of configurations.

[240] K. Kulpa and M. Malanowski. The concept of simple mimo pcl radar. In *Radar Conference, 2008. EuRAD 2008. European*, pages 240 –243, oct. 2008.

Abstract: The paper present a concept of a simple MIMO (multiple input multiple output) PCL (passive coherent location) radar relying on FM radio transmitters of opportunity. The use of MIMO approach instead the classical phased antenna results in significant increase in surveillance volume without changing requirements for computational power.

[241] R. van Dijk, E.H. van der Houwen, and A.P.M. Maas. Multi-mode fmcw radar array with independent digital beam steering for transmit and receive. In *Radar Conference, 2008. EuRAD 2008. European*, pages 412 –415, oct. 2008.

Abstract: A phased-array FMCW radar has been design and built from COTS components. The generation of the frequency sweep is done by mixing a central local oscillator signal with a baseband sweep of a direct digital synthesizer (DDS). To ensure maximum flexibility the receive side has been equipped with itpsilas own swept signal. The transmit frequency generation and receive frequency generation are derived from the same local oscillator signal and clock to ensure coherent operation. This architecture makes a very flexible platform as the waveforms can be changed, transmit and receive and be independently programmed and the system is scalable, also by the mechanical outline of the system and antenna.

[242] B. Yang, X. Zhuge, A.G. Yarovoy, and L.P. Ligthart. Uwb mimo antenna array topology design using pso for through dress near-field imaging. In *Radar Conference, 2008. EuRAD 2008. European*, pages 463 –466, oct. 2008.

Abstract: In this paper two novel MIMO UWB antenna arrays have been proposed for through dress imaging radar application. The advantage of using MIMO array is that the number of

elements can be reduced and the element spacing can be sparser than that of SIMO array, while the performance will be almost the same. Particle swarm optimization (PSO) method is used to determine the optimum antenna array topologies for different scenarios that can provide sufficient cross-range resolution and an acceptable mainlobe to side lobe level. The results demonstrated that by properly design the fitness function, we can trade off the cross-range resolution and mainlobe to sidelobe ratio and find proper array topologies for different scenarios.

[243] I. Maradi. Do we need next generation mobile networks ? yes. In *Telecommunications Network Strategy and Planning Symposium, 2008. Networks 2008. The 13th International*, pages 1 –23, 28 2008-oct. 2 2008.

Abstract: In this presentation, the concept of the next generation mobile networks (NGMNs) is introduced. The architecture, advantages, and the proposed implementation of NGMNs are presented.

[244] F. Barbaresco and P. Chevalier. Noncircularity exploitation in signal processing overview and application to radar. In *Waveform Diversity Digital Radar Conference - Day 1: Waveform Diversity Design, 2008 IET*, pages 1 –6, dec. 2008.

Abstract: With new generation of Active Digital Radar Antenna, there is a renewal of waveform generation and processing approaches, and new strategies can be explored to optimize waveform design and waveform analysis and to benefit of all potential waveform diversity. Among these strategies, building and exploitation of the Noncircularity of waveforms is a promising issue. Up to the middle of the nineties, most of the signals encountered in practice are assumed to be second order (SO) circular (or proper), with a zero second correlation function. However, in numerous operational contexts such as in radio communications, the observed signals are either SO noncircular (or improper) or jointly SO noncircular with a particular signal to estimate, to detect or to demodulate, with some information contained in the second correlation function of the signals. Exploitation of this information in the processing of SO noncircular signals may generate dramatic gain in performance with respect to conventional processing and opens new perspective in signal processing. The purpose of this paper is to present a short overview of the interest of taking into account the potential SO noncircularity of the signals in signal processing and to describe the potential interest of SO noncircular waveforms for radar applications.

[245] T. Naghibi and F. Behnia. Mmse based waveform design for mimo radars. In *Waveform Diversity Digital Radar Conference - Day 1: Waveform Diversity Design, 2008 IET*, pages 1 –5, dec. 2008.

Abstract: Waveform design problem for MIcircldquoMO radars has been studied in several recent works. Although signal dependent noise (clutter) is considered in some works aiming to design waveform to improve target detection in MIMO radars, there are less works on waveform design problem for target classification and estimation in the presence of clutter. Thus, here, we investigate this problem In contrast with previous works, our design leads to the convex optimization problem which can be efficiently solved through numerical methods and it can be guaranteed to converge to optimal solution. Optimal waveforms are found for two scenarios. In the first scenario it is assumed that different transmission antennas see uncorrelated aspects of the target and we consider the correlated target aspects (owing to the closed space anttenas) in the second scenario. Due to the interdependence of signal and clutter, target estimation error of the

first scenario will not zero even if the transmit power tends to infinity, i.e., clutter power also increases by increasing the transmission power. This is the major problem in target detection and estimation in the presence of clutter in radars. We show that in the second scenario the MIcircldquoMO radar receiver can nullify the clutter subspace. Thus by increasing the transmission power, estimation error becomes zero in the second scenario. Waveform design for MMSE estimator under both scenarios, leads to the Semi-definite programming (SDP) problems.

[246] A.M. Guidi, T.A. Sturman, P. Dingley, M.D.J. Bowyer, N.R. Petfield, and M. Moseley. Waveform diversity and design: Part i - issues for multi-antenna systems. In *Waveform Diversity Digital Radar Conference - Day 1: Waveform Diversity Design, 2008 IET*, pages 1 –11, dec. 2008.

Abstract: This paper, forming the first part of a two-part series, focuses on the design of error control codes (ECC) that are suitable for use in multiple-input multiple-output (MIMO) based systems. It has been shown in the past that the use of multiple antennas at both the transmitter and receiver can improve communication link performance. The use of higher spectral efficiency (increased bits per second per hertz of bandwidth) and link reliability via the implementation of diversity leads to significant increases in data throughput that can be sustained without additional bandwidth or transmit power. In order to further exploit the diversity introduced by MIMO, it is important to optimise use of the physical channel via the design of error control codes specific to the MIMO channel. Codes that have been optimised for use over such channels are termed space-time codes. An investigation of various space-time codes formed from a number of different underlying codes is presented herein. Space-time codes based on both turbo codes and low density parity check (LDPC) codes are investigated. Turbo codes and LDPC codes are discussed as these are two of the most powerful ECC derived for the single input single output (SISO) additive white Gaussian noise (AWGN) channel. The use of MIMO introduces diversity in the spatial domain. Fading across multiple antennas is optimally required to be independent in order to fully utilise the redundancy introduced via multiple antenna use. Diversity in the temporal domain is introduced via error control coding. Space-time codes operate across multiple antennas in order to maximise diversity in the spatial domain (diversity advantage) but also maximise diversity in the temporal domain (coding advantage). The paper explains design rules for maximising both diversity and coding advantage in order to design powerful space-time codes. Two specific examples are presented within the paper, one based on turbo codes and another based on LDPC codes. Turbo c- odes and LDPC codes provide maximum coding advantage for SISO based systems achieving performance extremely close to the AWGN channel capacity and therefore it makes sense to investigate the re-use of such coding schemes within the MIMO environment. There are many uses for MIMO including beamforming techniques typically used in sensor arrays for directional signal transmission or reception but the sole focus of this paper is on the code design for the space-time channel. Furthermore, MIMO and space-time codes have been developed principally for use in terrestrial applications where fading environments are exploited. This paper concludes with ideas for the application of MIMO to problems in satellite communications.

3.3 Conference papers published in 2009

[247] J.P. Browning, D.R. Fuhrmann, and M. Rangaswamy. A hybrid mimo phased-array concept for arbitrary spatial beampattern synthesis. In *Digital Signal Processing Workshop and 5th IEEE Signal Processing Education Workshop, 2009. DSP/SPE 2009. IEEE 13th*, pages 446 –450, jan. 2009.

Abstract: Multiple-input multiple-output (MIMO) radar is a multiple aperture technology characterized by the ability to transmit diverse signals at each aperture. This is in contrast to traditional phased-array radar whereby a single signal is transmitted with a phase shift applied at each element to enable steering of the transmit beam. The hybrid MIMO phased-array radar (HMPAR) concept is an outgrowth of the monostatic MIMO construct, in which all sensors have the same view of the far-field target. In the HMPAR, the full transmit array is partitioned into sub-arrays which can be electronically steered in different directions and driven by separate transmit waveforms; furthermore the configuration of the array into sub-arrays can be changed. Here we explore the variety of transmit beam patterns that could be achieved using such a system.

[248] F. Ahmad, M. Amin, and H. Estephan. Multistatic waveform design for seeing through the wall. In *Waveform Diversity and Design Conference, 2009 International*, pages 31 –35, feb. 2009.

Abstract: We present the matched illumination based waveform design for improved detection of targets behind walls and in enclosed structures using a multistatic radar system. The generalization of the matched illumination waveform design concept for through-the-wall multistatic operation bridges the problem to multiple-input multiple-output (MIMO) operation and puts in context the offering of MIMO to urban sensing and imaging of targets in enclosed structures.

[249] J.J. Zhang, G. Maalouli, A. Papandreou-Suppappola, and D. Morrell. Cramer-rao lower bounds for the joint estimation of target attributes using mimo radar. In *Waveform Diversity and Design Conference, 2009 International*, pages 103 –107, feb. 2009.

Abstract: We derive the Cramer-Rao lower bound (CRLB) on the covariance of the joint estimates of the parameters of moving targets using measurements from multiple-input, multiple-output (MIMO) radars. We first derive the CRLB for MIMO radars with colocated antennas for estimating the target's direction of arrival, range and range-rate. We then demonstrate that the CRLB for phased array radars is a special case of the CRLB for MIMO radars with colocated antennas. We also derive the CRLB for MIMO radars with widely-separated antennas for estimating the target's location and velocity, and we compare it to the CRLB for the multistatic radar. For both types of MIMO radar systems, we show that the CRLB is related to the parameters of the transmitted waveforms, as demonstrated with numerical simulations.

[250] Guohua Wang and Yilong Lu. Clutter rank of mimo radar with a speical class of waveforms. In *Waveform Diversity and Design Conference, 2009 International*, pages 108 – 112, feb. 2009.

Abstract: In this paper, the rank of clutter covariance matrix (CCM) is studied for space-time adaptive processing (STAP) implemented on the multiple-input multiple-output (MIMO) radar with waveform diversity. It is found that the clutter rank is dependent on the rank and structure of the covariance matrix of the transmitting waveforms, and that clutter rank of orthogonal waveforms acts as the upper bound for all kinds of waveforms. More specifically, three simple rules are proposed to estimate the clutter rank for one special class of waveforms. This class of waveforms, though we call it special, indeed can include coherent waveforms, orthogonal waveforms, as well as part of partially correlated waveforms. In this way, the method of estimating the clutter rank for both coherent and orthogonal waveforms are herein unified. The application of these rules only requires the computation of the waveform covariance matrix (WCM) and a polynomial based on the WCM, thus it is convenient and computationally efficient. The proposed rules are well verified by simulation results and also general enough to be suitable for both conventional space time radar systems and the MIMO radars with orthogonal waveforms.

[251] F. Daum and J. Huang. Mimo radar: Snake oil or good idea? In *Waveform Diversity and Design Conference, 2009 International*, pages 113 –117, feb. 2009.

Abstract: MIMO communication is theoretically superior to conventional comm. under certain conditions, and MIMO comm. also appears to be practical and cost effective in the real world for some applications. It is natural to suppose that the same is true for MIMO radar, but the situation is not so clear. Researchers claim many advantages of MIMO radar relative to phased array radars (e.g., better detection performance, better angular resolution, better angular measurement accuracy, improved robustness against RFI amp; ECM amp; multipath, etc.). We will evaluate such assertions from a system engineering viewpoint. In particular, there are serious tradeoffs of MIMO vs. phased array radars relative to cost, system complexity and risk, considering numerous real world effects that are not included in most theoretical analyses. Moreover, in many cases one can achieve essentially the same radar system improvement with phased array radars using simpler less expensive and less risky algorithms. We evaluate roughly a dozen asserted advantages of MIMO radar relative to phased arrays.

[252] D.W. Bliss, K.W. Forsythe, S.K. Davis, G.S. Fawcett, D.J. Rabideau, L.L. Horowitz, and S. Kraut. Gmti mimo radar. In *Waveform Diversity and Design Conference, 2009 International*, pages 118 –122, feb. 2009.

Abstract: Multiple-input multiple-output (MIMO) extensions to radar systems enable a number of advantages compared to traditional approaches. These advantages include improved angle estimation and target detection. In this paper, MIMO ground moving target indication (GMTI) radar is addressed. The concept of coherent MIMO radar is introduced. Comparisons are presented comparing MIMO GMTI and traditional radar performance. Simulations and theoretical bounds for MIMO GMTI angle estimation and minimum detectable velocity are presented. The simulations are evaluated in the time domain, enabling waveform design studies. For some applications, these results indicate significant potential improvements in clutter-mitigation SINR loss and reduction in angle-estimation error for slow-moving targets.

[253] J. Bergin, S. McNeil, L. Fomundam, and P. Zulch. Mimo phased-array for smti radar. In *Waveform Diversity and Design Conference, 2009 International*, page 123, feb. 2009.

Abstract: Summary form only given. Waveform diversity techniques for radar have gained considerable interest over the past several years. Novel radar waveforms have been proposed to improve detection performance and metric accuracy (i.e., angle estimation performance). This paper explores the potential for using a waveform diversity technique known as Multiple Input, Multiple Output (MIMO) radar to improve the detection performance of slow moving surface targets from a moving radar platform. The MIMO radar system achieves superior performance by transmitting unique uncorrelated waveforms from each antenna subaperture as opposed to the traditional approach of transmitting a single coherent waveform across the entire aperture. The results show that the radar system minimum detectable velocity (MDV) can be reduced by exploiting the ability of a MIMO system to effectively increase the radar antenna aperture.

[254] H. Godrich, A.M. Haimovich, and R.S. Blum. A comparative study of target localization in mimo radar systems. In *Waveform Diversity and Design Conference, 2009 International*, pages 124 –128, feb. 2009.

Abstract: In the paper, a study of target localization performances is presented for coherent multiple-input multiple-output (MIMO) and single-input multiple-output (SIMO) radars systems with widely separated elements. The evaluation is based on the best linear unbiased estimator (BLUE), providing the localization mean squared error (MSE) in a closed-form solution. This estimator elucidates the relation between the radar locations, target location, and localization accuracy through the use of the geometric dilution of precision (GDOP) metric. Contour maps of the GDOP relate a given deployment of sensors and the achievable accuracy to the at various target locations. This metric is shown to represent the spatial advantage of the system. The best achievable accuracy for both configurations is derived. MIMO radar systems with coherent processing are shown to benefit from higher spatial advantage, compared with SIMO systems. The advantage of the MIMO radar scheme over SIMO is evident when considering the achievable accuracy for a radar system with M transmitters and N receivers, rather than 1 transmitter and MN receivers. It is shown that MIMO radar, with a total of M + N sensors, has twice the performance (in terms of localization MSE) of a system with (MN + 1) sensors.

[255] Ming Xue, Xumin Zhu, Jian Li, Duc Vu, and P. Stoica. Mimo radar angle-doppler imaging via iterative space-time adaptive processing. In *Waveform Diversity and Design Conference, 2009 International*, pages 129 –133, feb. 2009.

Abstract: We consider using multi-input multi-output (MIMO) radar to improve the ground moving target indication (GMTI) performance, especially for slowly moving targets, for airborne surveillance systems. The increased virtual aperture afforded by MIMO radar systems enables many advantages, including enhanced spatial resolution, improved parameter identifiability and better performance for GMTI. To obviate the need of secondary data for space-time adaptive processing (STAP), we apply herein a user parameter-free and secondary data-free fully automatic weighted least squares based iterative adaptive approach (IAA) to angle-Doppler imaging via a standard MIMO scheme, two simplified MIMO schemes (which employ switching strategies for transmission), and also a conventional single-input multi-output (SIMO) scheme. The high-resolution angle-Doppler images formed by IAA, using the primary data only, are provided to compare the performance of the three MIMO schemes as well as the SIMO scheme.

[256] Marshall Greenspan. Panel discussion: Mimo radar - fact or fantasy? In *Waveform Diversity and Design Conference, 2009 International*, page 134, feb. 2009.

Abstract: The Special MIMO Radar - Fact or Fantasy? ; Session at the 4th International Waveform Diversity and Design Conference will be comprised of 20 minute technical presentations by each of the five invited speakers who were selected based on the quality of the papers that they had presented at other venues, their preeminence in the technical community as judged by their professional positions, their published journal papers or books, as well as their potentially controversial opinions on the potential benefits and pitfalls, that could result from the introduction of MIMO architectures into modern radar systems. The final 20 minutes of this 2 hour special session will be a open panel discussion involving the five prior speakers and Marshall Greenspan as the panel discussion moderator.

[257] B.B. Manjunath, J.J. Zhang, A. Papandreou-Suppappola, and D. Morrell. Waveform-agile sensing for range and doa estimation in mimo radars. In *Waveform Diversity and Design Conference, 2009 International*, pages 145 –149, feb. 2009.

Abstract: We propose an agile sensing algorithm to optimally select the transmission waveform of a multiple-input, multiple-output (MIMO) radar system in order to improve target localization. Specifically, we first derive the Cramer-Rao lower bound (CRLB) for the joint estimation of the antenna reflection coefficients and the range and direction-of-arrival of a stationary target using MIMO radar with colocated antennas. The resulting CRLB, that is a function of the transmitted waveform, is then compared to the estimation performance of a maximum-likelihood estimator. We configure waveform parameters to minimize the trace of the predicted error covariance by assuming that the covariance of the observation noise is approximated by the CRLB for high signal-to-noise ratios. In particular, we optimally select the duration and phase function parameters of generalized frequency-modulated chirps to minimize the estimation mean-squared error under constraints of fixed transmission energy and constant time-bandwidth product.

[258] D.R. Fuhrmann, J.P. Browning, and M. Rangaswamy. Constant-modulus partially correlated signal design for uniform linear and rectangular mimo radar arrays. In *Waveform Diversity and Design Conference, 2009 International*, pages 197 –201, feb. 2009.

Abstract: A method for generating partially correlated signals that result in arbitrary rectangular transmit beampatterns in a MIMO radar system is described. These signals are computed using frequency-offset complex exponentials (1-D) or Kronecker products of frequency-offset complex exponentials (2-D), followed by pointwise multiplication of the transmit signal vectors by a scalar pseudo-noise spreading sequence. Except for the spreading sequence, which can be pre-computed, the signals are given in closed form and thus require no numerical optimization. The transmit beampattern shape is controlled by one scalar parameter in 1-D and two scalar parameters in 2-D. The transmit beampattern is the convolution of a rectangle with a sincsquared function in 1-D, and the separable product of such functions in 2-D. The signals are constant-modulus, have desirable temporal autocorrelation properties, and are simple to compute.

[259] J.J. Zhang and A. Papandreou-Suppappola. Mimo radar with frequency diversity. In *Waveform Diversity and Design Conference, 2009 International*, pages 208 –212, feb. 2009.

Abstract: We propose a new multiple-input, multiple-output (MIMO) radar system with colocated antennas that can greatly reduce target fluctuations. This is achieved by employing frequency diversity. The proposed MIMO radar system results in a radar array with frequency-division multiplexing that can also incorporate beamforming to design the transmission beam pattern. After presenting an overview of existing MIMO radar systems and their related signal models, we provide a detailed description of the proposed frequency diversity technique and the corresponding transmitter and receiver structures. Furthermore, we present a maximum likelihood estimation algorithm that incorporates frequency diversity with MIMO radar, derive the corresponding Cramer-Rao lower bound, and demonstrate its improved performance using numerical results.

[260] Wenhua Li, Genshe Chen, E. Blasch, and R. Lynch. Cognitive mimo sonar based robust target detection for harbor and maritime surveillance applications. In *Aerospace conference, 2009 IEEE*, pages 1 –9, march 2009.

Abstract: Robust detection of various hostile threats is vital to protect Navy ships and other facilities within harbor and maritime environments. Traditional single-input single-output (SISO) sonar transmits single acoustic waveform by single projector, which has a few disadvantages including low target detection probability, low resolution, vulnerability of interception by the enemy, sensitivity to jamming, etc. Multi-input multi-output (MIMO), typically applied to communications and radar solutions, is an emerging technology that can be applied to sonar to overcome many of the SISO sonar disadvantages. In this paper, cognitive monostatic/bistatic/multistatic MIMO sonar approaches are proposed. MIMO sonar transmits different orthogonal acoustic waveforms from multiple projectors with different spatial distributions. Through space-time-waveform diversity, MIMO sonar is able to apply coherent processing techniques over the received signals, and acquires more diversity gains. The cognition concept proposed in the literature for radar and wireless communication is applied to MIMO sonar to improve its robustness and adaptability. The advantages of proposed cognitive MIMO sonar will be demonstrated by Monte Carlo computer simulations and compared to the SISO techniques.

[261] R. Agarwal and J.M. Cioffi. Beamforming design for the mimo downlink for maximizing weighted sum-rate. In *Information Theory and Its Applications, 2008. ISITA 2008. International Symposium on*, pages 1 –6, dec. 2008.

Abstract: This work studies linear transmit filter design for weighted sum-rate (WSR) maximization in the multiple input multiple output broadcast channel (MIMO-BC). The problem of finding the optimal transmit filter is non-convex and intractable to solve. Motivated by the iterative algorithm that solves for the optimal transmit and receive filters for minimizing sum-mean square error (MSE), this paper suggests to use weighted minimum mean square error (WMMSE) optimization in the MIMO-BC. The paper presents an iterative algorithm to maximize WSR. Numerical results for sum-rate using the derived filter are provided under different system settings.

[262] Chun-Yang Chen and P.P. Vaidyanathan. Joint mimo radar waveform and receiving filter optimization. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 2073 –2076, april 2009.

Abstract: The concept of MIMO (multiple-input multiple-output) radar allows each transmitting antenna element to transmit an arbitrary waveform. This provides extra degrees of freedom compared to the traditional transmit beamforming approach. It has been shown in the recent literature that MIMO radar systems have many advantages. In this paper, we consider the joint optimization of waveforms and receiving filters in the MIMO radar when the prior information of target and clutter are available. A novel iterative algorithm is proposed to optimize the waveforms and receiving filters such that the detection performance can be maximized. The proposed algorithm guarantees that the SINR performance improves in each iteration step. The numerical results show that the proposed methods have better SINR performances than existing design methods.

[263] D. Nion and N.D. Sidiropoulos. A parafac-based technique for detection and localization of multiple targets in a mimo radar system. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 2077 –2080, april 2009.

Abstract: In this paper, we show that the problem of detection and localization of multiple targets in a bistatic MIMO radar system can be solved by parallel factor (PARAFAC) analysis. Our method is deterministic and fully capitalizes on the strong algebraic structure of the received data, where the radar cross section (RCS) fluctuation is not regarded as a nuisance parameter but rather as a source of time diversity. Simulation results show that our technique outperforms existing beamforming-based radar imaging methods at a lower complexity.

[264] P. Pal and P.P. Vaidyanathan. Frequency invariant mvdr beamforming without filters and implementation using mimo radar. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 2081 –2084, april 2009.

Abstract: Frequency invariant beamforming with sensor arrays is generally achieved using filters in the form of tapped delay-lines following each sensor. However it has been recently shown that with the help of the rectangular smart antenna array, it is possible to generate frequency invariant beampattern without using filters. In this paper, this frequency invariant beamforming technique is utilized to perform MVDR beamforming in the beamspace by designing frequency invariant beams spanning the desired range of azimuthal angles and optimally combining them. However, the performance of the frequency invariant beamformer depends on the number of sensors which could be large for a rectangular array of size M times N. Making use of the virtual array concept used in MIMO radar, a novel method of producing the same frequency invariant beam, using only M transmitting and N receiving antennas, is proposed and a design example is provided to demonstrate the idea.

[265] T. Naghibi and F. Behnia. Optimal and robust waveform design for mimo radars. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 2085 –2088, april 2009.

Abstract: Waveform design for Target identification and classification in MIMO radar systems has been studied in several recent works. While the previous works considered signal independent

noise, here we extend the results to the case where signal-dependent noise, clutter, is also present and then we find the optimum waveform for several estimators differing in the assumptions on the given statistics. Computing the optimal waveforms for MMSE estimator leads to the Semi-definite programming (SDP) problem. Finding the optimal transmit signals for CSLS estimator results in a minimax eigenvalue problem. Finally it is shown that equal power waveforms are the best transmit signals for the SLS estimator.

[266] A. Hassanien and S.A. Vorobyov. Transmit/receive beamforming for mimo radar with colocated antennas. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 2089 –2092, april 2009.

Abstract: We propose a new technique for multiple-input multiple-output (MIMO) radar with colocated antennas. The essence of the proposed technique is to partition the transmitting array into a number of subarrays that are allowed to overlap. Each subarray is used to coherently transmit a waveform which is orthogonal to the waveforms transmitted by other subarrays. Coherent processing gain can be achieved by designing a weight vector for each subarray to form a beam towards a certain direction in space. Moreover, the subarrays are combined jointly to form a MIMO radar resulting in higher resolution capabilities. Simulation results show the substantial improvements offered by the proposed technique as compared to previous techniques that validate its effectiveness.

[267] Yao Yu, A.P. Petropulu, and H.V. Poor. Compressive sensing for mimo radar. In *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, pages 3017 –3020, april 2009.

Abstract: Multiple-input multiple-output (MIMO) radar systems have been shown to achieve superior resolution as compared to traditional radar systems with the same number of transmit and receive antennas. This paper considers a distributed MIMO radar scenario, in which each transmit element is a node in a wireless network, and investigates the use of compressive sampling for direction-of-arrival (DOA) estimation. According to the theory of compressive sampling, a signal that is sparse in some domain can be recovered based on far fewer samples than required by the Nyquist sampling theorem. The DOA of targets form a sparse vector in the angle space, and therefore, compressive sampling can be applied for DOA estimation. The proposed approach achieves the superior resolution of MIMO radar with far fewer samples than other approaches. This is particularly useful in a distributed scenario, in which the results at each receive node need to be transmitted to a fusion center for further processing.

[268] Guohua Wang, Yilong Lu, and Jinping Sun. Stap performance analysis for mimo radar with waveform diversity. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: This paper studies the waveform effect on the space time adaptive processing (STAP) of multiple-input multiple-output (MIMO) radar systems. A general signal model based on waveform diversity is constructed for MIMO STAP. System sensitivity and optimal adapted pattern are investigated according to waveform diversity. These studies show how the MIMO STAP performance is affected by waveform diversity, based on which we can do better trade-off to balance the system performance under different conditions.

[269] G.J. Frazer, Y.I. Abramovich, and B.A. Johnson. Mimo radar limitations in clutter. In *Radar Conference, 2009 IEEE*, pages 1 –5, may 2009.

Abstract: Recently discovered bounds for the clear-area available in the ambiguity domain for a MIMO radar waveform set are shown to be a significant limitation in radar applications having extended scatterer distributions. These limitations are demonstrated using an example from an experimental MIMO over-the-horizon radar. Two candidate waveform classes; time-staggered LFMCW, and frequency-staggered LFMCW, are suggested as possible MIMO waveforms in the case of an extended clutter scatterer environment. Each attains the best case bound on reduced clear-area in ambiguity. Limitations discussed in this paper impose significant restrictions to the applicability of MIMO techniques in other clutter-limited applications, such as airborne radar.

[270] W. Roberts, Jian Li, P. Stoica, T. Yardibi, and F.A. Sadjadi. Mimo radar angle-range-doppler imaging. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: Through waveform diversity, multiple-input multiple-output (MIMO) radar can achieve higher resolution and better sensitivity to slowly moving targets than phased-array radar systems. Furthermore, with a MIMO antenna array, the linear independence of reflected signals from scattering points allows for the direct application of adaptive array processing techniques. High levels of noise and strong clutter presence, however, significantly worsen detection performance. The iterative adaptive approach (IAA), a non-parametric and user parameter-free weighted least-squares algorithm, was recently shown to offer improved resolution and interference rejection for array processing applications. In this paper, we extend IAA to perform angle-range-Doppler imaging using a MIMO radar system. We furthermore demonstrate the superior performance of a MIMO radar system compared to a single-input multiple-output (SIMO) radar system.

[271] J.H.G. Ender and J. Klare. System architectures and algorithms for radar imaging by mimo-sar. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: The multi-input / multi-output (MIMO) principle is well known for communication applications, whereas at least the name dasiaMIMOpsila is relatively new for radar applications. Nevertheless, the principle has been analyzed and used in a few examples since the early 80s or even before. A MIMO-radar is characterised by a number N of transmitting and a number M of receiving antennas forming N times M Tx/Rx pairs where each propagation path from the nth transmit antenna to the object to the mth receive antenna is made available to the signal processing. This can be achieved by temporal multiplexing, spatial coding and/or orthogonal waveforms. A further step is to transfer this technique to the SAR case. Additionally, the whole array is moving, SAR processing can be applied. Possible geometries of MIMO-SAR are along track arrays (reduction of azimuth-ambiguities, moving target indication, super resolution) or across track arrays (reduction of elevation-ambiguities, interferometry, 3D down-looking SAR). In this paper, some aspects of moving MIMO-arrays for SAR will be addressed.

[272] M. Zatman. Beam steering techniques for phased array multi-input-multi-output (mimo) search radars. In *Radar Conference, 2009 IEEE*, pages 1 –5, may 2009.

Abstract: When exploiting the output from multiple transmitters to enhance some aspect of radar performance, MIMO radars need to coordinate transmissions so that each transmitter illuminates the target. This paper analyzes the performance of standard beam steering techniques for search

radars, and proposes a new technique that optimizes coverage out to the radar's instrumented range.

[273] D. Pastina, M. Bucciarelli, and P. Lombardo. Multi-platform isar for flying formation. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: In this paper we exploit a formation of two radar sensors carried by two air platforms to increase the cross-range resolution of ISAR imaging. This is particularly challenging when the motion of the target is limited, as for ISAR images of ship targets from helicopters when the sea state is low. A distributed ISAR technique is devised to process coherently the echoes received by the two radar systems appropriately separated in angle; if both of them are active sensors, one is assumed able to receive and separate the echoes both from its own transmission and from the transmission of the other sensor (MIMO distributed ISAR), otherwise a configuration with one active radar system and one receiving only device is considered (bistatic distributed ISAR). The distributed ISAR technique is tested on simulated data to evaluate its effectiveness in achieving an improvement of the cross-range resolution; for a given number of flying platforms better values of cross-range resolution are obtained when more than one receiving channel per sensor is considered. Specifically, with two platforms, an increase in resolution up to three times the single sensor ISAR case is demonstrated in the MIMO configuration, as opposed to the enhancement of a factor up to two achieved in the bistatic case. Moreover, results obtained by processing the experimental data collected by a ground based radar operating together with a rotating platform are shown to prove the effectiveness of the proposed technique.

[274] M. Lee, Sangjun An, S.M. Lee, Sangwook Suh, Kyutae Lim, and J. Laskar. Circuit level analysis of analog signal processing based mimo radar system. In *Radar Conference, 2009 IEEE*, pages 1 –4, may 2009.

Abstract: Conventional digital signal processing (DSP) based systems, when expanded into a multi input multi output (MIMO) system, suffer from increase of power consumption and computational burden. In this paper, an analog based MIMO radar system is introduced. The proposed system uses a combination of wavelets as its pulse at transmitters. Using the property of wavelets being orthogonal in time, our proposed system achieves waveform diversity. Implementation of a MIMO radar system based on analog circuitry results in significant decrease in power consumption of the system. This was verified by comparing systems with similar performance and estimating their power consumption. While our proposed system consumed 422.2 mW, a DSP-ASIC MIMO radar system consumed 2621.6 mW, a conventional DSP-ASIC single input single output (SISO) radar system consumed 1767 mW, and a conventional DSP-FPGA SISO radar system consumed 4158 mW.

[275] Hao He, P. Stoica, and Jian Li. Unimodular sequence sets with good correlations for mimo radar. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: A multi-input multi-output (MIMO) radar system that transmits orthogonal waveforms via its antennas can achieve a greatly increased virtual aperture compared with its phased-array counterpart. Practical radar requirements such as unit peak-to-average power ratio and range compression dictate that we use MIMO radar waveforms that have constant modulus and good auto- and cross-correlation properties. We present in this paper new computationally efficient cyclic algorithms for MIMO radar waveform synthesis. These algorithms can be used for the

design of unimodular MIMO sequences that have very low auto-and cross-correlation sidelobes in a specified lag interval, and of very long sequences that could hardly be handled by other algorithms previously suggested in the literature. A number of examples are provided to demonstrate the performances of the new waveform synthesis algorithms.

[276] M.A. Haleem, A. Haimovich, and R. Blum. Sidelobe mitigation in mimo radar with multiple subcarriers. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: This paper presents the studies on the reduction of peak sidelobe level in distributed MIMO radar with multiple subcarrier signals. Multiple subcarriers with sufficient frequency spacing become an alternative to increasing the number of sensors for sidelobe reduction. It is shown that the multiple subcarrier signals are most effective in reducing sidelobes at locations far from the target. Two signaling methods, namely continuous carrier transmission and Gaussian-OFDM signals are studied with respect to the sidelobe mitigation properties. The paper also presents an upper bound to the peak sidelobe level considering the non-coherent combining. It is shown that with non-coherent combining, the peak sidelobe of the localization metric scales down as 1/MNLsin(3pi/2L) where L is the number of subcarriers, and M, N are the number of transmit and receive sensors. While there are grating lobes present in the metric with non-coherent combining, there is a grating lobe free region around the mainlobe, lower bounded by rho = plusmnLrho0/2B . With coherent processing, multiple subcarriers are effective in reducing the sidelobes as well as grating lobes.

[277] D.R. Fuhrmann, J.P. Browning, and M. Rangaswamy. Ambiguity function analysis for the hybrid mimo phased-array radar. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: The hybrid MIMO phased array radar, or HMPAR, is a notional concept for a multisensor radar architecture that combines elements of traditional phased-array radar with the emerging technology of multiple-input multiple output (MIMO) radar. A HMPAR comprises a large number, MP, of T/R elements, organized into M subarrays of P elements each. Within each subarray, passive element-level phase shifting is used to steer transmit and receive beams in some desired fashion. Each of the M subarrays are in turn driven by independently amplified phase-coded signals. This paper derives a version of the radar ambiguity function that is appropriate for this radar architecture. The ambiguity function is a function of time delay, Doppler frequency shift, and two or more spatial variables. An illustrative example for a particular MIMO signal set is given.

[278] V.F. Mecca and J.L. Krolik. Mimo enabled multipath clutter rank estimation. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: Multiple-input multiple-output (MIMO) radar is an emerging technology that has the capability of providing range dependent transmit-domain degrees of freedom via receiver processing. When providing these additional degrees of freedom for target tracking, MIMO radar exhibits a lower signal-to-noise ratio (SNR) when compared to that of traditional single-input multiple-output (SIMO) phased array radar. Previous work has indicated the efficacy of combining MIMO operation with space-time adaptive processing (STAP) techniques in the presence of multipath clutter to improve the signal-to-clutter-plus-noise ratio (SCNR). The tradeoff between target SNR and SCNR in multipath propagation environments is a crucial

consideration in MIMO radar. In this paper, a transmit-receive directionality spectrum (TRDS) is used to examine the clutter characteristics at a range-Doppler bin of interest, most notably in multipath situations where MIMO operation is advantageous. In situations where ground clutter is spread in Doppler frequency and azimuth by motion in the propagation environment, the clutter rank can be significantly higher than a Brennan's rule estimate. However, the transmit observability within the MIMO data vector allows for a low rank representation of the clutter when compared to the total available degrees of freedom. A TRDS-based method based on the resolution limits of uniformly spaced linear transmit and receive arrays is presented which furnishes an estimate of the transmit-receive clutter rank in scenarios where Brennans rule provides a significantly underestimated measure. The proposed TRDS-based clutter rank estimation method is applied to both numerical simulations and experimental data.

[279] Xiufeng Song, Shengli Zhou, and P. Willett. Enhanced multistatic radar resolution via stc. In *Radar Conference, 2009 IEEE*, pages 1 –6, may 2009.

Abstract: MIMO radar can improve on conventional target detection, parameter identification, and target classification performance via diversity of, among other things, its simultaneously-transmitted waveforms. However, the mutual interference among the waveforms may lead to considerable performance degradation suppressing clutter near targets. In this paper, we consider the use of space time coding (STC) to mitigate waveform cross-correlation effects in MIMO radar. First, it turns out that a joint waveform optimization problem can be decoupled into a set of individual waveform design problems. Second, a number of monostatic waveforms can be directly used in a MIMO radar system, which offers flexibility in waveform selection. Numerical results demonstrate the effectiveness of STC in MIMO radar for waveform decorrelation.

[280] Qian He, R.S. Blum, and A.M. Haimovich. Non-coherent mimo radar for target estimation: More antennas means better performance. In *Information Sciences and Systems, 2009. CISS 2009. 43rd Annual Conference on*, pages 108 –113, march 2009.

Abstract: This paper presents an analysis of the joint estimation of target location and velocity using multiple-input multiple-output (MIMO) radar. A theorem is formulated on the asymptotic properties of the maximum likelihood (ML) estimate. The joint Cramer-Rao bound (CRB) is calculated for a Rayleigh fluctuating extended target. The mean square error (MSE) of the ML estimate is analyzed for orthogonal Gaussian pulses. It is shown that the signal to noise ratio (SNR) boundary between low and high MSE values can be lowered by increasing the number of antennas. The non-coherent MIMO radar ambiguity function (AF) is developed and illustrated by examples. It is shown that the product of the number of transmit and receive antennas can control the sidelobes level of the AF.

[281] M.A. Haleem and A. Haimovich. Range and speed resolution in coherent distributed mimo radar with gaussian pulse trains. In *Information Sciences and Systems, 2009. CISS 2009. 43rd Annual Conference on*, pages 114 –117, march 2009.

Abstract: This paper presents studies on the range and speed resolution in distributed MIMO radar with the use of finite duration Gaussian pulse trains. We consider a network of transmit and receive sensors, where the distance between the randomly placed sensors is comparable to the distance to the target. While the resolution capability of a single transmitter-receiver pair is determined by the carrier frequency and parameters of the pulse train, namely the pulse width,

pulse interval and the number of pulses, the orientations of the sensors with respect to the target has a major effect on the ambiguity due to subsidiary peaks. The randomness in the sensor locations randomizes the relative positions of subsidiary peaks of the ambiguity function. With multiple transmitter-receiver pairs, the randomness in the locations of sensors in effect reduces the subsidiary peaks in the ambiguity function of a single transmitter receiver-pair by a factor of MN, where M and N are the number of transmitters and receivers.

[282] J.J. Benedetto and J.J. Donatelli. Frames and a vector-valued ambiguity function. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 8 –12, oct. 2008.

Abstract: The setting is that of vector-valued codes of length N. The background for this setting is our construction of new complex valued constant amplitude zero autocorrelation codes (off dc) - CAZACs, which serve as coefficients for phase coded waveforms with prescribed ambiguity function behavior. Vector-valued CAZACs are relevant in light of vector sensor and MIMO technologies. The goal is to define the discrete vector-valued ambiguity function. Our notion of frame multiplication allows us to make this definition. The theory and relevance of such ambiguity functions is developed, including computation of code from received discrete vector-valued ambiguity function data.

[283] R. Daher and R. Adve. Analysis of random radar networks. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 21 –25, oct. 2008.

Abstract: We introduce the notion of random radar networks to analyze the effect of geometry in distributed radar systems. We first analyze unistatic systems with a single receiver selected at random from the available group. We approximate the distribution of the individual signal-to-interference-plus-noise (SINR) at the sensors and find the corresponding mean and variance. We then analyze multistatic systems and provide an upper bound on performance. We show that in order to exploit the spatial diversity available to the system, the sensors should be large enough to effectively cancel interfering sources. We underline a design tradeoff between spatial diversity and interference cancellation for multistatic radar networks. We finally provide the results of simulations to validate our analysis.

[284] Jun Zhang, B. Manjunath, G. Maalouli, A. Papandreou-Suppappola, and D. Morrell. Dynamic waveform design for target tracking using mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 31 –35, oct. 2008.

Abstract: In this paper, we investigate waveform design for dynamic target tracking using a multiple-input, multiple-output (MIMO) radar system. The agile tracking application is based on our recently derived Cramer-Rao lower bound (CRLB) for estimating target position and velocity, that is represented in terms of the transmitted waveform parameters. Using the CRLB at high signal-to-noise ratio (SNR), we adaptively select the waveform parameters that minimize the predicted mean-squared error (MSE) at each time step. We demonstrate the improvement in agile tracking using numerical simulations.

[285] Chun-Yang Chen and P.P. Vaidyanathan. Compressed sensing in mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 41 –44, oct. 2008.

Abstract: Compressed sensing is a technique for efficiently sampling signals which are sparse in some transform domain. Recently, the idea of compressed sensing has been used in the radar system. When the number of targets on the range-Doppler plane is small, the target scene can be reconstructed by employing the compressed sensing techniques. In this paper, we extend this idea to the MIMO radar. In the MIMO radar, the compressed sensing technique can be used to reconstruct the target scene when the signals are sparse in the range-Doppler-angle space. To effectively reconstruct the target scene, it is required that the correlation between the target responses be small. In this paper, a waveform design method is introduced to reduce the correlations between target responses. Because of the increased dimensionality in MIMO radars as compared to phased array radars, the impact of compressed sensing will be very significant there.

[286] Rabinder Madan. Session ma6: Mimo radar and sensor fusion. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 181 –182, oct. 2008.

Abstract: Not available

[287] F. Daum and J. Huang. Mimo radar: Snake oil or good idea? In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 183 –187, oct. 2008.

Abstract: MIMO communication is theoretically superior to conventional comm. under certain conditions, and MIMO comm. also appears to be practical and cost effective in the real world for some applications. It is natural to suppose that the same is true for MIMO radar, but the situation is not so clear. Researchers claim many advantages of MIMO radar relative to phased array radars (e.g., better detection performance, better angular resolution, better angular measurement accuracy, improved robustness against RFI amp; ECM amp; multipath, etc.). We will evaluate such assertions from a system engineering viewpoint. In particular, there are serious tradeoffs of MIMO vs. phased array radars relative to cost, system complexity and risk, considering numerous real world effects that are not included in most theoretical analyses. Moreover, in many cases one can achieve essentially the same radar system improvement with phased array radars using simpler less expensive and less risky algorithms. We evaluate roughly a dozen asserted advantages of MIMO radar relative to phased arrays.

[288] P.P. Vaidyanathan, P. Pal, and Chun-Yang Chen. Mimo radar with broadband waveforms: Smearing filter banks and 2d virtual arrays. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 188 –192, oct. 2008.

Abstract: In this paper MIMO radars with broadband waveforms are considered. A time domain viewpoint is taken, which allows frequency invariant beamforming with a filter bank called the smearing filter bank. Motivated by recent work on two dimensional arrays to obtain frequency invariant one dimensional beams, the generation of two dimensional virtual arrays from one dimensional ULAs is also considered. It is also argued that when the smearing filter bank is appropriately used, frequency invariant 2D beams can be generated.

[289] M.A. Haleem and A. Haimovich. On the distribution of ambiguity levels in mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 198 –202, oct. 2008.

Abstract: The statistical behavior of sidelobe-ambiguity arising in location estimation in distributed coherent MIMO radar is studied in this paper. A model is developed for analyzing the statistics of the localization metric under random sensor locations. Closed form expressions are obtained for the mean and variance of the localization metric. It is shown that the mean is independent of the number of sensors and its sidelobes decrease with the squared distance from the coherence point of the MIMO array. With M transmit sensors and N receive sensors, the variance behaves as 1/MN for locations beyond the vicinity of the target being observed. When all N sensors function as transceivers, the variance approaches 2/N2. Except in the vicinity of the target, the side lobe levels have equal distribution at every location. The study is extended to derive the statistics of the peak sidelobe level and a simple expression is obtained relating the required number of sensors for a tolerated level of peak sidelobes and a desired confidence level.

[290] A.P. Petropulu, Yao Yu, and H.V. Poor. Distributed mimo radar using compressive sampling. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 203 –207, oct. 2008.

Abstract: A distributed MIMO radar is considered, in which the transmit and receive antennas belong to nodes of a small scale wireless network. The transmit waveforms could be uncorrelated, or correlated in order to achieve a desirable beampattern. The concept of compressive sampling is employed at the receive nodes in order to perform direction of arrival (DOA) estimation. According to the theory of compressive sampling, a signal that is sparse in some domain can be recovered based on far fewer samples than required by the Nyquist sampling theorem. The DOAs of targets form a sparse vector in the angle space, and therefore, compressive sampling can be applied for DOA estimation. The proposed approach achieves the superior resolution of MIMO radar with far fewer samples than other approaches. This is particularly useful in a distributed scenario, in which the results at each receive node need to be transmitted to a fusion center.

[291] M. Akcakaya, M. Hurtado, and A. Nehorai. Mimo radar detection of targets in compound-gaussian clutter. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 208 –212, oct. 2008.

Abstract: Multiple-input multiple-output (MIMO) radars with widely-separated transmitters and receivers are useful to discriminate a target from clutter using the spatial diversity of the scatterers in the illuminated scene. We consider the detection of targets in compound-Gaussian clutter fitting for example scatterers with heavy-tailed distributions for high-resolution and/or low-grazing-angle radars in the presence of sea or foliage clutter. First, we introduce a data model using the inverse gamma distribution to represent the clutter texture. Then, we apply the parameter-expanded expectation-maximization (PX-EM) algorithm to estimate the clutter texture and speckle, as well as the target parameters.We develop a generalized likelihood ratio (GLR) test target detector using the estimates and show the advantages of MIMO using Monte Carlo simulations.

[292] C.R. Berger, Shengli Zhou, P. Willett, B. Demissie, and J. Heckenbach. Compressed sensing for ofdm/mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 213 –217, oct. 2008.

Abstract: In passive radar, two main challenges are: mitigating the direct blast, since the illuminators broadcast continuously, and achieving a large enough integration gain to detect targets. While the first has to be solved in part in the analog part of the processing chain, due to the huge difference of signal strength between the direct blast and weak target reflections, the second is about combining enough signal efficiently, while not sacrificing too much performance. When combining this setup with digital multicarrier waveforms like orthogonal frequency division multiplex (OFDM) in digital audio/video broadcast (DAB/DVB), this problem can be seen to be a version of multiple-input multiple-output (MIMO) radar. We start with an existing approach, based on efficient fast Fourier transform (FFT) operation to detect target signatures, and show how this approach is related to a standard matched filter approach based on a piece-wise constant approximation of the phase rotation caused by Doppler shift. We then suggest two more applicable algorithms, one based on subspace processing and one based on sparse estimation. We compare these various approaches based on a detailed simulation scenario with two closing targets and experimental data recorded from a DAB network in Germany.

[293] S. Searle, S. Howard, and B. Moran. The use of complementary sets in mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 510 –514, oct. 2008.

Abstract: In multstatic radar it is desirable to transmit waveforms which are completely mutually orthogonal in order to minimise cross-transmitter interference. Perfect orthogonality is impossible to achieve, and in reality adaptive processing is necessary to remove interference, with some mismatch loss in main lobe size. This study proposes a method of composing waveforms from mutually-orthogonal complementary sets. Each transmitter is assigned a set of complementary waveforms to be separated in frequency. Nonlinear processing of matched filter outputs can completely remove cross-transmitter interference and suppress autocorrelation sidelobes without cost. Cross terms introduced by the nonlinear operation are handled via frequency agility and Doppler processing. The principle is demonstrated by simulation.

[294] T. Aittomaki and V. Koivunen. Mimo radar direction finding performance using swerling model. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 518 – 522, oct. 2008.

Abstract: A MIMO radar uses multiple waveforms and other forms of diversity to improve the performance. A statistical MIMO radar that takes advantage of spatial diversity has been proposed earlier. This radar concept aims at mitigating the performance loss caused by fluctuations of the radio cross-section of the target. In this paper, we examine the direction finding performance of the statistical MIMO radar using the Swerling scattering model, which covers both fast and slow fluctuation of the target RCS. The direction finding performance has been studied before, but so far, the different cases of the Swerling model have not been considered. We derive the Cramer-Rao bound or a similar performance measure for each case. Numerical results are also provided.

[295] Rick Blum. Session mp1: Mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 606 –608, oct. 2008.

Abstract: Not available

[296] W. Roberts, T. Yardibi, Jian Li, Xing Tan, and P. Stoica. Sparse signal representation for mimo radar imaging. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 609 –613, oct. 2008.

Abstract: MIMO radar can achieve superior performance over the conventional phased-array radar through waveform diversity. Considerations in transmit waveform and receive filter design are central to attaining improved performance through a MIMO system. Moreover, adaptive array techniques are needed to improve accuracy, resolution and to further provide interference suppression. Recently, the weighted least-squares based iterative adaptive approach (IAA), a non-parametric and user parameter-free method was shown to provide good performance for array processing. In this paper, we demonstrate how IAA can be extended for MIMO radar applications. Our simulations show that IAA outperforms other well-established methods in the field.

[297] H. Godrich, A.M. Haimovich, and R.S. Blum. Target localization accuracy and multiple target localization: Tradeoff in mimo radars. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 614 –618, oct. 2008.

Abstract: This paper undertakes the study of localization performance of multiple targets in coherent MIMO radar systems with widely spread elements. MIMO radar systems with coherent processing and a single target were shown to benefit from a coherency and spatial advantages. The first is proportional to the ratio of the signal carrier frequency to the effective bandwidth, while the latter provides a gain proportional to the product of the number of transmitting and receiving sensors. In the current study, the model in extended to the estimation accuracy of multiple targets. The Cramer-Rao lower bound (CRLB) for the multiple targets localization problem is derived and analyzed. The localization is shown to benefit from coherency advantage. The tradeoff between target localization accuracy and the number of targets that can be localized is shown to be incorporated in the spatial advantage term. An increase in the number of targets to be localized exposes the system to increased mutual interferences. This tradeoff depends on the geometric footprint of both the sensors and the targets, and the relative positions of the two. Numerical analysis of some special cases offers an insight to the mutual relation between a given deployment of radars and targets and the spatial advantage it presents.

[298] Qian He, R.S. Blum, A.M. Haimovich, and Zishu He. Antenna placement for velocity estimation using mimo radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 619 –623, oct. 2008.

Abstract: Optimum antenna placement is considered for MIMO radar performing velocity estimation. A general optimization strategy for velocity estimation using MIMO radar is derived based on the Cramer-Rao bound analysis. Optimal antenna placement is investigated.We show that when orthogonal signals are adopted for transmission, symmetrically placing the transmit antennas as well as the receive antennas achieves the best performance, and the relative position of the transmitter and receiver can be arbitrary. Under the same condition, when optimal antenna

placement is employed, it is shown that increasing the signal time duration or the product of the number of transmitters and receivers can improve the velocity estimation accuracy.

[299] Zhe Zhang and D.R. Fuhrmann. Complex point target models for multistatic radar. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 624 –628, oct. 2008.

Abstract: A mathematical and statistical model for complex point targets is proposed that may be applicable to statistical inference problems in multistatic or MIMO radar systems. Such targets are not resolved in space, but exhibit varying complex reflectivity across different bistatic view angles. The complex reflectivity can be modeled as a complex stochastic process whose index set is the set of all bistatic view angles, and the parameters of this stochastic process follow from an analysis of a target model comprising a number of ideal point scatterers randomly located within some radius of the target's center of mass. Six different models are proposed, with different assumed distributions on the locations of the point scatterers within the target.

[300] Y.I. Abramovich and G.J. Frazer. Theoretical assessment of mimo radar performance in the presence of discrete and distributed clutter. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 629 –633, oct. 2008.

Abstract: We consider mitigation of clutter that is distributed in range and Doppler frequency for scenarios that have a difference in the direction-of-departure (DoD) between a target and a clutter patch at the same radar range. We demonstrate that efficient clutter mitigation can be achieved by a MIMO radar with a specific waveform set by (adaptive) non-causal beamforming of the transmit antenna under certain limitations on the total area in range and Doppler frequency occupied by all possible targets and clutter.

[301] V.F. Mecca and J.L. Krolik. Mimo stap clutter mitigation performance demonstration using acoustic arrays. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 634 –638, oct. 2008.

Abstract: This paper demonstrates MIMO STAP radar techniques for Doppler-spread clutter mitigation using a 5-element transmit speaker array and a 16-element receive microphone array. Doppler-spread clutter is mitigated by ldquovirtualrdquo transmit beampattern nulling using partially-adaptive beamspace slowtime MIMO STAP (SLO-MO) on received audio data. For a transmit beamspace dimension of three, the ability of SLO-MO processing to achieve a 30 dB suppression of Doppler-spread clutter using only a single adaptive transmit degree of freedom is demonstrated. Additionally, MIMO acoustic array processing is shown to be useful in understanding factors which impact radar performance like clutter spatial spread.

[302] G.J. Frazer, Y.I. Abramovich, and B.A. Johnson. Hf skywave mimo radar: The hilow experimental program. In *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pages 639 –643, oct. 2008.

Abstract: In the paper we report on an experimental program undertaken by the Defence Science and Technology Organisation and partners during the period from early 2006 to late 2007. The focus of the program was to investigate MIMO radar use in over-the-horizon radar. The program revealed that a specific MIMO radar technique: non-causal radar-transmit beamforming, can be

applied to this radar class. Examples of this technique were demonstrated, including non-causal fixed transmit beamforming as well as non-causal adaptive transmit beamforming and non-causal direction-of-departure estimation. This is the first case where practically useful adaptive transmitter beamforming has been demonstrated in OTHR.

[303] Qing Wang, Chunping Hou, and Yilong Lu. Wimax signal generation based on mimo-ofdm testbed for passive radar application. In *Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference on*, pages 2582 –2587, may 2009.

Abstract: In order to analyze the ambiguity function of WiMAX signals and evaluate their suitability for passive radar, the first step should be the generation of WiMAX transmission signal, including random data generation, modulation, Space Time Block Coding (STBC), preamble generation for synchronization and channel estimation, frame combination and Orthogonal Frequency Division Multiplexing (OFDM) modulation. In this paper, WiMAX signal generation based on a Multiple-Input-Multiple-output (MIMO) OFDM testbed as well as detailed baseband signal processing algorithms are presented. Field trials and measurements based on the MIMO-OFDM testbed in different channel conditions have verified that the signal generation method and the adopted baseband signal processing algorithms are effective.

[304] Hai Deng and B. Himed. Detection of low-speed ground moving targets using mimo radar. In *Antennas and Propagation Society International Symposium, 2009. APSURSI '09. IEEE*, pages 1 –4, june 2009.

Abstract: Summary form only given. For airborne radar systems, space-time adaptive processing (STAP) is the approach that is normally adopted to detect ground moving targets in ground clutter, but the technique becomes less effective if the speed of ground moving targets is very low because of the proximity of the Doppler frequency of targets to that of ground clutter. Typical low-speed ground target detection scenarios include detecting ground troops and slowly-moving ground vehicles. Multiple-input multiple-output (MIMO) radar possesses multiple transmitting and receiving channels providing additional diversified reflections for fusion processing in target detection and measurements. MIMO radar has been extensively investigated, but the exact structure of MIMO radar is defined widely different. In this work, an innovative multi-level MIMO radar signal processing architecture is proposed for airborne systems to effectively detect low-speed ground moving targets. The new MIMO-based approach is demonstrated to be effective for detecting such low-speed ground targets in this work, and some simulation results are presented subsequently.

[305] Jun Yan, Gong Zhang, and Ling Cheng. Research on dss-based mimo radar's detection performance. In *Information Processing, 2009. APCIP 2009. Asia-Pacific Conference on*, volume 1, pages 161 –164, july 2009.

Abstract: The application of multi-input multi-output (MIMO) radar concept to DSS (Distributed Small Satellite) is considered to make best use of the cooperative mode of DSS and the spatial diversity of MIMO radar. The DSS-based MIMO radar system is introduced in this paper. Using the receiving signalpsilas eigenvalue of covariance matrix, it analyses detection performance of MIMO radar, which canpsilat form a full-diversity path. The detection performance of MIMO radar based on moving platform are discussed. We show the influence of DSS platformpsilas

movement on radarpsilas detection performance, and discussed the feasibility of DSS-based MIMO radar system.

[306] G. Alfano, C.-F. Chiasserini, A. Nordio, and A.M. Tulino. Asymptotics of multi-fold vandermonde matriceswith applications to communications and radar problems. In *Communications, 2009. ICC '09. IEEE International Conference on*, pages 1 –5, june 2009.

Abstract: We study the performance of signal estimation and reconstruction systems, that exploit the linear minimum mean square error (LMMSE) technique. This model often occurs in signal processing and wireless communications; some examples are radar applications, MIMO communications, or sensor networks sampling a physical field. Our performance analysis implies the characterization of a random matrix product, involving a multifold Vandermonde matrix with complex exponential entries. We therefore derive the LMMSE by computing the eta-transform of this matrix product, which can be evaluated either by implicit as well as by explicit expression, using the matrix asymptotic moments. Finally, we show how our results can be applied in some cases of practical interest.

[307] Dang-Wei Wang, Nie jing Duan, Xiao-Yan Ma, and Yi Su. High-resolution imaging using a wideband mimo radar system. In *Information and Automation, 2009. ICIA '09. International Conference on*, pages 1150 –1155, june 2009.

Abstract: In this paper we propose an imaging method via wideband multiple-input multiple-output radar to reduce the hardware complexity of the system. Since a spatial parallel procedure to sample the scattered echoes during a single snapshot illumination, instead of the spatial sequential sampling procedure during multiple snapshot illuminations in classical ISAR imaging, is utilized in our method, the complex motion compensation in ISAR imaging can be avoided. Moreover, compared to the narrowband MIMO imaging system, every array element transmits and receives simultaneously in our array configuration, and therefore, the hardware complexity can be significantly reduced. Numerical simulations are provided for testing our proposed method.

[308] L.A. Balzan and L.B. White. Optimal waveform precoder design for narrowband mimo radar systems. In *Statistical Signal Processing, 2009. SSP '09. IEEE/SP 15th Workshop on*, pages 517 –520, 31 2009-sept. 3 2009.

Abstract: This paper addresses the problem of coded waveform design for Multiple Input - Multiple Output (MIMO) radar systems. The paper proposes a signal model based on the assumption of a small array aperture relative to the signal wavelength and a single target in far field. It is argued that near maximum likelihood performance can be obtained by choosing the transmitted waveforms on different antennas to be orthogonal. The Cramer-Rao Bound (CRB) for estimating the target distance, radial velocity and wavenumber is derived. The paper presents a convex optimisation procedure to yield an optimal energy distribution across the transmitted signals. Simulations demonstrate a reduction in CRB in the order of 25compared to the use of a random unitary code. The paper concludes by indicating a natural generalisation of the method to optimal design for MIMO tracking radars.

[309] T. Aittomaki and V. Koivunen. Beampattern optimization by minimization of quartic polynomial. In *Statistical Signal Processing, 2009. SSP '09. IEEE/SP 15th Workshop on*, pages 437 –440, 31 2009-sept. 3 2009.

Abstract: Beampattern synthesis is a common problem in array signal processing. Recently, methods for beampattern optimization using multiple simultaneously transmitted waveforms have been published in the context of MIMO radar. In this paper, we formulate the beampattern optimization problem as minimization of a multivariate quartic polynomial. The advantage of this approach is that iterative line searches are not needed and that the low-rank case can be solved directly without finding the minima of the full-rank system. The method does not guarantee convergence to the global minimum, but numerical examples provided demonstrate that results comparable to the other approaches are achieved.

[310] A. Yazici, A.C. Hamurcu, and B. Baykal. A practical point of view: Performance of neyman-pearson detector for mimo radar in k-distributed clutter. In *Statistical Signal Processing, 2009. SSP '09. IEEE/SP 15th Workshop on*, pages 273 –276, 31 2009-sept. 3 2009.

Abstract: Use of multiple transmit and receive antennas have become a popular research area in radar community after the success of the same concept in communication. It is shown by Fishler et al. that multi-input multi-output (MIMO) radar has considerable advantages compared to traditional radar and phased array radar systems. In this paper, detection performance of MIMO radar using Neyman-Pearson detector is investigated in K-distributed sea clutter for a practical scenario. Also, spikiness of K-distributed MIMO radar clutter is discussed with respect to the number of nodes.

[311] V.V. Chapoursky. Analysis of interference re-reflections in mimo radar at multiplicative processing. In *Microwave Telecommunication Technology, 2009. CriMiCo 2009. 19th International Crimean Conference*, pages 959 –960, sept. 2009.

Abstract: The mathematical model of influence of rereflections is presented for a small range radar with a step frequency modulation signal and for a spatially multi-channel antenna system of MIMO type. Presence and level of interferential marks in the system alarm function are analyzed for a multiplicative algorithm of processing for all pairs of ldquotransmitter-receiverrdquo elements.

[312] B. Yang, A. Yarovoy, P. Aubry, and X. Zhuge. Experimental verification of 2d uwb mimo antenna array for near-field imaging radar. In *Microwave Conference, 2009. EuMC 2009. European*, pages 97 –100, 29 2009-oct. 1 2009.

Abstract: In this paper two 2D MIMO antenna arrays for near-field imaging radar operating in the frequency band from 10 GHz till 18 GHz are presented. Two MIMO topologies have been proposed to achieve the point spread function (PSF) with narrow main lobe and low side-lobe level. Stacked patch antennas are used as antenna elements. Both designs have been verified experimentally and satisfactory agreement between theoretical and experimental results has been achieved. High-resolution images of a bottle of water are demonstrated.

[313] Yu.I. Abramovich, G.J. Frazer, B.A. Johnson, and N.K. Spencer. Iterative adaptive kronecker receiver for mimo over-the-horizon radar. In *Image and Signal Processing and Analysis, 2009. ISPA 2009. Proceedings of 6th International Symposium on*, pages 22 –27, sept. 2009.

Abstract: We introduce an iterative adaptive multiple-input-multiple-output (MIMO) radar receiver that is useful when the KL-variate adaptive transmit-receive beamformer is structured as the Kronecker product of a K-variate transmit and an L-variate receive beamformer. We consider the case of two clutter propagation modes with different elevation angles, and where the direction-of-departure (DoD) of one mode and the direction-of-arrival (DoA) of the other mode coincide with that of a target. For an example simulation scenario, we demonstrate that our iterative adaptive ldquoKronecker receiverrdquo achieves high performance.

[314] Zhaoyang Zhang, Yongbo Zhao, and Jingfang Huang. Array optimization for mimo radar by genetic algorithms. In *Image and Signal Processing, 2009. CISP '09. 2nd International Congress on*, pages 1 –4, oct. 2009.

Abstract: In this paper, technique for the array optimization of multiple-input multiple-output (MIMO) radar is investigated. The primacy focus of this study is improved two-way pattern performance of MIMO radar. Genetic algorithms (GA) is applied to the array optimization in order to reduce the peaks of side lobes (PSL) by acting on the elements positions. By using the property that the two-way pattern of MIMO radar equals to the product of the transmitting and receiving beam patterns, the computational complexity of algorithms in this paper is significantly decreased. For MIMO radar system with separate transmitting and receiving arrays, and both of them are composed of 25-element with an overall aperture of 50lambda (lambda being the wavelength), the two-way pattern obtained in this paper with PSL do not exceed -28.65 dB, which meets the requirement of project applications.

[315] Yongbo Zhao, Penglang Shui, and Hongwei Liu. Computationally efficient doa estimation for mimo radar. In *Image and Signal Processing, 2009. CISP '09. 2nd International Congress on*, pages 1 –3, oct. 2009.

Abstract: A computationally efficient direction-of-arrival (DOA) estimation algorithm is proposed for the multiple-input multiple-output (MIMO) radar with uniform linear array (ULA). In the proposed algorithm, the ULA structure is exploited to greatly reduce the array vector dimension, which results in a significant decrease in computational complexity. The effectiveness of the algorithm is verified by simulations.

[316] Zhi Dong Zheng, Jian Yun Zhang, Peng Ma, and Chun Sheng Liu. Angle estimation with automatic pairing for bistatic mimo radar. In *Image and Signal Processing, 2009. CISP '09. 2nd International Congress on*, pages 1 –5, oct. 2009.

Abstract: In this paper, a new joint direction of departure (DOD) and direction of arrival (DOA) estimation method is presented for bistatic multiple input multiple output (MIMO) radar. Because all the diagonal elements of the transmitting and receiving invariance matrices are located on the unit circle of the complex plane, we construct a complex matrix so that the DOD and DOA pairing is given automatically by the real and imaginary parts of its complex eigenvalues. Thus this method can be applied under any condition of target distribution, which does not suffer from

incorrect pairing problem as existing methods in literature. Simulation results show that the new method provides satisfactory performances but with drastically reduced computations compared with previous work.

[317] Y.I. Abramovich, G.J. Frazer, B.A. Johnson, and N.K. Spencer. Convergence analysis of the iterative adaptive kronecker receiver for mimo radar applications. In *Radar Conference, 2009. EuRAD 2009. European*, pages 497 –500, 30 2009-oct. 2 2009.

Abstract: We analyse an iterative adaptive multiple-input-multiple-output (MIMO) radar receiver in the situation where a K L-variate adaptive transmit-receive beamformer is structured as the Kronecker product of a K-variate (transmit) and an L-variate (receive) beamformer. We present results for the special case of two clutter propagation modes separated in elevation angle, where the direction-of-departure (DoD) of one mode and the direction-of-arrival (DoA) of the other mode coincide with that of a target. We introduce the analytical condition of convergence and signal-to-interference-plus-noise ratio (SINR) loss factor for a given training sample volume under a number of assumptions for a sample-matrix inversion (SMI)-based iterative algorithm, and demonstrate that the diagonally loaded SMI algorithm can provide significant improvement in the convergence rate of the iterative "Kronecker MIMO receiver".

[318] Y. Kalkan and B. Baykal. Mimo radar target localization by using doppler shift measurement. In *Radar Conference, 2009. EuRAD 2009. European*, pages 489 –492, 30 2009-oct. 2 2009.

Abstract: A new method for target localization in MIMO radar is proposed. Localization of a moving, non-maneuvering target is possible by using Doppler-shift measurements and angle information in MIMO radar systems. This is a nonlinear problem and it must be solved for a grid search strategy. If the received frequencies and the angels between the target and the transmitter and the target and the receiver are known, we can search space grid by grid for desired (x, y) coordinates to find the position of the target in 2D space.

[319] T.G. Savelyev, X. Zhuge, A.G. Yarovoy, L.P. Ligthart, and B. Levitas. Comparison of uwb sar and mimo-based short-range imaging radars. In *Radar Conference, 2009. EuRAD 2009. European*, pages 109 –112, 30 2009-oct. 2 2009.

Abstract: This paper compares and analyzes the imaging capability of two ultra-wideband radar systems which are based on synthetic aperture and sparse planar array respectively. The systems comprise the same 3.1-10.6 GHz antennas and video-impulse electronics. The SAR uses a transmit-receive antenna pair installed on 2D mechanical scanner, while the array represents an multiple input multiple output (MIMO) structure with four transmit and sixteen receive antennas. In both systems digital beamforming is applied to the acquired data. The comparison bases on measurements conducted for the same scenarios.

[320] S.H. Zhou, H.X. Wang, L.B Hu, X.C. Yang, and H.W. Liu. Signal fusion network for spatial diversity mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: This paper concerns target detection algorithms of spatial diversity MIMO radar. The GLRT algorithm is developed, under the assumption that clutters in different spatial diversity

channels follow independent Gaussian distributions with different covariance matrix. The global test statistics turns out to be a production of the local test statistics. Three signal fusion networks are introduced, in which each local site can detect targets with the CFAR property. The CFAR thresholds for the fusion centre and the local sensors can be estimated by offline numerical experiments. It is shown that the signal fusion network yields a better detection performance than that of the decision fusion network.

[321] Bin Xia, Jia Xu, Yingning Peng, and Xiutan Wang. Bounded mismatch model of steering vector error for adaptive array mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: A linear subspace model with upper bounded mismatch for array steering vector errors in multiple-input multiple-output (MIMO) radar is presented. Taking into account a possible mismatch between the actual steering vector and the presumed one, the model can serve as a tool for detector design of MIMO radar system.

[322] M.L. Yang, B.X. Chen, G.D. Qin, and S.H. Zhang. High range resolution based on multi-carrier-frequency mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: Multi-Carrier-Frequency MIMO (MCF MIMO) Radar is a radar system with multiple transmit antennas and multiple receive antennas capitalizing on frequency diversity and spatial diversity to obtain orthogonality of transmitted signals and it can combine a number of narrow bandwidth signals to form a large bandwidth signal to obtain high range resolution(HRR). Two processing methods based on dechirp processing and channel separation technique to obtain the HRR, which are respectively IDFT Coherent Synthesis method (short for ICS method) and Spatial Domain Synthetic Bandwidth method (short for SDSB method), are proposed in the paper. Also both methods are characterized by the reduction of the instantaneous bandwidth and slightly influence on the moving target. Finally the simulation results on the computer validate these conclusions.

[323] Christian Sturm and Werner Wiesbeck. Joint integration of digital beam-forming radar with communication. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: In many RF applications both, communications and Radar operate at the same time, but until now at different frequencies and in time division multiple assess. This wastes spectrum and contributes to information loss. Here it is proposed to jointly integrate Digital Beam-forming Radar and MIMO communications in one system, at one frequency with the identical waveform.

[324] Zheng Liu, Ruili Zhao, Yunfo Liu, and Zijing Zhang. Performance analysis on mimo radar waveform based on mutual information and minimum mean-square error estimation. In *Radar Conference, 2009 IET International*, pages 1 –6, april 2009.

Abstract: Multiple-Input Multiple-Output (MIMO) technology can improve the performance of radar by spatial diversity. Two methods for designing MIMO radar waveform are introduced in this paper. The first one is to design waveforms that maximize the conditional mutual information (MI) between the reflected waveform and the channel impulse response. The second one is to minimize the minimum mean-square error (MMSE) in channels estimation. A particular analysis

of detection performance is made here to illuminate the improvement. Finally the simulation results are presented and the performances of the two approaches are compared.

[325] R.D. Fry, D.A. Gray, and L.A. Balzan. Mimo arrays and array shading. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: A MIMO radar consisting of M transmit and N receive elements extracts MN signals using a matched filter bank. These signals can be considered as those received by a virtual array of MN elements. However, for many MIMO radar array geometries, multiple virtual array elements can exist at the same location. Therefore, an equivalent virtual array may consist of less than MN elements with some 'natural' weighting upon elements. Shading may be applied to the virtual array, incorporating the natural weights, to yield desired beampatterns. This paper investigates array shading for a range of MIMO radar array geometries. Robustness to element failure is also discussed.

[326] Bo Zhang and Bingqi Liu. Spatial correlation analysis on radar echoes of mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: Spatial correlation between the amplitudes of radar echoes has a great impact on the signal processing methods and the performance of MIMO radar. There is an urge need to analyze the spatial correlation in order to optimize the performance of radar system. In this paper, we model the target consisting of a finite number of scatterers distributed in three dimensions, and derive the formula to evaluate the spatial correlation between the echoes from different aspects. Furthermore, we precisely analyze the relationships between the spatial correlation and some important factors, such as the effective baselength and the scattering pattern. We also do experiments with the real models of two certain aircrafts. More importantly, reasonable physical interpretation for the simulation results is presented and the conclusions can be used in practical work.

[327] Guolong Cui, Lingjiang Kong, Xiaobo Yang, and Jianyu Yang. Coincidence of the rao test, wald test, and glrt of mimo radar in gaussian clutter. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: This paper deals with the problem of detecting signal with MIMO radar in correlated Gaussian clutter with known covariance matrix. The general MIMO model, with widely separated sub-arrays and co-located antennas at each sub-array, is adopted. It is proved that the Rao test and the Wald test coincide with Generalized Likelihood Ratio Test (GLRT).

[328] Juan Zhang, LinRang Zhang, and Nan Liu. A efficient doa estimation algorithm of coherent sources for mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –3, april 2009.

Abstract: To estimate the DOA of coherent sources of MIMO radar, a new spatial smoothing (SS) technique based on MIMO radar is presented using the diversity of the transmitted waveform and the independence of the transmitting-receiving channel. In the technique, the array is not necessary to be divided into sub-arrays, the received signal of the virtual sub-arrays are extracted from the output of the matched filter banks of MIMO radar, and then the auto-correlation matrix of the sub-array is derived. The technique in this paper can avoid the reduction of the array

effective aperture, and adapt to arbitrary array structures, and increase the maximum number of coherent signals that can be estimated. Some numerical examples are simulated to verify the effectiveness of the technique.

[329] Juan Zhang, LinRang Zhang, Nan Liu, and Qing Xu. An efficient algorithm for array optimization of mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: Array optimization of MIMO radar is important to obtain better system performance. Numbers of efficient virtual array elements that can be obtained by MIMO radar are analyzed and compared among different linear array arrangement. An efficient algorithm for array optimization of MIMO radar is presented, by the algorithm, the virtual array of MIMO radar is a MR array, and the most efficient virtual sensors can be obtained. Last, the performance of MIMO radar optimized by the algorithm in this paper are compared with the conventional ULA MIMO radar, the simulation results indicates that the resolution capability of the optimized MIMO radar is better than that of ULA MIMO radar when they have the same physical sensors.

[330] L.B. Hu, H.W. Liu, S.H. Zhou, and S.J. Wu. Convex optimization applied to transmit beampattern synthesis and signal waveform design for mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –5, april 2009.

Abstract: This paper deals with designing the signal waveforms transmitted via multiple-input multiple-output (MIMO) radar antennas to approximate a given transmit beampattern, and also to minimize the cross-correlation of different echoes. In this paper, we consider a non-uniform but fixed elemental power constraint instead of the uniform elemental power one while still maintaining the same total transmit power. With the relaxed constraint and for a given power gain, we first construct a set of transmit beams or signal waveform vectors with globally optimal peak sidelobe levels. Next, we combine these beams or the corresponding vectors according to some ratios to synthesize a desired transmit beampattern or its corresponding probing signal matrix. Convex optimization is applied to get these vectors and their ratios. Numerical comparison shows that our synthesized transmit beampattern has lower peak sidelobe levels and also has lower crosscorrelation peak sidelobe levels due to relaxing the uniform elemental power constraint. Additionally, the probing signal transmitted by each antenna element has a constant modulus because of the fixed elemental power constraint.

[331] Shenghui Zhou, Qiang Yang, and Weibo Deng. Mcpc signal applied in mimo hf radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: MIMO radar is a new concept in which radar employs multiple waveforms to improve its performance. The paper focuses on MCPC signal application in MIMO radar, and analyzes MCPC signal performance in MIMO high frequency radar system. In this paper we introduces MCPC signal structure and the information extract, and then plots MIMO high frequency radar position and velocity ambiguity function under different geometry arrangements, that transmitter/receiver is bistatic or cross-laying. In addition, we analyze the factors that influence target's velocity and range resolution, as well as how to enhance the resolution of the high frequency radar. Meanwhile, simulations verify theoretical analysis.

[332] G.D. Qin, B.X. Chen, and D.F. Chen. Impulse and aperture synthesis in multi-carrier-frequency mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: The multi-carrier-frequency MIMO radar uses a sparse-array to transmit the FMCW signals of multiple carrier frequencies, and an array to receive the echoes. The signal model of multi-carrier-frequency MIMO radar is analyzed in this paper. A new method for impulse and aperture synthesis is presented. Every range cell after coherent integration is divided equally into Nn parts, which is weighted by the coherent integration results. As a result, the range grating lobes are suppressed greatly and the aperture of transmitting and receiving array is utilized adequately. The simulation results indicate the validity of the method presented in this paper.

[333] Tian Jin, Qian Song, and Biying Lu. Virtual array imaging radar azimuth resolution analysis. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: In this paper, a virtual array technique is proposed for forward-looking imaging, where the virtual aperture is obtained on the multi-input/multi-output (MIMO) theory. The analytical expression of the azimuth resolution of the multi-input/ double-output virtual array is derived, which establishes the bridge between the virtual aperture technique and synthetic aperture technique and offers a unified frame to process virtual aperture images and synthetic aperture images. The theoretic analysis on the virtual array imaging radar azimuth resolution has also been validated using real data results.

[334] G.D. Qin, B.X. Chen, and D.F. Chen. A new method for velocity estimation in multicarrier-frequency mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: The multi-carrier-frequency MIMO radar transmits orthogonal signals of multiple carrier frequencies and capitalizes on the spatial and wave diversity to significantly improve the performance and the flexibility of the radar. A new velocity estimation which can overcome the velocity ambiguity is presented in this paper, using which the LS(least-squared) estimation of true velocity can be obtained from the Doppler shifts corresponding to the different transmit frequencies without transmitting multiple PRF(pulse repetition frequency) signals. Some numerical results are presented to verify the validity of this method.

[335] Wei-jun Long, De Ben, Ming-hai Pan, Xian-rong Shu, Yan-ming Han, and Jin-bo1 Pan. Opportunistic digital array radar and its technical characteristic analysis. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: Based on the Digital Array Radar (DAR), conformal array, sparse array, Multi-Input Multi-Output (MIMO) system and Ubiquitous radar, a new radar system;the Opportunistic Digital Array Radar (ODAR) has been proposed in recent years. The concept, principle and characteristics of the ODAR are presented in this paper. Furthermore, the challenges are also analyzed from the aspects of the random element distributing, digital beam forming, signal transmission synchronization and adaptively intelligent decision, etc. The Genetic Arithmetic (GA) is exploited to carry out the beam shaping optimization of 3-D randomly distributed elements. The simulation results indicate that the method is feasible. The mathematics models of phase perturbation are preformed to implement the clock synchronization and adaptive beam steering. The adaptive synchronization design of signal transmission is adopted to improve the

synchronization precision. The phase perturbation module is built to analyze the influence on ODAR specification by optical fibre or wireless links.

[336] Jun Li, Guisheng Liao, Ming Jin, and Qian Ma. Multitarget detection and localization method for bistatic mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: In this paper, we present a scheme of detection and localization of multiple targets in the same range cell using two transmitters bistatic MIMO radar. The signal model is constructed by means of the rotational factor produced by transmiter. Based on the signal model, canonical correlation test (CCT) method is extended directly to determine the number of targets. Furthermore, a close form solution for localization the multiple targets is presented via ESPRIT. The direction of arrivals (DOAs) and direction of departures (DODs) of the targets can be solved and paired automatically. Simulation results demonstrate the effectiveness of the methods.

[337] Ming Jin, Guisheng Liao, Jun Li, and Weiping Li. Direction finding using minimum redundancy mimo radar. In *Radar Conference, 2009 IET International*, pages 1 –4, april 2009.

Abstract: An augmented covariance matrix, which has the characteristics of Hermitian and Toeplitz, is constructed for minimum redundancy (MR) multiple-input multiple-output (MIMO) radar to implement direction finding using Capon algorithm. A diagonal loading technique is employed to avoid non-positive definite of the covariance matrix. The diagonal loading level is adjusted adaptively according to the eigenvalues of the covariance matrix. The proposed method not only expands the system degrees-of-freedom (DOFs), but also has robust spatial spectrum estimation performance. In addition, the method requires no priori knowledge of the number of targets. Simulation results showing the performance improvement of the proposed method is presented.

[338] Juting Wang, Shengli Jiang, Jin He, Zhong Liu, and C. Baker. Adaptive detectors for mimo radar with sidelobe signal rejection capabilities. In *Wireless Communications Signal Processing, 2009. WCSP 2009. International Conference on*, pages 1 –5, nov. 2009.

Abstract: Antenna beam patterns in MIMO radar systems (as in any radar system) exhibit sidelobes. Naturally it is possible for clutter and other undesirable signals to be detected accidently through these sidelobes. In a MIMO radar system this has the effect of misaligning the mainbeam steering vector and consequently reducing detection performance. In this paper we develop and examine two adaptive processing schemes aimed at reducing unwanted signals entering the system through sidelobes and hence restoring the steering vector to its true position. In this way signal to noise and detection performance are also largely restored. The MIMO version of an adaptive beamformer orthogonal rejection test (MIMO-ABORT) method together an adaptive detector with conic rejection (MIMO-ACR) are developed, that exploit the generalized likelihood ratio principle. Subsequently the constant false alarm rate (CFAR) properties of the two proposed detectors are demonstrated. The performance of the MIMO-ABORT and the MIMO-ACR detectors are numerically evaluated. The results show that the two detectors can reject sidelobe signals with good performance at the cost of a slight reduction in mainlobe signal detection performance, as compared with MIMO version of Kelly's GLRT (MIMO-GLRT).

[339] Wen-Qin Wang, Qicong Peng, and Jingye Cai. Diversified mimo sar waveform analysis and generation. In *Synthetic Aperture Radar, 2009. APSAR 2009. 2nd Asian-Pacific Conference on*, pages 270 –273, oct. 2009.

Abstract: Inspired by recent advances in multiple-input and multiple-output (MIMO) radar, which has the potential to dramatically improve the performance of radar systems over single antenna systems. This paper proposes a waveform diversity-based MIMO synthetic aperture radar (SAR) concept. The fundamental difference between MIMO SAR and conventional SAR is that the latter seeks to maximize coherent processing gain, while MIMO SAR capitalizes on the diversity of target scattering to improve imaging performance. The system concept and signal models are developed. An example diversified waveform using for MIMO SAR is designed, along with several computer simulations that investigate the correlation performance of the designed waveform. Furthermore, a direct digital synthesizer (DDS)-based approach of diversified waveform generation, in which parallel DDSs are applied, is proposed for MIMO SAR systems.

[340] Wang Libao, Xu Jia, Peng Shibao, Huang Fu Kan, and Peng Yingning. Ground moving target indication for mimo-sar. In *Synthetic Aperture Radar, 2009. APSAR 2009. 2nd Asian-Pacific Conference on*, pages 173 –176, oct. 2009.

Abstract: The multi-input multi-output synthetic aperture radar (MIMO-SAR) is an innovative concept, which can bring high degrees of freedom for SAR system with limited transmitting/ receiving (T/R) elements. In this paper, ground moving target indication (GMTI) for MIMO-SAR is studied based on reasonable usage of the space-time equivalent samplings. Furthermore, this paper gives a deep insight of the azimuth Ã‚¿spurious peaksÃ‚¿ effect, caused by the periodically modulated error signal due to the radial velocity of moving target. Also, the compensation method is given to suppress the unwanted Ã‚¿spurious peaksÃ‚¿. Finally, the numerical experiments are also provided to demonstrate the effectiveness of the MIMO-SAR GMTI.

[341] Xie Xiaochun and Zhang Yunhua. 3d isar imaging based on mimo radar array. In *Synthetic Aperture Radar, 2009. APSAR 2009. 2nd Asian-Pacific Conference on*, pages 1018 –1021, oct. 2009.

Abstract: In 3-D ISAR imaging, the separation of scatterers which have same Range-Doppler location is a key problem. In this paper, we propose to use a MIMO radar array, which is located in the z-axis direction, to measure the positions of scatterers of a synthesis scatterer. The x- and y-coordinates of scatters are obtained from ISAR image directly. The z-coordinates are reconstructed by the spatial frequencies of scatterers in each synthesis scatterer based on the MIMO radar array. The simulation results show that the proposed method is effective for 3-D image reconstruction.

[342] A. Tajer, G.H. Jajamovich, Xiaodong Wang, and G.V. Moustakides. Optimal point target detection with unknown parameters by mimo radars. In *Military Communications Conference, 2009. MILCOM 2009. IEEE*, pages 1 –6, oct. 2009.

Abstract: We consider multiple-input multiple-output (MIMO) radar systems with widely spaced transmit and receive antennas. We treat the problem of detecting point targets when one or more target parameters of interest are unknown. We provide a composite hypothesis testing framework

for jointly estimating such parameters along with detecting the target while only a finite number of signal samples are available. The test offered is optimal in a Neyman-Pearson-like sense such that it provides a Bayesian-optimal detection test, minimizes the average mean-square parameter estimation error subject to an upper bound constraint on the false-alarm probability, and requires a finite number of samples. While the test can be applied for concurrently detecting the target along with estimating any unknown parameter of interest, we consider the problem of detecting a target which lies in an unknown space range and find the range through estimating the vector of time delays that the emitted waveforms undergo from being illuminated to the target until being observed by the receive antennas. We also analyze the diversity gain which we define as the rate that the probability of mis-detecting a target decays with the increasing SNR and show that for a MIMO radar system with Nt and Nr transmit and receive antennas, respectively, the diversity gain is 1 for point targets.

[343] Xin Gao, Xiaofei Zhang, Gaopeng Feng, Ziqing Wang, and Dazhuan Xu. On the music-derived approaches of angle estimation for bistatic mimo radar. In *Wireless Networks and Information Systems, 2009. WNIS '09. International Conference on*, pages 343 –346, dec. 2009.

Abstract: We investigate the topic for the direction of departure (DOD) and direction of arrival (DOA) estimation in bistatic multiple-input-multiple-output (MIMO) radar systems with the exploitation of array invariance. Several MUSIC-derived algorithms for angle estimation in MIMO radar have been presented and compared for their complexity costs against that of ESPRIT. The proposed scheme of multi-invariance multiple signal classification (MI-MUSIC) has the best performance and also can be considered as a generalization of MUSIC. Simulations verify the collaborative usefulness of our algorithm.

[344] Wang Jing, Luo Feng, Wu Shunjun, and Fu ShaoFeng. The optimization of orthogonal coded signal group based on multiple population evolving strategies. In *Information, Computing and Telecommunication, 2009. YC-ICT '09. IEEE Youth Conference on*, pages 502 –505, sept. 2009.

Abstract: An improved genetic algorithm based on multiple population evolving is presented and applied to the optimization of orthogonal coded signal group for MIMO radar systems. According to the fitness of individuals, the population is divided into three groups and different evolving strategies are applied to every sub-population. The inoculation to all sub-population is actualized. This algorithm can strengthen and preserve the diversity of population. Meanwhile it can enhance the constringency speed and overcome the precocity of GA. Simulation results show that the improved genetic algorithm is effective and the optimized signal can used in MIMO radar.

[345] Xiao-Feng Ma, Wei-Xing Sheng, and Fei Huang. Mono-static mimo radar array design for interferences suppressing. In *Microwave Conference, 2009. APMC 2009. Asia Pacific*, pages 2683 –2686, dec. 2009.

Abstract: The multiple-input multiple-output (MIMO) radar has drawn considerable interest recently. Many notable research results have been obtained, such as virtual receive array (VRA) concept for orthogonal waveform transmitting MIMO radar. The mono-static MIMO radar proposed in this paper shares the same transmit and receive antenna array, so it is very similar to conventional transmit/receive (T/R) digital beamforming (DBF) radar. The VRA concept can be

easily extended to T/R DBF radar system by re-designing the antenna array structure. In this paper, an optimal antenna array design for mono-static MIMO radar is proposed in order to improve the interferences rejection capabilities. The minimum redundancy array (MRA) concept is also used to maximize the antenna virtual aperture for an array of given numbers of elements. Simulation results show that compared with the T/R DBF radar, the proposed monostatic MIMO radar can effectively improve the interferences rejection capabilities, especially the mainlobe interferences rejection capabilities. Moreover, mono-static MIMO radar with MR VRA has better interferences rejection performance than mono-static MIMO radar with uniform VRA.

[346] Qing Wang, Yilong Lu, and Chunping Hou. An experimental wimax based passive radar study. In *Microwave Conference, 2009. APMC 2009. Asia Pacific*, pages 1204 –1207, dec. 2009.

Abstract: Singapore has launched the world's first maritime WiMAX service network which also has introduced a new illuminator of opportunity for passive radar study. This paper presents a new study of passive radar using WiMAX signals. In this paper, the WiMAX standards, WiMAX-based passive radar demonstrator design based on a MIMO-OFDM testbed, and a primary field measurement for detecting ground vehicle are described. Interesting field measurement results may help us to understand the potential capabilities of WiMAX-based passive radar for range and Doppler detection and measurement of moving targets.

[347] Zeng Jiankui and Zhang Junlin. Study on mimo radar detection performance. In *Power Electronics and Intelligent Transportation System (PEITS), 2009 2nd International Conference on*, volume 2, pages 324 –326, dec. 2009.

Abstract: Multiple input multiple output (MIMO) radar is a new radar technique. It has many advantages over conventional phased radar in many ways such as anti-intercept of radar signal, low velocity target detection, and resolution. In this paper, we analyze the signal model and signal processing for MIMO radar. And we compare the SNR of MIMO radar with that of conventional phased array radar. It can be seen that the SNR of MIMO radar is the same as that of phased array radar.

[348] E.K.A. Ampoma, T.R. Rao, and V.A. Labay. Capacity-performance issues in a mimo based mb-ofdm ultrawide band communication system. In *Adaptive Science Technology, 2009. ICAST 2009. 2nd International Conference on*, pages 432 –439, jan. 2009.

Abstract: Ultra wideband (UWB) technology is one of the promising solutions for future short-range communication which has recently received a great attention by many researchers. However, interest in UWB devices prior to 2001 was primarily limited to radar systems, mainly for military applications, due to bandwidth resources becoming increasingly scarce and also its interference with other commutation networks. This research work provides performance analysis of multiband orthogonal frequency division multiplexing (MB-OFDM) UWB MIMO system in the presence of binary phase-shift keying time-hopping (BPSK-TH) UWB or BPSK-DS UWB interfering transmissions under Nakagami-m and log- normal fading channels employing various modulation schemes using MATLAB simulations. Also, provides capacity analysis showing variation of channel capacity with respect to distance well as signal-to-noise ratio.

[349] F. Roemer, H. Becker, M. Haardt, and M. Weis. Analytical performance evaluation for hosvd-based parameter estimation schemes. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 77 –80, dec. 2009.

Abstract: Subspace-based high-resolution parameter estimation schemes are used in a variety of signal processing applications including radar, sonar, communications, medical imaging, and the estimation of the parameters of the dominant multipath components from MIMO channel sounder measurements. It is of great theoretical and practical interest to predict the performance of these schemes analytically. Since they rely on the estimate of the signal subspace obtained via a singular value decomposition (SVD), significant contributions to the perturbation analysis of the SVD have been made in the last decades.

[350] A. Hassanien and S.A. Vorobyov. Direction finding for mimo radar with colocated antennas using transmit beamspace preprocessing. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 181 –184, dec. 2009.

Abstract: The problem of direction finding for multiple targets in mono-static multiple-input multiple-output (MIMO) radar systems is considered. Assuming that the targets are located within a certain spatial sector, we focus the energy of multiple (two or more) transmitted orthogonal waveforms within that spatial sector using appropriately designed transmit beamforming. The transmit beamformers are designed so that match-filtering the received data to the waveforms yields multiple (two or more) data sets with rotational invariance property that allows applying search-free direction finding techniques such as ESPRIT. Unlike previously reported MIMO radar ESPRIT-based direction finding techniques, our method is applicable to arbitrary arrays and achieves better estimation performance at lower computational cost.

[351] C.J. Baker, H.D. Griffiths, and P.F. Sammartino. Mimo radar: From a different perspective. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 185 –188, dec. 2009.

Abstract: MIMO radar is an emerging topic receiving an increasing amount of attention mostly aimed at developing concepts and understanding potential capability. As an emerging topic MIMO radar doesn't have an IEEE definition and if taken literally includes many techniques that have existed much longer than the term itself. In this paper we set MIMO in the context of diversity sensing and draw on the physical interpretation implied by differing concepts to explain expected performance. In this way we present MIMO and related techniques as new and largely unexplored series of radar system design freedoms that offer additional capability. This provides a powerful new paradigm based on diversity for future radar sensors with enormous potential when combined with cognitive processing.

[352] Yang Yang, R.S. Blum, Zishu He, and D.R. Fuhrmann. Alternating projection for mimo radar waveform design. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 169 –172, dec. 2009.

Abstract: Recently there has been a surge of interest in waveform design for multiple-input multiple-output (MIMO) radar, and a great deal of efforts have been devoted to this topic. In this

paper, we revisit an earlier examined MIMO radar waveform design problem which optimizes both minimum mean-square error estimation (MMSE) and mutual information (MI). We formulate a new waveform design problem and provide some further results, which complement the previous study. More specifically, we present an iterative optimization algorithm based on the alternating projection method, to determine waveform solutions that can simultaneously satisfy a structure constraint and optimize the design criteria. Numerical examples are provided, which illustrate the effectiveness of the proposed approach. In particular, we find that the waveform solutions obtained through our proposed algorithm can achieve very close and virtually indistinguishable performance from that predicted in the previous study.

[353] S. Sen and A. Nehorai. Ofdm mimo radar design for low-angle tracking using mutual information. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 173 –176, dec. 2009.

Abstract: We develop an information theoretic waveform design algorithm for target tracking in the presence of multipath. We employ a co-located multiple-input-multiple-output (MIMO) radar configuration using wideband orthogonal frequency division multiplexing (OFDM) signalling scheme. Apart from the frequency diversity provided by OFDM, we also exploit polarization to resolve the multipath signals by using polarization-sensitive transceivers. Thus, we can track the scattering coefficients of the target at different frequencies along with its position and velocity. We apply a sequential Monte Carlo method (particle filter) to track the target, while integrating an optimal waveform design technique based on mutual information criterion. Our numerical examples demonstrate the achieved performance improvement due to the adaptive waveform design.

[354] H. Godrich, A.M. Haimovich, and H.V. Poor. An analysis of phase synchronization mismatch sensitivity for coherent mimo radar systems. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 153 –156, dec. 2009.

Abstract: In this study, the hybrid Cramer-Rao bound (CRB) is developed for target localization, to establish the sensitivity of the estimation mean-square error (MSE) to the level of phase synchronization mismatch in coherent multiple-input multiple-output (MIMO) radar systems with widely distributed antennas. The lower bound on the MSE is derived for the joint estimation of the vector of unknown parameters, consisting of the target location and the mismatch of the allegedly known system parameters, i.e., phase offsets at the radars. Synchronization errors are modeled as being random and Gaussian. A closed-form expression for the hybrid CRB is derived for the case of orthogonal waveforms. The bound on the target localization MSE is expressed as the sum of two terms, the first represents the CRB with no phase mismatch, and the second captures the mismatch effect. The latter is shown to depend on the phase error variance, the number of mismatched transmitting and receiving sensors and the system geometry. For a given phase synchronization error variance, this expression offers the means to analyze the achievable localization accuracy. Alternatively, for a predetermined localization MSE target value, the derived expression may be used to determine the necessary phase synchronization level in the distributed system.

[355] R. Boyer. Co-located mimo radar with orthogonal waveform coding : Cramer-rao lower bound. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2009 3rd IEEE International Workshop on*, pages 149 –152, dec. 2009.

Abstract: In this paper, we derive and analyze closed form (nonmatrix) expression of the Cramer-Rao lower bound (CRB) for the location and the velocity of moving targets contaminated by a structured noise (clutter echoes) and a background noise. The context of our analysis is the co-located MIMO (multiple-input multiple-output) radar system, ie., we dispose of multiple antennas in transmission and reception which are close in space. In addition as it is standard in modern MIMO radar, several noncoherent orthogonal waveforms are transmitted. The analysis of the proposed expressions of the CRB allows to better understand the characterisation of the target. In particular, we prove (1) the estimation of the direction parameter and the velocity of the target are cross-linked ; (2) it is more difficult to estimate the target velocity if the radar station is moving ; (3) if the radar station is not moving, the estimation of the target velocity is isotropic ; (4) it is more difficult to accurately localize fixed or slow moving targets and finally, the CRB for a MIMO radar is a lower bound of the one for the SIMO (single-input multiple-output) radar.

3.4 Conference papers published in 2010

[356] Zeng Jiankui, Xiang Lijuan, Dong Zhiming, and Yuan Shangzun. A new detection method for mimo radar using hidden markov model. In *Computer Modeling and Simulation, 2010. ICCMS '10. Second International Conference on*, volume 2, pages 341 –343, jan. 2010.

Abstract: MIMO radar is a new radar technique developed recently. It can achieve better detection performance than conventional phased radar. Based on the scattering statistic of clutter and man-made target, we propose that hidden Markov models (HMM) can be used to model the clutter and target signals, and that the HMMs can be used to detect target. Simulation results verify its efficiency.

[357] S. Al-Ahmadi and H. Yanikomeroglu. On the use of high-order moment matching to approximate the generalized-k distribution by a gamma distribution. In *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, pages 1 –6, 30 2009-dec. 4 2009.

Abstract: Composite fading takes place in several communication channels due to the random variations of the local average power of the received multipath-faded signal. The generalized-K (gamma-gamma) probability density function (PDF) has been proposed recently to model composite fading in wireless channels. However, further derivations using the generalized-K PDF have shown to be quite involved due to the computational and analytical difficulties associated with the arising special functions. In this paper, the approximation of the generalized-K PDF by a gamma PDF using the moment matching method is explored. As expected, matching positive and negative moments leads to a better approximation in the upper and lower tail regions, respectively. However, due to arising limitations for small values of the multipath fading and shadowing parameters, and the higher level of accuracy sought, the use of an adjustable form for the expressions of the approximating gamma PDF parameters, obtained by matching the first two positive moments, is devised. The optimal values of the adjustment factor for different integer and non-integer values of the fading and shadowing parameters are given. The introduced approximation may simplify performance analysis in distributed antenna systems (DASs), network MIMO, multihop relay networks, radar, and sonar systems.

[358] V.K. Ithapu and A.K. Mishra. Hybrid diversity strategy using mimo radar for target tracking. In *Applied Electromagnetics Conference (AEMC), 2009*, pages 1 –4, dec. 2009.

Abstract: For the development of radar systems with enhanced performance in target detecting and tracking abilities, various research groups have been investigating multiple input multiple output (MIMO) based radar systems. They have shown that MIMO radars perform better compared to conventional systems like bistatic or even SIMO radars. Especially MIMO capitalizes several diversity parameters inherent to its design to give higher resolution in both range and range rate. Several papers address these diversities. The current work aims at parameterizing these diversities especially spatial, waveform and frequency diversities and hence designing a system which employees a the resultant diversity constraints on the transmitter architecture and on the type and properties of transmit signals. As done in conventional system analysis, here also the formulation of ambiguity function is addressed and in the process a new tool called ambiguity function pair is developed. It has been shown with example evaluations that

this ambiguity function pair is more mature in analyzing and tracking targets with systems employing diversity constraints. In the process of evaluation a new strategy with adaptive framework for tracking targets and getting higher range resolution and is addressed.

[359] Yao Yu, A.P. Petropulu, and H.V. Poor. Mimo radar based on reduced complexity compressive sampling. In *Radio and Wireless Symposium (RWS), 2010 IEEE*, pages 21 –24, jan. 2010.

Abstract: In their previous work, the authors considered a multiple-input multiple-output (MIMO) radar implemented by a set of randomly dispersed nodes within a small scale network. Exploiting the sparseness of targets in the angle-Doppler space, compressive sampling was exploited for obtaining joint angle-Doppler information on potential targets based on a small number of observations. That approach achieves the superior resolution of MIMO radar with far fewer samples than required by conventional approaches. However, it involves a discretization of the angle-Doppler space, and as the discretization step decreases in order to achieve high resolution, complexity increases. In this paper, a scheme to reduce the complexity of the aforementioned approach for the case of slowly moving targets is considered. The complexity reduction is achieved by decoupling angle and Doppler estimation. An approach is also proposed for identifying angle estimates that correspond to jammers.

[360] C. Du, J. Thompson, B. Mulgrew, and Y. Petillot. Detection performance of mimo radar with realistic target models. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –5, oct. 2009.

Abstract: We simulate a multiple-input multiple-output (MIMO) radar system involving a realistic target, which is a life-size land vehicle modeled using a EM simulator FEKO. Numerical results showing the detection performance of a MIMO radar are provided, which is measured based on multiple realizations of the channel matrix generated using the available FEKO data. The results validate in a practical setting the improvements in detection performance available from MIMO radar configurations.

[361] G.J. Frazer, Y.I. Abramovich, and B.A. Johnson. Mimo based spatial calibration of othr transmit arrays. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –5, oct. 2009.

Abstract: Spatial calibration of OTHR transmitting and receiving arrays is an important issue when implementing this class of radar. In the paper we demonstrate how MIMO radar techniques can be applied to the calibration of an OTHR transmit array. We provide experimental results to validate our approach.

[362] D. Pastina, M. Bucciarelli, and P. Lombardo. Multi-platform distributed isar for surveillance and recognition. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –6, oct. 2009.

Abstract: In this paper we exploit the data acquired by multiple radar systems carried by multiple air platforms to increase the cross-range resolution of ISAR images. The distributed ISAR technique is devised for two different cases: (i) multistatic with a single platform carrying an active radar and the remaining platforms equipped with receiving only devices, (ii) MIMO with

each platform carrying an active radar. The processing chain needed by the distributed ISAR is shown with the results obtained against simulated ISAR data for both multistatic and MIMO cases; the performance analysis shows that the proposed technique is able to provide an increase of the cross-range resolution up to the number of radar systems in the multistatic case or even higher in the MIMO case, if the platforms are properly located. The performance degradation arising from errors in the knowledge of both the target rotation motion and the acquisition geometry is also analyzed. Results obtained by processing the experimental data collected by a ground based radar operating together with a rotating platform are shown to validate the proposed approach.

[363] Guisheng Liao, Ming Jin, and Jun Li. A two-step approach to construct minimum redundancy mimo radars. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –4, oct. 2009.

Abstract: A two-step approach is developed for constructing minimum redundancy (MR) multiple-input multiple-output (MIMO) radars. The minimum total number of transmitting and receiving antenna elements is determined for given virtual aperture in the first step. In the second step, the virtual aperture is expanded by adjusting the number between the transmitting and receiving antennas, and by changing the spacings between the elements. Simulation results showing the performance improvement of the MR MIMO radars is presented.

[364] S. Searle and S. Howard. Waveform design and processing for multichannel mimo radar. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –6, oct. 2009.

Abstract: In MIMO radar several transmitters broadcast independent waveforms which must be separated at the receivers. Typically waveforms having low auto- and cross-correlation values are used. This study proposes the transmission of several waveforms across multiple independent channels by each transmitter. Waveform sets formed from mutually-orthogonal complementary codes are shown to provide perfect resolution of returns with no cross-transmitter interference when separated in time. Square-complementary waveforms separated in frequency and subject to nonlinear processing can also resolve targets but introduce cross terms instead of correlation sidelobes. Cross terms are mitigated with frequency agility and pulse-Doppler processing.

[365] C. Du, J.S. Thompson, and Y.R. Petillot. Detection and direction finding performance of hybrid bistatic radar. In *Radar Conference - Surveillance for a Safer World, 2009. RADAR. International*, pages 1 –6, oct. 2009.

Abstract: The conventional phased-array radar provides coherent processing gain while the MIMO radar exploits spatial diversity gain to improve the system performance. We investigate a hybrid bistatic radar combining these two configurations to take advantage of both gains. The probability of detection of the hybrid system is derived, and the CRB and the MSE of the maximum likelihood estimation for both angle of departure and angle of arrival are evaluated to assess the direction finding performance.

[366] A.A. Gorji, R. Tharmarasa, and T. Kirubarajan. Tracking multiple unresolved targets using mimo radars. In *Aerospace Conference, 2010 IEEE*, pages 1 –14, march 2010.

Abstract: Multiple Input Multiple Output (MIMO) radars are a new generation of radar systems that may bring about many benefits compared to traditional phased-array and multistatic radars. Although different aspects of MIMO radars have been discussed in the literature, the application of MIMO radars in target tracking problems has not been explored in depth. Target localization using MIMO radars with co-located antennas has been discussed in the literature. The main limitation of those approaches is that the number of targets that can be uniquely localized in one cell is restricted. This paper presents a new application of MIMO radars in Multi-Target Tracking (MTT) problems. The main contribution is to show that the use of prior information about the motion of targets relaxes the limitation on the number of targets that can be uniquely detected. A general MTT problem with several targets in the same resolution cell is considered. The goal is to propose a technique to estimate targets' states and the number of targets in one cell. Because multiple targets may fall in the same cell, the measurement in a cell is associated with more than one target. Measurements are outputs of matched filters and range bins that are nonlinear functions of targets' states. Multiple hypotheses are generated based on the uncertainty in target-to-cell association. Then, the best model which gives the number of new targets whose estimates are obtained by the localization algorithm, is selected according to its likelihood . Finally, due to the nonlinearity in measurement model, a UKF based method is used to update estimates of new targets and initialize new born targets. Simulation results show the superiority of the proposed method for joint localization and tracking compared to the previous localization approach suggested in the literature for unresolved targets.

[367] B.K. Habtemariam, R. Tharmarasa, and T. Kirubarajan. Multitarget track before detect with mimo radars. In *Aerospace Conference, 2010 IEEE*, pages 1 –9, march 2010.

Abstract: Recent advances in Multiple-Input-Multiple-Output (MIMO) radar systems show that they have the potential to improve detection and localization performance of targets over bistatic and multistatic radars. Unlike beam forming, which presumes a high correlation between signals either transmitted or received by an array, the MIMO system exploits the independence between signals at the array elements due to transmit diversity. Previous works focus on waveform design, signal processing and target localization with MIMO radars while no attention has been given to tracking algorithms. In this work, the problem of tracking multiple targets using MIMO radars is considered. The scenario includes multiple targets in a widely-separated MIMO architecture in which Radar-Cross-Section (RCS) diversity can be utilized. Multi target version of Track-Before-Detect (TBD) algorithm is implemented for the collected M ÃƒÂ— N orthogonal signals at the receiver, where M is the number of transmitters and N is the number of receivers. Besides having the advantage of integrating information over time on unthresholded measurements to yield detection and tracking simultaneously, the TBD technique enables tracking and detecting targets in low Signal-to-Noise-Ratio (SNR) environments. Also, a modified multiple sensor TBD, which weights the target observability to the sensor as a result of target RCS diversity in the likelihood calculation to best fit the centralized MIMO tracking is proposed. Finally, Monte Carlo simulations are performed to evaluate the performance of the proposed tracking algorithm.

[368] Zeng Jiankui, Xiang Lijuan, Dong Ziming, and Yuan Shangzhun. A novel signal processing method for mimo radar based on channel estimation. In *Computer and Automation Engineering (ICCAE), 2010 The 2nd International Conference on*, volume 3, pages 413 –415, feb. 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar is a new radar technique. It has many advantages over conventional phased radar in many ways such as anti-intercept of radar signal, low velocity target detection, and resolution. The signal transmit matrix of MIMO radar has much information such as target angle. In this paper, we analyze the signal model for MIMO radar. And then we present a new method to estimate the target angle from the matrix. At last, we show the efficiency by some simulations.

[369] S. Middleton, A. Van Wyk, P. Jardin, F. Nadal, and J. Cilliers. A wideband beamformer extended to mimo radar. In *Measuring Technology and Mechatronics Automation (ICMTMA), 2010 International Conference on*, volume 1, pages 381 –385, march 2010.

Abstract: MIMO radar algorithms are the latest generation of techniques which can be applied to phased array radars. They offer the potential to improve the resolution, number of targets that can be identified, and Ã‚Â¿exibility in beam pattern design. To date, most of the work on MIMO radar has been performed assuming the signals are narrowband. However, wideband signals can also improve radar resolution, among other benefits, and are sometimes unavoidable when stringent range resolution specifica-tions must be met. This paper presents a method for extending the MIMO narrowband model to a wideband model. This is necessary to obtain improved results from parameter estimation when the transmitted signals are wideband. The results show that the method greatly improves the results compared to those obtained when no techniques are implemented to compensate for a wideband signal. However, best performance is still obtained with a narrowband signal, and therefore the technique presented might only be of interest when a wideband signal is required.

[370] Yao Yu, A.P. Petropulu, and H.V. Poor. Range estimation for mimo step-frequency radar with compressive sensing. In *Communications, Control and Signal Processing (ISCCSP), 2010 4th International Symposium on*, pages 1 –5, march 2010.

Abstract: The authors recently proposed a parameter estimation technique for multiple-input/multiple-output (MIMO) radar systems that employ compressive sensing (CS), and which applies to the case of slowly moving targets. This technique is based on the use of a step-frequency technique, and it allows angle, Doppler and range information to be estimated in a decoupled fashion. This decoupling significantly reduces the complexity of parameter estimation without a concurrent performance loss. The current paper considers the range-estimation performance of this method for the particular cases of linear and random step-frequency techniques. It is shown that the linear step-frequency technique requires less bandwidth than the random step-frequency technique in order to achieve the same performance.

[371] G.H. Jajamovich, M. Lops, and Xiaodong Wang. Transmit policies for mimo radar detection and time-delay estimation. In *Communications, Control and Signal Processing (ISCCSP), 2010 4th International Symposium on*, pages 1 –4, march 2010.

Abstract: This paper is aimed at investigating the role of Space-Time Coding (STC) for target detection and time-delay estimation through MIMO radars with widely spaced antennas. To this end we formulate the waveform optimization problem as a constrained maximization of some detection-oriented figures of merit under an accuracy constraint. Interestingly, such an additional constraint deeply modifies the optimal transmit policy. We also offer closed-form formulas of the Fisher Information in target delay estimation as a function of the singular values of the code matrix. Numerical results validating the theoretical findings are also given.

[372] H. Godrich and A.M. Haimovich. Localization performance of coherent mimo radar systems subject to phase synchronization errors. In *Communications, Control and Signal Processing (ISCCSP), 2010 4th International Symposium on*, pages 1 –5, march 2010.

Abstract: Localization advantages of coherent Multiple-Input Multiple-Output (MIMO) radar systems are reliant on full phase synchronization among all participating radars. Phase synchronization errors are practically inevitable, reflecting on the system localization performance. In this paper quantitative tools to asses this effect are provided. The lower bound on the mean-square error (MSE) is set by the hybrid Cramer-Rao bound (HCRB) for the joint estimation of the target location and the phase synchronization offsets at the radars. The latter are modeled as random unknown. The HCRB of the unknown target location is shown to be equal to the CRB derived by discarding the random phase synchronization errors through marginalization, i.e., treating them as nuisance parameters. Therefore, the HCRB closed-form expression provides an asymptotically tight bound on target location estimation MSE at high signal-to-noise ratio (SNR). The bound is shown to follow the CRB in the absence of phase errors up to a threshold point, determined by the synchronization error variance, the SNR, and the number of mismatched transmitting and receiving sensors. Beyond this point, the HCRB asymptotically reaches a lower limit, proportional to the synchronization errors variance and independent of the SNR. The value of the threshold point and lower limit are determined for symmetrical radar deployments.

[373] Qian He and R.S. Blum. Diversity gain for mimo radar employing nonorthogonal waveforms. In *Communications, Control and Signal Processing (ISCCSP), 2010 4th International Symposium on*, pages 1 –6, march 2010.

Abstract: Initially we formulate a very general hypothesis testing problem where we attempt to distinguish between zero-mean Gaussian clutter-plus-noise only and returns which are a linear transformed version of a zero-mean Gaussian random vector plus this clutter-plus-noise. We show that the diversity gain of the optimum processing for this hypothesis testing problem must be less than or equal to the rank of the linear transform. Next we apply this result to study diversity gain for optimum MIMO radar processors for cases with M transmit antennas, N receive antennas, and a target composed of Q scatterers. If the transmitted waveforms span a lower dimension M' than M, then the largest possible diversity gain is no greater than min(NM', Q). We also show a diversity gain of min(NM', Q) can be achieved under certain conditions. For a general correlated Gaussian clutter-plus-noise model and a general correlated Gaussian reflection coefficient vector, the diversity gain for noncoherent and coherent processing is discussed.

Extensions of all results to cases with nonGaussian reflections and clutter-plus-noise are discussed.

[374] T. Aittomaki and V. Koivunen. Mimo radar target detection with parametric scattering correlation model. In *Communications, Control and Signal Processing (ISCCSP), 2010 4th International Symposium on*, pages 1 –5, march 2010.

Abstract: Multiple-input multiple-output (MIMO) radars utilize various sources of diversity to improve the performance of the radar. A MIMO radar in which angular diversity is achieved by using widely distributed antennas has been proposed to reduce the impact of the fluctuations of the target radar cross-section. This type of system is also known as the statistical MIMO radar. Typically, it has been assumed that the signals received by different antennas are either fully correlated or independent depending on the configuration. In this paper, we assume more realistically that the scattering from the target is correlated. We show that taking the correlation of the scattered signals into account can improve the probability of detecting the target. This is achieved by using a parametric model for the scattering which allows one to efficiently estimate the scattering covariance matrix. The numerical examples demonstrate that the probability of detection remains good even when parameters of the model are inaccurate.

[375] Xun Chen and R. Blum. Non-coherent mimo radar in a non-gaussian noise-plus-clutter environment. In *Information Sciences and Systems (CISS), 2010 44th Annual Conference on*, pages 1 –6, march 2010.

Abstract: The initial papers on MIMO radar have triggered a tremendous amount of research work recently. How the MIMO radar detector, previously designed for Gaussian noise, performs when the noise-plus-clutter is non-Gaussian is still unknown. In this paper, we evaluate the detection performance of the Gaussian detector under the non-Gaussian noise-plus-clutter in a non-coherent MIMO radar system. Using the theory of Spherically Invariant Random Vectors (SIRVs), we study three non-Gaussian noise-plus-clutter models employing the K, Laplace, and Student-T distributions, respectively. Simulations are carried out for different numbers of antennas, SNRs and false alarm probabilities. The results show that non-Gaussian noise-plus-clutter has no impact on the diversity gain of a MIMO radar system although it degrades the detection performance in some other ways. We also verify some known results on the optimality of the Gaussian detector for SIRV noise-plus-clutter models, while showing this is not true for non-SIRV models.

[376] Chuanming Wei, Qian He, and R.S. Blum. Cramer-rao bound for joint location and velocity estimation in multi-target non-coherent mimo radars. In *Information Sciences and Systems (CISS), 2010 44th Annual Conference on*, pages 1 –6, march 2010.

Abstract: In this paper, we focus on a performance bound for joint location and velocity estimation in non-coherent MIMO radars with multiple targets, which has not been studied before. Closed-form expressions for the Cramer-Rao bound are provided for a two-target case. We use numerical simulations to validate the Cramer-Rao bounds and use these bounds to study the performance of a non-coherent MIMO radar system. We analyze the influence of the distance between two targets on the estimation performance. Simulation results reveal that the spatial advantage, which was uncovered previously for a single-target case, also applies for two targets.

[377] R.S. Blum. Ordering for estimation. In *Information Sciences and Systems (CISS), 2010 44th Annual Conference on*, pages 1 –6, march 2010.

Abstract: A discretetized version of a continuous optimization problem is considered for the case where data is obtained from a set of dispersed sensor nodes and the overall metric is a sum of individual metrics computed at each sensor. An example of such a problem is maximum likelihood estimation based on statistically independent sensor observations. By ordering transmissions from the sensor nodes, a method for achieving a saving in the average number of sensor transmissions is described. While the average number of sensor transmissions is reduced, the approach always yields the same solution as the optimum approach where all sensors transmit. The approach is described first for a general optimization problem. A maximum likelihood target location and velocity estimation example for a multiple node non-coherent MIMO radar system is later described. In particular, for cases with near ideal signals, sufficiently small surveillance region and sufficiently large signal-to-interference-plus-noise ratio, the average percentage of transmissions saved approaches 100 percent as the number of discrete grid points in the optimization problem Q becomes significantly large. In these same cases, the average percentage of transmissions saved approaches (Q - 1)/Q Ã*f*Â— 100 percent as the number of sensors N in the network becomes significantly large. Similar savings are illustrated for general optimization (or estimation) problems with well designed systems.

[378] T. Strohmer and B. Friedlander. Compressed sensing for mimo radar - algorithms and performance. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 464 –468, nov. 2009.

Abstract: Compressed sensing techniques make it possible to exploit the sparseness of radar scenes to potentially improve system performance. In this paper compressed sensing tools are applied to MIMO radar to reconstruct the scene in the azimuth-range-Doppler domain. Conditions are derived for the radar waveforms and the transmit and receive arrays so that the radar sensing matrix has small coherence and sparse recovery becomes possible. Theoretical performance bounds are presented and validated by numerical simulations.

[379] M. Zatman. Multi-face radar processing: A new application of mimo radar. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 477 –481, nov. 2009.

Abstract: Radar systems that utilize multiple phased arrays to obtain 360Ã‚Â° coverage suffer from reduced sensitivity off-boresite from the phased array faces (aka Ã‚Â¿scan lossÃ‚Â¿). Multiface radar processing is a MIMO radar technique that takes advantage of the overlapping coverage from adjacent phased array faces to provide up to 5 dB more sensitivity, compensating for the scan loss that would otherwise be incurred.

[380] Rui Fa, R.C. de Lamare, and P. Clarke. Reduced-rank stap for mimo radar based on joint iterative optimization of knowledge-aided adaptive filters. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 496 –500, nov. 2009.

Abstract: MIMO radar has received significant attention in the past five years. In this paper, we focus on the advantage of MIMO radars in achieving better spatial resolution by employing the

colocated antennas and propose a reduced-rank knowledge-aided technique for MIMO radar space-time adaptive processing (STAP) design. The scheme is based on joint iterative optimization of knowledge-aided adaptive filters (JIOKAF) and takes advantage of the prior environmental knowledge by employing linear constraint techniques. A recursive least squares (RLS) implementation is derived to reduce the computational complexity. We evaluate the algorithm in terms of signal-to-interference-plus-noise ratio (SINR) and probability of detection PD performance, in comparison with the state-of-the-art reduced-rank algorithms. Simulations show that the proposed algorithm outperforms existing reduced-rank algorithms.

[381] Qian He and R.S. Blum. Performance and complexity issues in noncoherent and coherent mimo radar. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1206 –1210, nov. 2009.

Abstract: Joint target position and velocity estimation is considered when a MIMO radar system employs either coherent or noncoherent processing and a suitable antenna placement for the processing employed. A theorem is presented for the case of orthogonal signals in temporally and spatially white noise-plus-clutter which shows that the MSE for the estimate of the noncoherent system approaches that of the coherent system as the product of the number of transmit and receive antennas is made sufficiently large. Numerical examples are also provided. Initially, we study systems without constraining the complexity and energy, where each added transmit antenna employs a fixed energy so that the total transmitted energy is allowed to increase as we increase the number of transmit antennas. Later we also look at constrained systems, where adding a transmit antenna splits the total system energy and the total number of antennas employed is restricted.

[382] Yang Yang, R.S. Blum, Zishu He, and D.R. Fuhrmann. Waveform design for mimo radar using an alternating projection approach. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1201 –1205, nov. 2009.

Abstract: Revisiting an earlier examined multiple-input multiple-output (MIMO) radar waveform design problem which optimizes both minimum mean-square error estimation (MMSE) and mutual information (MI), we formulate a new waveform design problem and provide some further results in this paper, which complements the previous study. More specifically, we present an iterative optimization algorithm based on the alternating projection method, to determine waveform solutions that can simultaneously satisfy a structure constraint and optimize the design criteria. Numerical examples are provided, which illustrate the effectiveness of the proposed approach. In particular, we find that the waveform solutions obtained through our proposed algorithm can achieve very close and virtually indistinguishable performance from that predicted in the previous study.

[383] Yao Yu, A.P. Petropulu, and H.V. Poor. Reduced complexity angle-doppler-range estimation for mimo radar that employs compressive sensing. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1196 –1200, nov. 2009.

Abstract: The authors recently proposed a MIMO radar system that is implemented by a small wireless network. By applying compressive sensing (CS) at the receive nodes, the MIMO radar

super-resolution can be achieved with far fewer observations than conventional approaches. This previous work considered the estimation of direction of arrival and Doppler. Since the targets are sparse in the angle-velocity space, target information can be extracted by solving an Ã‚Â¿1 minimization problem. In this paper, the range information is exploited by introducing step frequency to MIMO radar with CS. The proposed approach is able to achieve high range resolution and also improve the ambiguous velocity. However, joint angle-Doppler-range estimation requires discretization of the angle-Doppler-range space which causes a sharp rise in the computational burden of the Ã‚Â¿1 minimization problem. To maintain an acceptable complexity, a technique is proposed to successively estimate angle, Doppler and range in a decoupled fashion. The proposed approach can significantly reduce the complexity without sacrificing performance.

[384] T. Aittomaki and V. Koivunen. Exploiting correlation in target detection using mimo radar with angular diversity. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1191 –1195, nov. 2009.

Abstract: Multiple-input multiple-output (MIMO) radars utilize multiple waveforms simultaneously to improve performance. A MIMO radar in which angular diversity is achieved by using widely distributed antennas has been proposed before. This type of system is also known as the statistical MIMO radar. Typically, it has been assumed that the signals received by different antennas are either fully correlated or independent depending on the configuration. We make a more realistic assumption of partially correlated scattering from the target. In this paper, we show that taking the correlation of the scattered signals into account can improve the probability of detecting the target. It is shown that the scattering statistics do not need to be known, but can be estimated reliably from the received signal if a certain type of scattering model is assumed. In this paper, the GLRT using the maximum likelihood estimates of the unknown parameters is proposed for target detection.

[385] H. Godrich, A.M. Haimovich, and R.S. Blum. A mimo radar system approach to target tracking. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1186 –1190, nov. 2009.

Abstract: In this paper, tracking performance of MIMO radar systems with distributed antennas and non-coherent processing is studied. The Bayesian Cramer-Rao bound (BCRB) on target location and velocity tracking is derived and the effect of the radars geometric layout and the target location on tracking accuracies is analyzed. The impact of the number of radars on the estimation errors is examined and the contribution of the target reflectivity and path loss to tracking performance is evaluated.

[386] Ruixin Niu, R.S. Blum, P.K. Varshney, and A.L. Drozd. Target tracking in widely separated non-coherent multiple-input multiple-output radar systems. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1181 –1185, nov. 2009.

Abstract: In a widely separated multiple-input multiple-out (MIMO) radar system with non-coherent receivers, the maximum likelihood estimator (MLE) of target location and the corresponding CRLB matrix are derived. Further, two interactive signal processing and tracking algorithms are developed based on the Kalman filter and the particle filter respectively. For a

system with a small number of elements and a low SNR value, the particle filter outperforms the KF significantly. In both methods, the tracker provides predictive information regarding the target location, so that the matched filter can match to the most probable target locations, reducing the cost and improving the tracking performance. It is shown that the non-coherent MIMO radar provides a significant performance improvement over a monostatic radar with high range and azimuth resolutions.

[387] A. Tajer, G.H. Jajamovich, Xiaodong Wang, and G.V. Moustakides. Finite-sample optimal joint target detection and parameter estimation by mimo radars. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1176 –1180, nov. 2009.

Abstract: We consider MIMO radar systems with widely-spaced antennas. We treat the problem of detecting extended targets when one or more target parameters of interest are unknown. We provide a composite hypothesis testing framework for jointly detecting the target along with such parameter estimation while only a finite number of signal samples are available. The test offered is optimal in a Neyman-Pearson-like sense such that it offers a Bayesian-optimal detection test, minimizes the average maximum likelihood parameter estimation error subject to an upper bound constraint on the false-alarm probability, and requires a finite number of samples. While the test can be applied for concurrently detecting the target along with estimating any unknown parameter of interest, we consider the problem of detecting a target which lies in an unknown space range and find the range through estimating the time delays that the emitted waveforms undergo from being illuminated to the target until being observed by the receive antennas. We also analyze the diversity gain which we define as the rate that the probability of mis-detecting a target decays with the increasing SNR for a controlled false-alarm and show that for a MIMO radar with Nt and Nr transmit and receive antennas, respectively, the diversity gain is Nt ÃƒÂ— Nr.

[388] Ming Xue, Duc Vu, Luzhou Xu, Jian Li, and P. Stoica. On mimo radar transmission schemes for ground moving target indication. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1171 –1175, nov. 2009.

Abstract: We compare several multiple-input multiple-output (MIMO) radar transmission schemes, including code division, time division and Doppler frequency division multiplexing approaches, for ground moving target indication (GMTI). To utilize probing waveforms with low sidelobe levels for range compression, we transmit sequences specifically designed to have low correlation levels. At the receiver side, we apply the iterative adaptive approach (IAA), which uses only the primary data, to form high resolution angle-Doppler images. To mimic real world scenarios, we apply our algorithms to a simulated dataset which contains high-fidelity, site-specific, simulated ground clutter returns. By combining the usage of intelligent transmission schemes, probing waveforms with good correlation properties, and the adaptive angle-Doppler imaging approach, we show that slow moving targets can be more clearly separated from the clutter ridge in the angle-Doppler images and potentially more easily detected by MIMO radar than by its conventional single-input multiple-output (SIMO) counterpart.

[389] S. Gogineni and A. Nehorai. Polarimetric mimo radar with distributed antennas for target detection. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 1144 –1148, nov. 2009.

Abstract: Distributed antenna radar systems provide spatial diversity gain by viewing the target from different angles. Polarimetric radar offers improved performance over conventional radar systems by exploiting polarization diversity. We propose a radar system that offers both spatial and polarimetric diversity gains for detecting stationary point-like targets. The receive antennas of the proposed system use 2D vector sensors, each measuring the horizontal and vertical components of the received electric field separately. We design the Neyman-Pearson detector for this proposed system and analyze its performance. This analysis is used to select the optimal transmit polarizations for this system. Using simulations, we demonstrate the improvement offered by the optimal choice of polarizations. We also show the spatial diversity offered by MIMO radar.

[390] B. Manjunath, J.J. Zhang, A. Papandreou-Suppappola, and D. Morrell. Sensor scheduling with waveform design for dynamic target tracking using mimo radar. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 141 –145, nov. 2009.

Abstract: Multiple-input, multiple-output (MIMO) radar systems have gained significant attention as they can enhance target detection, identification and parameter estimation performance. In this paper, we consider the problem of optimizing the target tracking performance of a widely-separated MIMO radar system by scheduling the transmitter sensors and adaptively designing their waveforms. Specifically, for a tracking scenario consisting of a large number of MIMO radars, we propose: (a) a transmitter scheduling algorithm to achieve tracking performance gains based on resource constraints; and (b) an adaptive waveform optimization algorithm that further improves tracking performance. Under an ideal receiver assumption, we evaluate the predicted tracking mean-squared error using the derived CrameÃ‚Â¿r-Rao lower bound (CRLB) on the estimation of the target states. The scheduling algorithm is then formulated as a mixed boolean-convex optimization problem to minimize the CRLB. The optimum waveform parameters are adaptively obtained using sequential quadratic programming. The effectiveness of combining the MIMO radar technology with adaptive waveform design and sensor scheduling was demonstrated with simulations.

[391] G. Hickman and J.L. Krolik. Mimo field directionality estimation using orientation-diverse linear arrays. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 146 –150, nov. 2009.

Abstract: This paper addresses the estimation of power versus azimuth and elevation using a sparse sensor array. In MIMO radar, clutter and noise field directionality can be measured both from the transmit array and to the receive array. In applications where sparse arrays must be used, however, often substantial ambiguities in the field directionality map occur due to spatial under-sampling and/or sidelobe leakage. In this paper, we propose an alternative field-directionality mapping approach which incoherently combines the outputs of several uniform linear arrays with different orientations. The proposed orientation-diverse multi-line array (ODMA) treats the 1-D field directionality estimate from each line array as a projection of a 2-D spatial spectrum. Two methods for reconstruction from these projections are presented: 1) least-squares estimation

subject to a positivity constraint, and 2) maximum likelihood estimation using the EM algorithm. Simulation results suggest both methods achieve ODMA field directionality maps with improved ambiguity resolution and sidelobe performance versus conventional beamforming techniques.

[392] S. Sen and A. Nehorai. Ofdm mimo radar for low-grazing angle tracking. In *Signals, Systems and Computers, 2009 Conference Record of the Forty-Third Asilomar Conference on*, pages 125 –129, nov. 2009.

Abstract: We develop a low-grazing angle (LGA) tracking method considering realistic physical and statistical effects, such as earth's curvature, vertical refractivity gradient of standard lower atmosphere, and non-Gaussian characteristics of sea-clutter. We employ a co-located multiple-input-multiple-output (MIMO) radar configuration using wideband orthogonal frequency division multiplexing (OFDM) signalling scheme. Apart from the frequency diversity provided by OFDM, we also exploit polarization to resolve the multipath signals by using polarization-sensitive transceivers. Thus, we can track the scattering coefficients of the target at different frequencies along with its position and velocity. We apply a sequential Monte Carlo method (particle filter) to track the target. Our numerical examples demonstrate the achieved performance improvements due to realistic physical modeling and OFDM MIMO configuration.

[393] Yongshun Zhang, Yiduo Guo, Xinliang Niu, and Guoqing Zhao. Angle estimation of coherent multi-target for mimo bistatic radar. In *Image Analysis and Signal Processing (IASP), 2010 International Conference on*, pages 146 –149, april 2010.

Abstract: The angle estimation algorithm of coherent multi-target for MIMO bistatic radar is presented. In the algorithm, the virtual array data from multi-target in MIMO receiver is firstly decorrelated, then special matrix based on the ESPRIT method is constructed, finally the eigenvalues and the eigenvectors of the matrix are used to estimate direction of departures and direction of arrivals. In this algorithm, the parameters can be directly paired by the relationship between the eigenvalues and eigenvectors. The correctness and performance of the proposed method are verified by the computer simulation.

[394] L. Venturino, Ke Dong, Xiaodong Wang, and M. Lops. A stochastic-gradient method to design optimal space-time codes for mimo radar detection. In *Wireless Conference (EW), 2010 European*, pages 752 –757, april 2010.

Abstract: We consider a MIMO radar system with widely-spaced transmit/receive antennas and study the problem of designing the signal waveforms transmitted by each source node so as to maximize the detection probability for a fixed false alarm rate under correlated Gaussian clutter. The proposed design procedure relies on a stochastic-gradient search and is general enough to be applied to any statistical target model. Examples are provided to compare the performance of the proposed codes with other known coding schemes.

[395] Xiufeng Song, Shengli Zhou, and P. Willett. Waveform interference mitigation for a shared spectrum mimo radar system. In *Radar Conference, 2010 IEEE*, pages 1386 –1391, may 2010.

Abstract: MIMO radars may outperform conventional ones as regards target detection, parameter estimation and classification via spatial and waveform diversities. MIMO radar is a kind of shared

spectrum system: the mutual interference among the waveforms may lead to considerable performance degradation, especially with multiple targets. As a result, preserving MIMO radar performance under such conditions via waveform design becomes an interesting research topic. In this paper, we consider the marriage of space time coding (STC) and Golay complementary pairs to mitigate both waveform autocorrelation and cross-correlation effects, and hence to enhance range resolution. The implementation is discussed, and an application for instantaneous polarization is briefly introduced.

[396] J. Kantor and S.K. Davis. Airborne gmti using mimo techniques. In *Radar Conference, 2010 IEEE*, pages 1344 –1349, may 2010.

Abstract: The performance of a ground moving target indicator (GMTI) radar is strongly driven by the length of the radar aperture, as longer apertures enable lower minimum detectable velocity (MDV) and better target geolocation. Multiple-input multiple-output (MIMO) techniques can enable the use of long sparse array geometries while avoiding the adverse sidelobe effects typical of such arrays. In 2009 an experiment was conducted at Ft. Devens, MA to collect MIMO GMTI data on instrumented ground targets. A reconfigurable S-band antenna array was programmed to transmit both conventional single-input multiple-output (SIMO) and MIMO waveforms. Analysis of the data indicates improved detection performance with the MIMO techniques compared to the conventional SIMO approach.

[397] S.H.R. Brady and M.A. Saville. Scaling radar measurements for advanced algorithms. In *Radar Conference, 2010 IEEE*, pages 1161 –1166, may 2010.

Abstract: This paper describes waveform diverse signal measurements using a two channel laboratory radar system. Using a combination of a Lab-Volt; radar training system, Tektronix; arbitrary waveform generator (AWG), Tektronix; digital oscilloscope (DSO), and Tektronix; real-time spectrum analyzer (RSA), a two channel, waveform diverse, multiple-input, multiple-output (MIMO) system is configured to collect both MIMO and bistatic radar measurements. In the experiments, the radar operates at X-band and samples the echoes at radio frequency (RF) before down-conversion into in-phase and quadrature (I/Q) channels. The laboratory environment does not need any special treatment as an anechoic chamber because the system uses very short duration and low power waveforms. Measured data for the MIMO radar is presented along with discussion of the bistatic configuration.

[398] D.R. Fuhrmann and J. VanderLaan. Detection of complex point targets in a mimo radar system with distributed assets and partially correlated signals. In *Radar Conference, 2010 IEEE*, pages 1134 –1139, may 2010.

Abstract: A complex point target is a mathematical model for a radar target that is not resolved in space, but exhibits varying complex reflectivity across different bistatic view angles. The complex reflectivity can be modeled as a complex stochastic process whose index set is the set of all bistatic view angles, and the parameters of this stochastic process follow from an analysis of a target model comprising a number of ideal point scatterers randomly located within some radius of the targets center of mass. Six different models are summarized here, with different assumed distributions on the locations of the point scatterers within the target. We develop data models for the received signals from such targets in a MIMO radar systems with distributed assets and partially correlated signals, and consider the resulting detection problem. The problem reduces to

the familiar Gauss-Gauss detection problem with hypoexponential test statistic. A related problem of adapting the transmitted signals to the target model is discussed.

[399] D.R. Fuhrmann, J.P. Browning, and M. Rangaswamy. Advanced signaling strategies for the hybrid mimo phased-array radar. In *Radar Conference, 2010 IEEE*, pages 1128 –1133, may 2010.

Abstract: The Hybrid MIMO Phased Array Radar, or HMPAR, is a notional concept for a multisensor radar architecture that combines elements of traditional phased-array radar with the emerging technology of Multiple-Input Multiple Output (MIMO) radar. A HMPAR comprises a large number, MP, of T/R elements, organized into M subarrays of P elements each. Within each subarray, passive elementlevel phase shifting is used to steer transmit and receive beams in some desired fashion. Each of the M subarrays are in turn driven by independently amplified phase-coded signals. This paper proposes new transmit signal selection strategies based on the observation that some MIMO signal sets, such as those proposed by us previously, cause a very rapid sequential or raster scan across some field of view. Exploiting this property allows one to create and process multiple beams simultaneously. Furthermore, there exists a range-angle coupling in the transmit and receive signals that may lead to high-resolution target localization.

[400] H. Godrich, V.M. Chiriac, A.M. Haimovich, and R.S. Blum. Target tracking in mimo radar systems: Techniques and performance analysis. In *Radar Conference, 2010 IEEE*, pages 1111 –1116, may 2010.

Abstract: In this paper, moving target tracking performance in multiple input multiple output (MIMO) radar systems with distributed antennas and non-coherent processing is studied. Due to the use of multiple, widely distributed antennas, MIMO radar architectures support both centralized and decentralized tracking techniques. Each receiving radar may contribute to central processing by providing either raw data or partially/fully processed data. Estimation performance of centralized and decentralized tracking is analyzed through the Bayesian Cramer-Rao bound (BCRB). The BCRB offers insight into the effect of the radars geometric layout, the target location, and propagation path losses on tracking accuracies. It is shown that, with different propagation path loss, the manner in which decentralized estimations are combined in the fusion center effects the overall estimation performance. Two tracking algorithms are proposed, corresponding to respectively, a centralized and decentralized modes of operation. It is demonstrated that communication requirements and processing load may be reduced at a relatively low performance cost. Based on mission needs, the system may use either approach: centralized for high accuracy or decentralized for resource-aware tracking.

[401] D. Wilcox and M. Sellathurai. Resolution of two point targets using sub-arrayed mimo radar. In *Radar Conference, 2010 IEEE*, pages 999 –1004, may 2010.

Abstract: Recent works on MIMO radar have shown benefits in optimising the signal covariance matrix for estimation of target parameters, over the performance of conventional radar and the orthogonal waveform approach used in much of the MIMO radar literature to date. The full diversity approach requires a large amount of flexibility at the transmitter and computation prior to transmission. In this work, we study the performance of a sub-arrayed transmit beamforming approach for MIMO Radar, which greatly reduces the requirements of the transmitter, for the important case of resolving two point targets.

[402] R.J. Riddolls, M. Ravan, and R.S. Adve. Canadian hf over-the-horizon radar experiments using mimo techniques to control auroral clutter. In *Radar Conference, 2010 IEEE*, pages 718 –723, may 2010.

Abstract: High frequency Over-the-Horizon Radar (OTHR) provides an economical means to track noncooperative air targets over large expanses of land and ocean. However, early attempts to run OTHR in Canada in the 1970s were confounded by the presence of intense radar clutter originating in the auroral zone. Recent advances in Multiple-Input Multiple-Output (MIMO) OTHR technology, namely orthogonal waveform transmit arrays and fully sampled receive arrays, provide an opportunity to revisit the possibility of OTHR in Canada. An OTHR testbed has been built in Ottawa, Canada to determine the capabilities of the technology. The testbed consists of a MIMO OTHR with 4 transmit channels and 4 receive channels. Some preliminary data show that MIMO processing is effective in suppressing the clutter. It is then proposed to upgrade the testbed to a larger-scale system.

[403] V.M. Chiriac and A.M. Haimovich. Ziv; zakai lower bound on target localization estimation in mimo radar systems. In *Radar Conference, 2010 IEEE*, pages 678 –683, may 2010.

Abstract: This paper presents the derivation of the Ziv-Zakai bound (ZZB) for the localization problem in a MIMO radar system. The target is positioned in the near-field of a network of radars of arbitrary geometry. The radars have ideal mutual time and phase synchronization. The target location is estimated by coherent processing exploiting the amplitude and phase information between pairs of radars. An analytical expression is developed for the ZZB relating the estimation mean square error (MSE) to the carrier frequency, signal bandwidth, the number of sensors, and their location. From numerical calculations of the bound, three regions of signal-to-noise ratio (SNR) can be distinguished in the performance of the location estimator: a noise-dominated region, an ambiguity region, and an ambiguity free region. In the noise-dominated region, the signals received by the radars are too weak, and thus the localization error is limited only by the a priori information about the location of the target. In the ambiguity region, the performance of the location estimator is affected by sidelobes. In the ambiguity free region, estimation errors are very small and the ZZB approaches the Cramer-Rao lower bound (CRLB).

[404] A. Srinivas, S. Badrinath, and V.U. Reddy. Frequency-hopping code optimization for mimo radar using the hit-matrix formalism. In *Radar Conference, 2010 IEEE*, pages 631 – 636, may 2010.

Abstract: There has been a recent interest in the application of multiple-input multiple-output (MIMO) communication concepts to radars. While traditional phased-array radars transmit coherent waveforms from their many antenna elements, MIMO radars transmit incoherent waveforms from their transmitters, which offer additional benefits like spatial diversity and spatial resolution. In recent literature, the optimization of orthogonal frequency-hopping waveforms for MIMO radars has been discussed. This optimization is done using a ‘cost function’ derived from a newly formulated MIMO radar ambiguity function. In our paper, we extend the scope of this ambiguity function to large values of target Doppler. We also propose the use of the ‘hitmatrix’ as a tool to optimize frequency-hopping codes under the large Doppler scenario, since it results in a cost function with a significantly lower computational complexity.

The hit-matrix is a generalization of the hit-array, which has been used in the context of frequency-hopping waveforms for phased-array radars.

[405] Ming Xue, W. Roberts, Jian Li, Xing Tan, and P. Stoica. Mimo radar sparse angle-doppler imaging for ground moving target indication. In *Radar Conference, 2010 IEEE*, pages 553 –558, may 2010.

Abstract: We present in this paper a regularized sparse signal recovery algorithm, referred to as sparse learning via iterative minimization (SLIM), to provide ground moving target indication (GMTI) through multiple-input multiple-output (MIMO) radar angle-Doppler imaging. A slow-time modulation scheme with code division multiplexing is employed to achieve transmit diversity. In this way, we avoid the high correlation properties of orthogonal waveforms and the Doppler ambiguity that is encountered with Doppler division multiplexing schemes. After removing jammer and clutter effects using semi-unitary projections, we show that SLIM, using primary data only, is able to form sparse angle-Doppler images and to provide for accurate target localization.

[406] R. Sharma. Analysis of mimo radar ambiguity functions and implications on clear region. In *Radar Conference, 2010 IEEE*, pages 544 –548, may 2010.

Abstract: Multiple input multiple output (MIMO) radar offers the potential for improved performance over more traditional single input multiple output (SIMO) radar. MIMO radar operates by transmitting separable waveforms from multiple transmitters and the resulting radar echos are received by multiple receivers. While there is a great deal of literature discussing the benefits of MIMO techniques, a handful of publications discussing the limitations of MIMO radar techniques have appeared in the literature. Of particular interest is the work addressing the reduction of the clear area in range-Doppler space. Using a particular form of the MIMO ambiguity function, it was shown for a MIMO radar transmitting N waveforms there is a reduction of the clear area by a factor of 1/N. In this paper, we repeat this analysis for the ambiguity function applicable to a coherent MIMO radar. We show the MIMO ambiguity function proposed in does not fully capture some important features of coherent MIMO radar and differs from versions of the ambiguity function proposed by other authors. In the second half of this paper, we derive the MIMO ambiguity function for coded pulse train waveforms. In addition to the traditional narrowband assumption, we develop the MIMIO ambiguity function using the start-and-hop radar signal model.

[407] P.F. Sammartino, C.J. Baker, and H.D. Griffiths. Range-angle dependent waveform. In *Radar Conference, 2010 IEEE*, pages 511 –515, may 2010.

Abstract: In this paper the concepts of the Frequency Diverse Array and the Waveform-Diversity MIMO radar systems are combined. When the elements of an Electronically Steered Array transmit a number of pseudo-noise codes at slightly different carrier frequencies simultaneously, the coherent summation of the codes originates a waveform whose shape changes in both angle and range. In fact, the MIMO technique provides the angle-changing characteristic, whilst the FDA technique contributes to a range-changing propagating waveform. Therefore, this technique allows to associate a waveform to each point of the range/angle of the space, with the possibility of recovering this information at the receiver after appropriate processing.

[408] S. Ahmed, J.S. Thompson, B. Mulgrew, and Y. Petillot. Fast computations of constant envelope waveforms for mimo radar transmit beampattern. In *Radar Conference, 2010 IEEE*, pages 458 –463, may 2010.

Abstract: Designing transmit beampattern with MIMO radars generally requires the waveforms to be able to have arbitrary cross-correlation values. In contrast to the available algorithms, the proposed technique provides a closed-form solution for the synthesis of covariance matrix, R, of the waveforms to obtain desired beampattern match. To synthesis R the constraints and redundant information in R are leveraged, which convert the constrained problem into un-constrained problem. Next a novel method for generating the constant-envelope (CE) waveforms to realise the synthesised covariance matrix, R, is proposed. This method also yields a closed-form solution and choose the symbols from the binary-phase shift-keying (BPSK). Here, Gaussian random-variables (RV's) are mapped onto the CE RV's by a memoryless non-linear transformation, which converts the problem of finding the non-Gaussian RV's to realise a given covariance matrix R into finding the Gaussian RV's to realise covariance matrix Rg. Simulation results are presented to demonstrate the effectiveness of both methodologies.

[409] Jia Xu, Xi-Zeng Dai, Xiang-Gen Xia, Li-Bao Wang, Ji Yu, and Ying-Ning Peng. Optimal transmitting diversity degree-of-freedom for statistical mimo radar. In *Radar Conference, 2010 IEEE*, pages 437 –440, may 2010.

Abstract: Statistical multiple-input multiple-output (MIMO) radar may improve the fluctuated target detection by utilizing the multiple separate transmitting and receiving elements. Nevertheless, the transmitting power of single element is reciprocal to the transmitting element number, and the ultimate detection performance of MIMO radar may be inversely deteriorated with the increase of the transmitting elements. In this letter, the optimal transmitting diversity DOF, i.e., the optimal separate transmitting elements, is defined based on the proposed likelihood ratio test (LRT) detectors. Furthermore, with the given false alarm probability and detection probability, the closed-form optimal DOF approximations are derived for the two sub-forms of statistical MIMO radar, i.e., distributed MIMO radar and multiple-input single-output (MISO) radar, respectively. It is shown that a small transmitting diversity DOF, as well as the small number of orthogonal transmitting waveforms, may be needed for optimizing the statistical MIMO radar spatial diversity performance. Finally, numerical experiments are also provided to demonstrate the effectiveness of the proposed methods.

[410] Guolong Cui, Lingjiang Kong, Xiaobo Yang, and Jianyu Yang. Two-step glrt design of mimo radar in compound-gaussian clutter. In *Radar Conference, 2010 IEEE*, pages 343 –347, may 2010.

Abstract: This paper mainly deals with the target detecting problem using a MIMO radar against compound-Gaussian clutter with an unknown covariance matrix. The space-time coding MIMO radar model has adopted, and developed to compound-Gaussian case. The detector based on generalized likelihood ratio test (GLRT) criterion is studied, and two-step design procedure is adopted. Specifically, the GLRT is derived by assuming known covariance matrix, and then, a suitable estimate based on secondary data is inserted into the derived detector to make fully adaptive. Some numerical results are given, showing that the derived GLRT can provide a good performance in spikier clutter and the adaptive loss is acceptable.

[411] V.S. Chernyak. On the concept of mimo radar. In *Radar Conference, 2010 IEEE*, pages 327 –332, may 2010.

Abstract: Two classes of MIMO radars are briefly considered. MIMO radars with colocated antennas and coded signals represent a new and prospective concept. MIMO Radars with widely separated antennas (Statistical MIMO radars) are a particular case of well-known Multisite (Multistatic) radar systems. Most results presented by the authors of Statistical MIMO radars were obtained under much more general conditions and published many years ago. Besides, ignoring some specific features of radar has led to serious errors.

[412] C.M. Teixeira. Performance bounds on mimo radar with optimized coded constant modulus waveforms. In *Radar Conference, 2010 IEEE*, pages 304 –309, may 2010.

Abstract: A multiple-input, multiple-output (MIMO) radar system uses multiple, spatially diverse transmitters and receivers with separable, independent waveforms with the goal of enhancing resolution and, thus, improving performance. Key to the achievement of these performance benefits is the degree to which the transmitted waveforms may be separated on receive, e.g. the correlation properties amongst the waveforms. A previously defined correlation metric useful for designing good waveforms is simplified and its global minimum prescribed for M coded constant modulus waveforms each consisting of N chips and shown to be equal to M-1 (independent of the number of chips). The theory is validated using random phase waveforms as well as optimized waveforms using a previously defined iterative procedure, which is shown to effectively achieve the derived minimum bound. An important consequence of this large level of correlation residue for an optimal waveform set when used to perform a ground moving target indicator (GMTI) function in an airborne radar observing distributed clutter is that the rank of the resulting MIMO interference covariance is increased beyond that of an idealized orthogonal waveform set leading to significant degradation in the clutter mitigation performance, as shown through simulation. An approach to mitigating this effect through the use of partially optimized waveforms tailored to the scenario of interest is demonstrated to achieve the performance of an idealized orthogonal waveform set.

[413] M. Akcakaya and A. Nehorai. Mimo radar detection and adaptive design in compound-gaussian clutter. In *Radar Conference, 2010 IEEE*, pages 236 –241, may 2010.

Abstract: Multiple-input multiple-output (MIMO) radars with widely separated transmitters and receivers are useful to discriminate a target from clutter using the spatial diversity of the scatterers in the illuminated scene. We consider the detection of targets in compound-Gaussian clutter. Compound-Gaussian clutter describes heavy-tailed distributions fitting high-resolution and/or low-grazing-angle radars in the presence of sea or foliage clutter. First, we introduce a data model using the inverse gamma distribution to represent the clutter texture. Then, we apply the parameter-expanded expectation-maximization (PX-EM) algorithm to estimate the clutter texture and speckle as well as the target parameters. We develop a statistical decision test using these estimates and approximate its statistical characteristics. Based on the approximation of the statistical characteristics of this test, we propose an algorithm to adaptively distribute the total transmitted energy among the transmitters. We demonstrate the advantages of MIMO and adaptive energy allocation using Monte Carlo simulations.

[414] S. Gogineni and A. Nehorai. Target tracking using monopulse mimo radar with distributed antennas. In *Radar Conference, 2010 IEEE*, pages 194 –199, may 2010.

Abstract: We propose a Multiple Input Multiple Output (MIMO) radar system with distributed antennas that employs monopulse processing at the receivers. We also propose an algorithm to track a moving target using this system. This algorithm is simple and practical to implement. It efficiently combines the information present in the local estimates of the receivers. Since most modern tracking radars already use monopulse processing at the receiver, the proposed system does not need much additional hardware. Using numerical simulations, we demonstrate the advantages of the proposed system over conventional single antenna monopulse radar. We also show that the proposed algorithm keeps track of rapidly maneuvering airborne and ground targets.

[415] R. Sharma. Application of mimo to ifsar. In *Radar Conference, 2010 IEEE*, pages 81 – 84, may 2010.

Abstract: Synthetic Aperture Radar (SAR) provides all day, all weather and long stand off range capability of imaging large areas of the Earth. Single pass Interferometric SAR (IFSAR) using a pair of vertically displaced phase centers can be effectively used to estimate height using SAR images corresponding to each phase center. In recent years, multiple input multiple output (MIMO) radar techniques have received considerable attention. In this paper, we discuss the application of MIMO radar techniques for improving IFSAR height estimation. Additionally, we discuss IFSAR height estimation using multiple SAR images. We present an approach for selecting transmit waveforms to facilitate the computation of multiple SAR images corresponding to the virtual phase centers inherent in MIMO processing. With minimal modifications to existing two phase center IFSAR systems height estimation accuracy can be improved using MIMO techniques. Specifically, if the separation distance of the two phase centers is D, then using MIMO techniques the two phase center IFSAR system is transformed into a virtual three phase center IFSAR system with antenna element separation D and antenna length 2D. Example results are presented to demonstrate the benefits of this approach.

[416] J. Akhtar. A power distribution scheme for correlated mimo radar transmitters. In *Radar Conference, 2010 IEEE*, pages 85 –89, may 2010.

Abstract: MIMO (multiple-input multiple-output) radar systems with distributed transmitters and receivers have potential to significantly improve the performance of radar systems. MIMO systems benefit by utilizing the notion of spatial diversity as the receivers have the ability to observe incoming echos originating off various aspect angles. This capability is however dependent upon the fact that the antennas are not correlated with each others which can diminish the diversity gain. This article attempts to improve correlated MIMO system performance by proposing a power distribution algorithm which weights the antennas taking account of any correlation present at the emitters. Antennas who show strong correlations transmit pulses with less power so that the total available energy is spread across diversity branches more befittingly. Simulations are used to validate the results.

[417] Jun Li, Guisheng Liao, Kejiang Ma, and Cao Zeng. Waveform decorrelation for multitarget localization in bistatic mimo radar systems. In *Radar Conference, 2010 IEEE*, pages 21 –24, may 2010.

Abstract: The autocorrelation and crosscorrelation properties of transmit waveform set have great effect on the performance of MIMO radar systems. However, it is difficult to design waveform set which have ideal autocorrelation property as well as crosscorrelation one. In this paper, a decorrelation method has been proposed to cancel the effects of the autocorrelation and crosscorrelation of the transmit waveform by exploiting the given statistical properties of waveform. The correlation property of noise after decorrelation is also analyzed. Then a close form solution for localization of the multiple targets is presented via ESPRIT. Simulation results demonstrate the effectiveness of the proposed methods.

[418] Huang Yong and Guan Jian. A track-before-detect algorithm for statistical mimo radar multitarget detection. In *Radar Conference, 2010 IEEE*, pages 12 –16, may 2010.

Abstract: This paper investigates the early detection problem of multiple moving targets in statistical MIMO radar systems using the track-before-detect (TBD) techniques. At first, assuming prior knowledge of the number of targets, a binary generalized likelihood ratio test (GLRT) is derived, which shows that the optimal implementation of the GLRT requires multidimensional joint search. To reduce the implementation complexity, a suboptimum multitarget TBD algorithm using successive-target-cancellation and polar Hough transform (STC-PHT) is proposed. In addition to low complexity, the new proposed algorithm doesn't need the prior information of the number of targets, and can avoid the implementation of multi-hypothesis test when the number of targets is unknown. The simulation results show that this algorithm can effectively improve the detection performance of statistical MIMO radar at low signal-to-noise ratio (SNR).

[419] Y.I. Abramovich, G.J. Frazer, and B.A. Johnson. Markov model for convergence analysis of the adaptive kronecker mimo oth radar beamformer. In *Radar Conference, 2010 IEEE*, pages 1 –5, may 2010.

Abstract: We introduce an iterative procedure for design of adaptive KL-variate linear beamformers that are structured as the Kronecker product of K-variate (transmit) and L-variate (receive) beamformers. Focusing on MIMO radar applications for scenarios where only joint transmit and receive adaptive beamforming can efficiently mitigate multi-mode propagated backscatter interference, we introduce a Markov model for the adaptive iterative routine, specify its convergence condition, and derive final (stable) signal-to-interference-plus-noise ratio (SINR) performance characteristics. Simulation results demonstrate high accuracy of the analytical derivations.

[420] S. Ahmed, J.S. Thompson, B. Mulgrew, and Y. Petillot. Constant envelope waveform design for mimo radar. In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pages 4066 –4069, march 2010.

Abstract: A method for generating constant envelope (CE) waveforms to realise a given covariance matrix for a closely spaced MIMO radar system is proposed. In contrast to available algorithms, the technique provides closed form solutions for finding the required waveforms and

suggests that waveforms can be chosen from finite alphabets such as binary-phase shift keying (BPSK) and quadrature-phase shift keying (QPSK). Gaussian random-variables (RV's) are mapped onto CE non-Gaussian RV's using memoryless non-linear functions. The relationship between the correlation of Gaussian RV's at the input to the nonlinear functions and non-Gaussian RV's at their output is established. Simulation results are presented to demonstrate the effectiveness of the methodology.

[421] Y.-C. Wang, Hongwei Liu, and Z.-Q. Luo. Iterative design of mimo radar transmit waveforms and receive filter bank. In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pages 2770 –2773, march 2010.

Abstract: In this paper, we propose an iterative design approach to jointly optimize probing signal waveforms and a receive filter bank for a multiple-input multiple-output (MIMO) radar under a constant modulus constraint. The design goals are to approximate a desired beampattern and to minimize the auto-/cross- correlation levels of the probing signal waveforms for different time lags and between different spatial angles. Since the overall design problem is nonconvex, we propose to optimize the transmit probing signals and receive filter bank separately and alternately. The optimization of receive filter bank is a standard least squares problem, while the optimization of the constant modulus transmit signal waveforms is a norm-constrained least squares problem which can be approximately solved using a low-rank semidefinite relaxation procedure. We demonstrate the effectiveness of our proposed approach through a simulation example.

[422] Rui Fa and R.C. de Lamare. Knowledge-aided reduced-rank stap for mimo radar based on joint iterative constrained optimization of adaptive filters with multiple constraints. In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pages 2762 –2765, march 2010.

Abstract: In this paper, a reduced-rank knowledge-aided technique for MIMO radar space-time adaptive processing (STAP) design is proposed. We focus on the advantage of MIMO radars in achieving better spatial resolution by employing the colocated antennas. The scheme is based on knowledge-aided constrained joint iterative optimization of adaptive filters (KAC-JIOAF) and takes advantage of the a priori covariance matrix by employing additional linear constraints in the design. A recursive least squares (RLS) implementation is derived to reduce the computational complexity. We evaluate the algorithm in terms of signal-to-interference-plus-noise ratio (SINR) and probability of detection PD performance and compare it with the state-of-the-art reduced-rank algorithms. Simulations show that the proposed algorithm outperforms existing reduced-rank algorithms.

[423] F. Roemer, H. Becker, and M. Haardt. Analytical performance assessment for multi-dimensional tensor-esprit-type parameter estimation algorithms. In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pages 2598 –2601, march 2010.

Abstract: Subspace-based high-resolution parameter algorithms such as ESPRIT, MUSIC, or RARE are known as efficient and versatile tools in various signal processing applications including radar, sonar, medical imaging, or the analysis of MIMO channel sounder measurements. Since these techniques are based on the singular value decomposition (SVD), their performance can be analyzed with the help of SVD-based perturbation theory. Recently we have

demonstrated that in the R-dimensional case, the estimation accuracy of these schemes can be improved by replacing the measurement matrix by a measurement tensor and the SVD by the Higher-Order SVD (HOSVD). In case of ESPRIT, this gives rise to the family of Tensor-ESPRIT algorithms, e.g., standard Tensor-ESPRIT and Unitary Tensor-ESPRIT. In this paper we derive the analytical performance for Tensor-ESPRIT-type algorithms via a recently introduced perturbation theory for the HOSVD-based signal subspace estimate. All expressions are asymptotic in the SNR, but not in the sample size. We first present the explicit equations as a function of the current noise realization, where no assumption on the statistics of symbols or noise are required. Next, we show the result of performing statistical expectation over white Gaussian noise. To demonstrate the usefulness of the results we also present a compact expression for the asymptotic efficiency in the case of a single source, which is only a function of the array size.

[424] M. Akcakaya and A. Nehorai. Mimo radar detection under phase synchronization errors. In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pages 2578 –2581, march 2010.

Abstract: We consider the problem of target detection for coherent multi-input multi-output (MIMO) radar with widely separated antennas in the presence of phase synchronization mismatch between the transmitter and receiver pairs. First, we introduce a data model using von-Mises distribution to represent the phase error terms. Then we employ expectation-maximization algorithm to estimate the error distribution parameter and target returns as well as the noise variance. We develop a generalized likelihood ratio test (GLRT) target detector using these estimates and demonstrate the effect of phase uncertainties on the detection performance using Monte Carlo simulations.

[425] Xiaodong Zhuge and Alexander Yarovoy. Near-field ultra-wideband imaging with two-dimensional sparse mimo array. In *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on*, pages 1 –4, april 2010.

Abstract: In this paper, we investigate the feasibility of utilizing the concept of effective aperture for designing sparse multiple-input multiple-output (MIMO) array oriented for ultrawideband (UWB) near-field imaging. The array design approach based on the effective aperture concept was previously applied under narrowband far-field conditions. Numerical and experimental studies are performed to show that such method can be still feasible in the near-field of the UWB array aperture. Two-dimensional MIMO array is designed based on the design method with extension using the principle of separable aperture functions. The real 2-D aperture array is compared with its effective aperture measured with synthetic aperture radar (SAR) technique. The similarity of their beam pattern and imaging capabilities confirm the feasibility of the effective aperture approach, and demonstrate the potential of UWB near-field imaging system with 2-D sparse multi-static array configuration.

[426] Hong Jiang, De-Fa Wang, and Chang Liu. Estimation of dod and 2d-doa and polarizations for bistatic mimo radar. In *Wireless and Optical Communications Conference (WOCC), 2010 19th Annual*, pages 1 –5, may 2010.

Abstract: Multi-parameter estimation is investigated for target discrimination and localization in multiple-input multiple-output (MIMO) radar system. With an M-element uniform linear array in

the transmitter and a square array consisting of N2 pair of crossed-dipoles in the receiver, a novel method is proposed for joint estimation of direction-of-departures (DODs), two-dimensional direction-of-arrivals (2D-DOAs) and polarizations of multiple targets for bistatic MIMO radars. Its signal model is described, and the algorithm is given by exploiting rotational invariance property of ESPRIT and polarization sensitive array processing technology in transmit and receive arrays. To discriminate and localize targets in a 3-D plane, more information than those of traditional bistatic MIMO radar algorithms is provided using the proposed method. Also, by making use of polarization diversity, its resolution capability is greatly improved when two targets are closely spaced.

[427] M. Jahn, A. Stelzer, and A. Hamidipour. Highly integrated 79, 94, and 120-ghz sige radar frontends. In *Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International*, page 1, may 2010.

Abstract: This paper reflects on design aspects for multi-channel frequency-continuous (FMCW) wave radar frontends from conception to application on board. In the 79-GHz domain, multi-channel applications are recapitulated, and in the 94-GHz domain, a broadband transceiver is presented along with a voltage-controlled oscillator (VCO) that covers a tuning range of 12 GHz. The functionality of the 94-GHz chipset was verified by means of a four-channel multiple-input multiple-output (MIMO) radar prototype. Finally, a highly integrated 120-GHz transceiver with on-chip signal generation is presented.

[428] W. Holpp. Status and trends in aesa-based radar. In *Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International*, page 1, may 2010.

Abstract: Radar technology, predominantly in the area of defence applications, is in a continuous process of extending its present capabilities. Especially Active Electronically Scanned Array (AESA) radars, with their unprecedented degree of operational flexibility, are currently about to revolutionise the performance of air- and spaceborne, naval and ground radars. The current status of AESA radar and the trends in system and technology advances are discussed. Trends on system level will be the use of MIMO-architectures and shared antenna apertures.

[429] H. van Bezouwen, H.-P. Feldle, and W. Holpp. Status and trends in aesa-based radar. In *Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International*, pages 526 –529, may 2010.

Abstract: Radar technology, predominantly in the area of defence applications, is in a continuous process of extending its present capabilities. Especially Active Electronically Scanned Array (AESA) radars, with their unprecedented degree of operational flexibility, are currently about to revolutionise the performance of air- and spaceborne, naval and ground radars. The current status of AESA radar and the trends in system and technology advances are discussed. Trends on system level will be the use of MIMO-architectures and shared antenna apertures.

[430] M. Jahn, A. Stelzer, and A. Hamidipour. Highly integrated 79, 94, and 120-ghz sige radar frontends. In *Microwave Symposium Digest (MTT), 2010 IEEE MTT-S International*, pages 1324 –1327, may 2010.

Abstract: This paper reflects on design aspects for multichannel frequency-continuous wave (FMCW) radar frontends from conception to application on board. In the 79-GHz domain, multi-channel applications are recapitulated, and in the 94-GHz domain, a broadband transceiver is presented along with a voltage-controlled oscillator (VCO) that covers a tuning range of 12 GHz. The functionality of the 94-GHz chipset was verified by means of a four-channel multiple-input multiple-output (MIMO) radar prototype. Finally, a highly integrated 120-GHz transceiver with on-chip signal generation is presented.

[431] P.P. Vaidyanathan and Ching-Chih Weng. Active beamforming with interpolated fir filterin. In *Circuits and Systems (ISCAS), Proceedings of 2010 IEEE International Symposium on*, pages 173 –176, 30 2010-june 2 2010.

Abstract: The interpolated FIR (IFIR) radar was recently introduced in the context of MIMO radar theory. It was shown that this system has a signal to clutter ratio intermediate between those of the SIMO and MIMO radars. This paper considers the optimal design of the active IFIR beamformer in presence of jammers. It is shown that this beamformer can achieve beamwidths as sharp as those of colocated MIMO radars with full-length virtual arrays. At the same time, the extra complexity of MIMO radars, which arises from use of multiple transmitter waveforms and several sets of receiver matched filter banks, is not present in the IFIR realization. Design examples for IFIR radars which optimize the receiver beamforming weights in presence of jammers for fixed transmitter are also presented.

[432] Xichuan Zhang, Yongshun Zhang, Wenchong Xie, Yongliang Wang, and Tao Yan. Clutter characteristics analysis of airborne mimo radar under the degradation of transmit waveforms orthogonality. In *Industrial Mechatronics and Automation (ICIMA), 2010 2nd International Conference on*, volume 2, pages 617 –621, may 2010.

Abstract: This paper addresses the issues of clutter characteristics of airborne MIMO radar in presence of degradation of transmit waveforms orthogonality. Firstly, synthesis subarray space and synthesis transmit signal space caused by the degradation are illustrated. Clutter model of airborne MIMO radar is developed under the orthogonal degradation. Clutter models with arbitrary waveform are unified in this model via the transform of array space and signal space. Secondly, an estimation rule for the number of clutter DOFs is presented based on band-limited signal theory. It shows that clutter DOFs is dependent on both the number of inner elements in synthetic subarray and synthetic signal. Finally, clutter characteristics under the influence of degradation are analyzed compared with the ideal MIMO radar model and phase array radar, and the effectivity of the estimation rule is verified in the numerical examination.

[433] Zeng Jiankui and Dong Ziming. Some mimo radar advantages over phased array radar. In *Industrial Mechatronics and Automation (ICIMA), 2010 2nd International Conference on*, volume 2, pages 211 –213, may 2010.

Abstract: MIMO radar is a new radar technique developed recently. It can achieve better detection performance than conventional phased radar. In this paper, we investigate some

advantages of MIMO radar on the non-ideal factor of transmitting signal such as the instability in signal phase and the spur in transmitting signal etc. And then, a simulation system was established, some simulation shows the advantage of MIMO radar over its conventional counterpart.

[434] Zeng Jiankui. The application of chaotic signal in mimo radar. In *Industrial Mechatronics and Automation (ICIMA), 2010 2nd International Conference on*, volume 2, pages 214 –216, may 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar is a new radar technique. It has many advantages over conventional phased radar in many ways such as anti-intercept of radar signal, low velocity target detection, and resolution. The signal design is a chief problem for radar. In this paper, we analyze the chaotic signal for MIMO radar.

[435] Fulai Liu and Jinkuan Wang. Ad-esprit for multi-target localization in bistatic mimo radar system. In *Computer Design and Applications (ICCDA), 2010 International Conference on*, volume 4, pages V4–545 –V4–548, june 2010.

Abstract: In this paper, an ESPRIT-based approach named as AD-ESPRIT is presented to jointly estimate the directions of arrival (DOAs) and directions of departure (DODs) estimation of interesting multi-targets for bistatic MIMO radar system. The proposed method does not need two-dimensional (2-D) or multiple 1-D spectrum peak searching. Thus, the computational complexity of the proposed algorithm is reduced for the direction finding cross localization in bistatic MIMO radar system. Furthermore, the estimated DODs and DOAs is automatically determined. Simulation results are presented to verify the effectiveness of the proposed method.

[436] Fulai Liu and Jinkuan Wang. Ad-music for jointly doa and dod estimation in bistatic mimo radar system. In *Computer Design and Applications (ICCDA), 2010 International Conference on*, volume 4, pages V4–455 –V4–458, june 2010.

Abstract: In this paper, a MUSIC-based approach named as AD-MUSIC is presented to jointly estimate the directions of arrival (DOAs) and directions of departure (DODs) estimation for the direction finding cross localization of multi-targets in bistatic MIMO radar system. The MUSIC algorithm for the DOD estimation is referred to as the D-MUSIC algorithm. On the other hand, the A-MUSIC, which estimates the DOA, is introduced as well. The proposed AD-MUSIC combines two one dimensional (1-D) MUSICs along with the spatial beamforming technique to jointly estimate the DOAs and DODs. At the same time, the estimated DOAs and DODs is automatically determined. Simulation results are presented to verify the effectiveness of the proposed method.

[437] Fulai Liu and Jinkuan Wang. An effective virtual esprit algorithm for multi-target localization in bistatic mimo radar system. In *Computer Design and Applications (ICCDA), 2010 International Conference on*, volume 4, pages V4–412 –V4–415, june 2010.

Abstract: In a bistatic multiple input multiple output (MIMO) radar system, the location of each interesting target can be determined by the direction finding cross localization with the direction-of-departure (DOD) and direction-of-arrival (DOA). In this paper, an effective virtual ESPRIT algorithm is proposed for jointly DOA and DOD estimation in bistatic MIMO radar system. The

pairing problem is addressed as well, for jointly DOA and DOD estimation. Simulation results are presented to verify the effectiveness of the proposed method.

[438] Vamsi Krishna Ithapu, Amit Kumar Mishra, and Rajib Kumar Panigrahi. Diversity employment into target plus clutter sar imaging using mimo configuration. In *A Workshop on Advanced Antenna Technology, 2010 Indian Antenna Week*, pages 1 –4, 31 2010-june 4 2010.

Abstract: Multiple Input Multiple Output (MIMO) configurations in radar systems provide architectural and performance advantage over conventional monostatic and bistatic systems due to the implicit diversity characteristics of any MIMO system. Various authors are individually addressed either of these diversities. This work aims at parameterizing all the three, spatial, frequency and waveform diversities and hence designing a new MIMO SAR system for high resolution achievement. This system is designed taking into account both target and clutter, as clutter background pollutes the images substantially. The parameterizations and hence the constraints obtained on the system architecture and transmit signal properties ensure high resolution and better performance over conventional SAR imaging systems.

[439] Mohamed Laid Bencheikh, Yide Wang, and Hongyang He. A subspace-based technique for joint doa-dod estimation in bistatic mimo radar. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: In this paper, we propose a new subspace-based approach for joint DOA-DOD estimation in the bistatic MIMO radar. This method use a polynomial root findings for determining jointly the DOA-DOD directions. This algorithm allows an efficient estimation of the target DOA and DOD with automatic pairing. The simulation results of the proposed algorithms are presented and the performances are investigated and discussed.

[440] Jabran Akhtar. Energy allocation for correlated mimo radar antennas with ricean targets. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: MIMO (multiple-input multiple-output) radar systems with widely separated transmitters and receivers have capacity to considerably improve the performance of radar systems. This is accomplished by utilizing the notion of spatial diversity as receivers can observe incoming echos originating off various aspect angles. This work attempts to alleviate the performance of MIMO systems in the existence of correlation and Ricean scattering models by proposing a power allocation scheme. The scheme adjusts weights at the antennas proportionally by taking account of any correlation and line-of-sight information present at the transmitters. Antennas who are correlated or perceive low line-of-sight reflectivity are allocated less power so that the total available energy is spread across diversity branches and strong reflectors more accordingly. Simulations are used to validate the results.

[441] D. Deiana, A. S. Kossen, and W. L. van Rossum. Multipath exploitation in an urban environment using a mimo surveillance radar. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: Surveillance in an urban environment under all atmospheric conditions and situations can be performed by means of radars. The multipath created by buildings and moving targets can be exploited, for example in order to increase SNR. In this paper we present the initial results of

the measurements of a moving target in a roadblock scenario in non line of sight (NLOS). The results suggest that MIMO systems are suitable for urban environment surveillance.

[442] Pu Wang, Hongbin Li, and Braham Himed. Moving target estimation using distributed mimo radar in non-homogeneous clutter. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: In this paper, we consider parameter estimation for moving target detection using a distributed MIMO radar, where the multi-static transmit-receive configuration causes non-homogeneous clutter. Specifically, the clutter power for the same resolution cell may vary significantly from one transmit-receive pair to another, due to azimuth-selective backscattering. Moreover, the clutter power may also vary across resolution cells in the neighborhood of the test cell. In this work, the non-homogeneous clutter is modeled using a subspace approach, whereby the subspace is spanned by a few Fourier bases and the non-homogeneity of the clutter is captured by coefficients that vary with different transmit-receive pairs and/or different resolution cells. The choice of the Fourier bases is based the fact that the clutter Doppler spectrum is bandlimited. We develop a maximum likelihood (ML) estimator for the parameters associated with the target and clutter. The Cramer-Rao bound (CRB) for velocity estimation is also derived. Numerical results show that the proposed estimator outperforms an alternative solution that ignores the non-homogeneous nature of the clutter.

[443] Timofey Savelyev, Xiaodong Zhuge, Bill Yang, Alexander Yarovoy, Leo Ligthart, Michail Drozdov, and Boris Levitas. Development of uwb microwave array radar for concealed weapon detection. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: This paper describes two approaches to short-range microwave imaging by means of ultra-wideband (UWB) technology. The first approach deals with synthetic aperture radar (SAR) that employs a transmit-receive antenna pair on mechanical scanner. The second one represents a multiple input multiple output (MIMO) antenna array that scans electronically in the horizontal plane and mechanically, installed on the scanner, in the vertical plane. The mechanical scanning in only one direction reduces significantly the measurement time. Two respective prototypes have been built and compared. Both systems comprise the same 10 18 GHz antennas and multichannel video impulse electronics while the same focusing based on Kirchhoff migration is applied to acquired data for radar imaging. The study has been carried out for an application of concealed weapon detection.

[444] B. Magaz, M. L. Bencheikh, Y. Wang, and A. Belouchrani. Numerical analysis of mimo radar detection performance under weibull-distributed clutter. In *Radar Symposium (IRS), 2010 11th International*, pages 1 –4, june 2010.

Abstract: In this paper, the detection performance of a MIMO radar under Weibull distributed clutter is investigated. Numerical results, based on Monte-Carlo simulations, showing the detection performance are provided. The false alarm rate and the detection performance are carried out for different values of the shape parameter of the Weibull distribution and the number of transmit-receive pairs used in the MIMO radar configuration. The obtained results validate the improvements in detection performance available from a MIMO radar against a mono radar. The obtained performances are presented and discussed in this paper.

[445] Min Lu, Yutao Zhu, Yi Su, Chunlin Huang, and Jian Wang. A kind of mimo ground penetrating radar plane antenna array and corresponding imaging method. In *Ground Penetrating Radar (GPR), 2010 13th International Conference on*, pages 1 –4, june 2010.

Abstract: Antenna array is widely used in real time imaging of ground penetrating radar (GPR). With circumstance restricting, the number and interval of antenna elements are difficult to fit the need of high imaging resolution. In this paper, a kind of 4-transmitter and N-receiver MIMO GPR plane antenna array is proposed. Based on phase center approximation (PCA) theory, its equivalent antenna array is a uniform square antenna array with 4N T/R antenna elements, and the interval of equivalent elements is half of that of the real receiving elements. The equivalent uniform square antenna array has two synthetic apertures and can obtain the 2D information of target. So, the 2D image of the target can be derived by using narrowband transmitting signals and the 3D image can be derived by using wideband transmitting signals. Corresponding imaging method and procedure are also given in this paper.

[446] Ying Luo, Jin He, Xian jiao Liang, and Qun Zhang. Three-dimensional micro-doppler signature extraction in mimo radar. In *Signal Processing Systems (ICSPS), 2010 2nd International Conference on*, volume 2, pages V2–1 –V2–4, july 2010.

Abstract: In traditional monostatic radar, only the micromotion signatures projected in line-of-sight (LOS) could be extracted from the target's echoes, which are insufficient for accurate target recognition due to the target-aspect sensitivity. In this paper, we propose an algorithm for the three-dimensional micro-Doppler signature extraction using the multi-input multi-output (MIMO) radar technique. The micro-Doppler effect in MIMO radar induced by rotation is analyzed. Profited from the multi-view of MIMO radar, the three-dimensional micro-motion features, which are not sensitive to the target's aspect anymore, are obtained by solving nonlinear multivariable equation systems. Simulations are given to validate the effectiveness of the proposed algorithm.

[447] Xie Wencheng, Zhang Xiaoling, and Shi Jun. Mimo antenna array design for airborne down-looking 3d imaging sar. In *Signal Processing Systems (ICSPS), 2010 2nd International Conference on*, volume 2, pages V2–452 –V2–456, july 2010.

Abstract: Airborne down-looking three dimensional imaging SAR (ADL-3D-SAR) is a new radar system developed in recent years, which overcomes the shadowing effects and can gather more information compared to the conventional side looking SAR systems. However, it still has many constraints, e.g. antenna array configuration designing, cross-track resolution and vibration errors. In this paper, we focus on the designing of antenna configuration and propose several new multiple-input-multiple-output (MIMO) antenna array models which can provide more reasonable properties for 3D SAR system's stability, applicability, and vibration errors reduction. The validity of these models is discussed in the end.

[448] Yu Zhang and Jianxin Wang. Transmit-receive beamforming for mimo radar. In *Signal Processing Systems (ICSPS), 2010 2nd International Conference on*, volume 3, pages V3–803 –V3–806, july 2010.

Abstract: MIMO radar with orthogonal signal transmission is equivalent to form virtual sensors at the receiver. The virtual sensors can be used to form narrower beams with lower sidelobes. The pattern of MIMO radar can be decomposed into transmit pattern and receive pattern by

mathematical analysis. In this paper, we apply conventional beamforming and MVDR beamforming algorithms to MIMO radar. At last, the comparisions of two algorithms for phased-array radar and MIMO radar are given.

[449] Yu Zhang and Jianxin Wang. An approach for extracting the transmitted waveforms based on compound filter for mimo radar. In *Signal Processing Systems (ICSPS), 2010 2nd International Conference on*, volume 1, pages V1–665 –V1–667, july 2010.

Abstract: Extracting the transmitted waveforms is crucial for MIMO radar. A new eatracting approach is proposed in this paper based on the compound filter. The proposed method can compress the input pulse width to a narrower one and suppress range sidelobe level lower than a matched filter. The computer simulation proves the efficiency of the method.

[450] A. Srinivas and V.U. Reddy. Transmit beamforming for colocated mimo radar. In *Signal Processing and Communications (SPCOM), 2010 International Conference on*, pages 1 –5, july 2010.

Abstract: MIMO radar has seen growing interest in recent years owing to the many advantages that it offers over conventional radar, including spatial diversity and enhanced target direction resolution. Unlike standard phased array (SIMO) radar that transmits scaled versions of a single waveform from its many transmit antennas, a MIMO radar can transmit distinct waveforms from each antenna. Such an increase in the number of degrees of freedom for waveform design can potentially be used to obtain beamforming performance similar to SIMO radars with a far fewer total number of transmit and receive antennas. In recent literature, the problem of finding a signal correlation matrix that achieves a desired transmit beam pattern has been addressed, but a closed form solution for this problem has been lacking. In this paper, we first formulate a new spatial ambiguity function that simultaneously specifies the transmit beam pattern as well as the cross-correlation beam pattern. We then provide a closed form solution for the signal correlation matrix whose spatial ambiguity function is closest to a desired function (in the mean square sense), when using colocated uniform linear arrays. Further, we show how a suitable tapering window could be applied on the signal correlation matrix to tradeoff sidelobe levels for mainlobe width in the spatial ambiguity function.

[451] Dong Zhiming and Zeng Jiankui. The application of imm in mimo radar. In *Environmental Science and Information Application Technology (ESIAT), 2010 International Conference on*, volume 2, pages 600 –602, july 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar has drawn much attention from researcher. It can effectively improve radar performance by transmitting specially designed orthogonal signals. In this paper, interacting Multiple Model(IMM) estimator is applied to MIMO radar. The detection flow based on IMM is presented in this paper.

[452] Dong Zhiming and Zeng Jiankui. Study on mimo radar velocity resolution. In *Environmental Science and Information Application Technology (ESIAT), 2010 International Conference on*, volume 2, pages 603 –606, july 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar is a novel radar technique developed recently. It has many advantages over conventional phased radar in many ways such as anti-

intercept of radar signal, low velocity target detection, and resolution. In this paper, the signal model and signal processing for MIMO radar is studied. And then, a simulation platform is established with Matlab. Using this platform, the advantage of velocity resolution of the MIMO radar over conventional phased array is researched.

[453] Xiang Lijuan and Zeng Jiankui. Wavelet based signal for mimo radar. In *Environmental Science and Information Application Technology (ESIAT), 2010 International Conference on*, volume 2, pages 607 –610, july 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar can effectively improve radar performance by transmitting specially designed orthogonal signals. In this paper, the orthogonal wavelet division multiplexing is used because of their prominent properties such as favorable ambiguity function and high bandwidth efficiency. The signal design flow is presented in this paper.

[454] Xiang Lijuan and Zeng Jiankui. The chaotic signal design for mimo radar. In *Environmental Science and Information Application Technology (ESIAT), 2010 International Conference on*, volume 2, pages 611 –614, july 2010.

Abstract: The study of multiple-input multiple-output (MIMO) radar has received much attention from researchers in recent years. It has many advantages over conventional phased radar in many ways such as anti-intercept of radar signal, low velocity target detection, and resolution. The signal design is an important problem for radar which decides the performance of radar. In this paper, the chaotic signal is employed to the MIMO radar application. Some preprocessed method is employed to make the signal has small Crest Factor (CF), large bandwidth. Some simulation is presented to show efficiency of proposed method.

[455] O. Daoud, A. Damati, and W. Al-Sawalmeh. Enhancing the mimo-ofdm radar systems performance using ga. In *Systems Signals and Devices (SSD), 2010 7th International Multi-Conference on*, pages 1 –5, june 2010.

Abstract: This paper proposes a new peak-to-average power ratio (PAPR) reduction method for a multiple-input multiple-output (MIMO)-orthogonal frequency division multiplexing (OFDM) systems based on a genetic algorithm (GA). It has been introduced to be compatible with Radar systems, where the GA was used to optimize the MIMO-OFDM symbols in such way that could improve the system's performance. During this work, there was a comparison that has been stated among three systems; original radar system, radar system-based MIMO-OFDM and radar system-based MIMO-OFDM uses GA. Finally, a range of simulation results are provided to demonstrate the superiority of the proposed scheme, since it is showed an enhancement in the coverage distance besides reducing the PAPR effects.

[456] D.W. Bliss. Coherent mimo radar. In *Waveform Diversity and Design Conference (WDD), 2010 International*, page 1, aug. 2010.

Abstract: Multiple-input multiple-output (MIMO) extensions to radar systems enable a number of advantages compared to traditional approaches. These advantages include improved angle estimation and target detection. In this tutorial, an overview of MIMO radar is provided, and the concept of coherent MIMO radar is defined. In addition, two topics are addressed more

thoroughly: MIMO waveform/array geometry optimization for target tracking, and MIMO ground moving target indication (GMTI).

[457] Hao He, P. Stoica, and Jian Li. Wideband mimo waveform design for transmit beampattern synthesis. In *Waveform Diversity and Design Conference (WDD), 2010 International*, pages 000006 –000010, aug. 2010.

Abstract: The usage of multi-input-multi-output (MIMO) systems such as a MIMO radar allows the array elements to transmit different waveforms freely. This waveform diversity can lead to flexible transmit beampattern synthesis, which is useful in many applications such as radar/sonar and biomedical imaging. In the past literature most attention was paid to receive beampattern design due to the stringent constraints on waveforms in the transmit beampattern case. Recently progress has been made on MIMO transmit beampattern synthesis but mainly only for narrowband signals. In this paper we propose a new approach that can be used to efficiently synthesize MIMO waveforms in order to match a given wideband transmit beampattern, i.e. to match a transmit energy distribution in both space and frequency. The synthesized waveforms satisfy the unit-modulus or low peak-to-average power ratio (PAR) constraints that are highly desirable in practice. Several examples are provided to investigate the performance of the proposed approach.

[458] S. Gogineni and A. Nehorai. Adaptive design for distributed mimo radar using sparse modeling. In *Waveform Diversity and Design Conference (WDD), 2010 International*, pages 000023 –000027, aug. 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar systems with widely separated antennas provide spatial diversity gain by viewing the targets from different angles. In this paper, we propose an approach to accurately estimate the properties (position, velocity) of multiple targets using such systems by employing sparse modeling. We also propose a new metric to analyze the performance of the radar system. We develop an adaptive mechanism for optimal energy allocation at different transmitters. We show that this adaptive mechanism outperforms MIMO radar systems that transmit fixed equal energy across all the antennas.

[459] Liangbing Hu, Hongwei Liu, Da zheng Feng, Bo Jiu, Xu Wang, and Shunjun Wu. Optimal mismatched filter bank design for mimo radar via convex optimization. In *Waveform Diversity and Design Conference (WDD), 2010 International*, pages 000126 –000131, aug. 2010.

Abstract: In this paper, a mismatched filter bank is designed for suppressing the autocorrelation peak sidelobe level (PSL) and the peak cross-correlation level (PCCL) of an orthogonal polyphase sequence set applied in a multiple-input multiple-output (MIMO) radar system. The mismatched filter bank is obtained by minimizing a weighted maximum of the PSL and PCCL on the basis of the convex optimization. Compared with the iteratively reweighted least squares (IRLS) method, the proposed convex method can get the optimal mismatched filter bank with the minimum PSL and PCCL, and can also control the system signal-to-noise ratio loss (SNRL). Numerical examples show that the optimal mismatched filter bank at the cost of a slight SNRL can achieve a good improvement of the PSL and a moderate improvement of the PCCL, if the filter length P and the weighting factor w between the PSL and PCCL are appropriately chosen.

[460] X.P. Masbernat, M.G. Amin, F. Ahmad, and C. Ioana. An mimo-mti approach for through-the-wall radar imaging applications. In *Waveform Diversity and Design Conference (WDD), 2010 International*, pages 000188 –000192, aug. 2010.

Abstract: In this paper, we apply Multiple-Input Multiple-Output (MIMO) configurations to Moving Target Identification (MTI) for urban sensing using radars. In particular, we consider MIMO-MTI formulations for detecting slow-moving personnel inside enclosed structures and behind walls. Using signal multiplexing from two transmitters and several receiver positions, it is shown that the virtual array (co-array) implementing MIMO schemes, applied to stepped-frequency radars, permit improvement in image resolution of moving targets. Laboratory experiments are conducted to validate the proposed approach with targets walking behind walls.

[461] D. Fuhrmann, P. Browning, and M. Rangaswamy. Waveform diversity and advanced signaling strategies for the hybrid mimo phased array radar. In *Waveform Diversity and Design Conference (WDD), 2010 International*, page 283, aug. 2010.

Abstract: The Hybrid MIMO Phased Array Radar, or HMPAR, is a notional concept for a multisensor radar architecture that combines elements of traditional phased-array radar with the emerging technology of Multiple-Input Multiple Output (MIMO) radar. A HMPAR comprises a large number, MP, of T/R elements, organized into M subarrays of P elements each. Within each subarray, passive elementlevel phase shifting is used to steer transmit and receive beams in some desired fashion. Each of the M subarrays are in turn driven by independently amplified phase-coded signals. This paper proposes new transmit signal selection strategies based on the observation that some MIMO signal sets, such as those proposed by us previously, cause a very rapid sequential or raster scan across some field of view. Exploiting this property allows one to create and process multiple beams simultaneously. Furthermore, there exists a range-angle coupling in the transmit and receive signals that may lead to high-resolution target localization.

[462] Xinchao Li, Yiduo Guo, Yongshun Zhang, and Di Shen. Joint angle estimation for bistatic mimo radar. In *Wireless Communications Networking and Mobile Computing (WiCOM), 2010 6th International Conference on*, pages 1 –4, sept. 2010.

Abstract: A new joint direction of arrivals (DOAs) and direction of departures (DODs) estimation algorithm for bistatic multiple-input multiple-output (MIMO) radar is proposed. Instead of two-dimensional nonlinear search or iterative computation, the algorithm uses a one-dimensional search to estimate the DOAs, and then the DODs can be obtained; therefore they can be paired automatically. Furthermore, the algorithm can solve the problem of joint angle estimation when angle ambiguity of DODs occurs. The performance of the proposed algorithm is validated by the simulation results.

[463] D.R. Fuhrmann, J.P. Browning, and M. Rangaswamy. Adapting a mimo/phased-array radar transmit beampattern to target location. In *Cognitive Information Processing (CIP), 2010 2nd International Workshop on*, pages 354 –359, june 2010.

Abstract: Proposed MIMO and hybrid MIMO/phased array (HMPAR) radar systems have the potential for tremendous flexibility in the choice of the transmit beampattern, through the selection of multiple transmitted signals. This paper considers how one might exploit that flexibility in light of prior information or uncertainty in target spatial location, for parameter

estimation or tracking applications. We first consider an idealized problem of distributing energy across multiple target sites given a prior probability distribution on those sites. It shown that the optimal allocation of energy would be proportional to the square root of the prior probability. Second, we propose a method to approximate this optimal distribution of energy using a MIMO radar or HMPAR radar system. The method chooses signals that realize an intrapulse beamscan over the region of interest, with a nonuniform distribution of scan points matched to the desired distribution of energy.

[464] N. Janatian, M. Modarres-Hashemi, and A. Sheikhi. Generalization of automatic censored mean level detector (acmld) for mimo radars. In *Information Sciences Signal Processing and their Applications (ISSPA), 2010 10th International Conference on*, pages 430 –433, may 2010.

Abstract: Constant False Alarm Rate (CFAR) processors are useful for detecting radar targets in background for which all parameters in the statistical distribution are not known and may be nonstationary. Many CFAR techniques have been proposed for conventional radars in nonhomogeneous background. One of the most robust CFAR detectors in multiple target situations is Automatic Censored Mean Level Detector (ACMLD) which does not require any prior knowledge about the number of interfering targets. In this paper, ACMLD algorithm is generalized for Multiple Input-Multiple Output (MIMO) radar. An exact expression for the false alarm probability of the proposed algorithm (M-ACMLD) is presented. Then, the performance analysis of M-ACMLD is studied in both homogeneous environment and multiple target situations.

[465] G. Hickman and J.L. Krolik. Mimo gmti radar with multipath clutter suppression. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2010 IEEE*, pages 65 – 68, oct. 2010.

Abstract: This paper address ground-moving target indicator (GMTI) radar operation in the presence of strong multipath spread-Doppler clutter (SDC). Spacetime adaptive processing (STAP) for single-input-single-output (SIMO) radar is designed to mitigate direct-path SDC which leaks into the sidelobes of a moving radar platform. However, multipath SDC often returns via the receiver mainlobe and cannot be suppressed in a SIMO radar without also canceling the target. In this paper, we study multipath SDC mitigation using multiple-input-multiple-output (MIMO) GMTI radar. Clutter loci and adaptive array patterns for MIMO GMTI are presented in multipath SDC. By achieving range-dependent nulling on transmit, the effectiveness of MIMO GMTI radar at suppressing multipath SDC is shown.

[466] A. Hassanein, S.A. Vorobyov, A.B. Gershman, and M. Rubsamen. Estimating the parameters of a moving target in mimo radar with widely separated antennas. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2010 IEEE*, pages 57 –60, oct. 2010.

Abstract: In this paper, we develop a new maximum likelihood (ML) moving target parameter estimation technique for multiple-input multiple-output (MIMO) radar. It is required for this technique that different receive antennas have the same time reference, but no synchronization of initial phases of the receive antennas is needed and, therefore, the estimation process is noncoherent. The target motion within a certain processing interval is modeled as a second-order polynomial whose coefficients are given by the initial location, velocity, and acceleration of the

target. The proposed ML estimator is able to jointly process the data collected from multiple consecutive radar pulses. It is shown that the considered ML problem simplifies to the classic overdetermined nonlinear least-squares problem. The proposed ML estimator requires multi-dimensional search over the unknown location, velocity, and acceleration parameters. The performance of the proposed estimator is validated by simulation results.

[467] T.K. Sarkar and M.S. Palma. Mimo radars or is it smart antennas? In *Wireless Information Technology and Systems (ICWITS), 2010 IEEE International Conference on*, pages 1 –4, 28 2010-sept. 3 2010.

Abstract: Radars were originally designed as detectors of targets. The goal was to transmit a signal with the maximum available power and then observe whether the received signal contained a portion of the transmitted signal. A matched filter was then designed using the transmitted waveform to detect the received signal and based on some statistical hypothesis testing a decision was made on whether a target is present or absent. However, when multiple targets are to be examined or one wants to search for a low observable near a large target, the conventional detection based radar processing is not adequate. A need for finding small targets in the presence of clutter and jammer evolved into an estimation theory problem rather than detection. It is illustrated that use of a phased array in a SIMO mode can perform quite well as one does not have to worry about the inhomogenity of the clutter associated with multiple transmissions in a MIMO system as the processing becomes quite complicated. Also, the compensation of mutual coupling becomes difficult in a practical deployment on a moving platform. It is important to note that one can still exploit the advantages of super-resolution processing using estimation theory keeping the advantages of a single high power transmitting antenna in a phased array deployment. This paper illustrates such a methodology which has been in the published literature for at least a decade and compares it with the recent MIMO developments. Examples are presented related to a single snapshot based least squares methodology that can cancel interferer in the main beam using a phased array radar but performing a deterministic processing using the same number of degrees of freedom as a multisnapshot case for coherent processing.

[468] N.S. Ahmad and J.J. Soraghan. A preliminary study towards the implementation of mimo radar system for agriculture applications. In *Infrared Millimeter and Terahertz Waves (IRMMW-THz), 2010 35th International Conference on*, pages 1 –2, sept. 2010.

Abstract: The revolution of MIMO radar system has the potential to be applied in many areas of applications such as in agriculture sector. It is inspired from MIMO system in telecommunications and uses multiple antennas to observe the different aspect of targets, hence produce high resolution radar image.

[469] D. Wilcox and M. Sellathurai. Beampattern optimisation for sub-arrayed mimo radar for large arrays. In *Phased Array Systems and Technology (ARRAY), 2010 IEEE International Symposium on*, pages 567 –572, oct. 2010.

Abstract: The estimation of the direction of arrival (DOA) of signals in the far-field of an array has been an area of continued research. Recent advances in MIMO radar techniques have led to results whereby prior knowledge of the approximate target locations is used to generate arbitrary signals which are transmitted from an active array to improve DOA estimates. This would be a useful in a scenario such as target tracking. However, this neglects the complexities of the

hardware required for larger arrays, and further, the amount of computation required on the transmit side alone. A sub-optimal method employing sub-arrays to reduce hardware requirements, and a low complexity algorithm to determine the optimal steering vectors for the arrays is presented and compared to the optimal full diversity transmit strategy.

[470] T.S. Ralston, G.L. Charvat, and J.E. Peabody. Real-time through-wall imaging using an ultrawideband multiple-input multiple-output (mimo) phased array radar system. In *Phased Array Systems and Technology (ARRAY), 2010 IEEE International Symposium on*, pages 551 –558, oct. 2010.

Abstract: A real-time acquisition and processing architecture has been developed for an ultrawideband (UWB) S-band (2-4 GHz) multiple-input multiple-output (MIMO) phased array radar system that facilitates greater than 10 Hz imaging rates, providing a video-like radar image of what is behind a concrete wall. Video rate imaging enhances the interpretability of range vs. range through-wall and free-space radar imagery. Images are formed without a-priori information. Video framerate imaging is achieved by designing an electronically switched bi-static array using high-performance microwave components, a multi-threaded data pipeline, and efficient hardware-accelerated processing algorithms. Experiments successfully image low radar cross section (RCS) objects, fast moving objects in free-space, and a human behind a 10 cm-thick solid concrete wall.

[471] Min Jiang, Jianguo Huang, and Yunshan Hou. Mimo radar joint estimation of target location and velocity with multiple subcarrier signals. In *Phased Array Systems and Technology (ARRAY), 2010 IEEE International Symposium on*, pages 398 –402, oct. 2010.

Abstract: This paper analyzes the effect of waveform parameters on the joint target location and velocity estimation by non-coherent multiple-input multiple-output (MIMO) radar transmitting multiple subcarriers signals without energy constraint. How the number of subcarriers influence the estimation accuracy is illustrated by considering the joint Cramer-Rao bound (CRB) and the mean square error (MSE) of the maximum likelihood (ML) estimate. The non-coherent MIMO radar ambiguity function (AF) with multiple subcarriers is developed and investigated by changing the number of subcarriers, the pulse width and the frequency spacing between adjacent subcarriers. The numerical results show that more subcarriers means more accurate estimate and higher localization resolution, larger pulse width results in worse performance of target location estimation, while the frequency spacing affects target location estimation little.

[472] F. Belfiori and P. Hoogeboom. Analysis of a novel mimo system for security applications. In *Phased Array Systems and Technology (ARRAY), 2010 IEEE International Symposium on*, pages 338 –343, oct. 2010.

Abstract: Recent years have shown how the performances of the standard radar systems can be significantly improved by using a multiple-input multiple output (MIMO) approach. MIMO technique is an already well studied method for communications applications thanks to the benefits that it offers in multipath fading environments. This paper is aimed to present the design of a new MIMO based, short range, surveillance radar for local area security purpose. One of the main addressed features to the system under consideration is the capability to provide full 360 azimuth coverage within its working area. The following analysis will be focused on the system structure description and on the first simulated results.

[473] P. Jardin, F. Nadal, and S. Middleton. On wideband mimo radar: Extended signal model and spectral beampattern design. In *Radar Conference (EuRAD), 2010 European*, pages 392 –395, 30 2010-oct. 1 2010.

Abstract: MIMO radar systems can increase the radar resolution, the number of targets that can be identified, and the flexibility in beampattern design in comparison with standard phased array radars. To date, most of the work on MIMO radar has been performed assuming the signals are narrowband. However, wideband signals can improve radar resolution, among other benefits, and are sometimes unavoidable when stringent range resolution specifications must be met. In this paper, we present a method for extending the MIMO narrowband model to a wideband model. Next, from the exact expression of the spatial power distribution involving the CSDM (Cross-Spectral power Density Matrix), we propose a suboptimal transmit beampattern synthesis technique, which can be used in the context of wideband signals.

[474] V.S. Chernyak. Mimo radars. what are they? In *Radar Conference (EuRAD), 2010 European*, pages 137 –140, 30 2010-oct. 1 2010.

Abstract: Two classes of MIMO radars are briefly considered. MIMO radars with colocated antennas and coded signals represent a new and prospective concept. MIMO Radars with widely separated antennas (Statistical MIMO radars) are a particular case of well-known Multisite (Multistatic) radar systems. Most results presented by the authors of Statistical MIMO radars; were obtained under much more general conditions and published many years ago. Besides, ignoring some specific features of radar by the authors of Statistical MIMO radars has led to serious errors.

[475] Y. Kalkan and B. Baykal. Target localization methods for frequency-only mimo radar. In *Radar Conference (EuRAD), 2010 European*, pages 396 –399, 30 2010-oct. 1 2010.

Abstract: When the time resolution of the signals is not so good, we can't rely on the time of arrival (TOA) information. On the other hand, if the frequency resolution of the signals is good, than frequency of arrival (FOA) informations will be more reliable. Localization of a moving, non-maneuvering target is possible by using Doppler-shift measurements in MIMO radar systems. A new method for target localization in frequency-only MIMO radar is proposed and it is compared with previous method. These methods use only received frequencies, and all of other unknown quantities can be written by using locations of the target, the receivers and the transmitters. If the received frequencies are known only, desired area can be searched grid by grid for all possible (x, y) coordinates to find the position of the target in 2D space.

[476] H. Griffiths. Multistatic, mimo and networked radar: The future of radar sensors? In *Radar Conference (EuRAD), 2010 European*, pages 81 –84, 30 2010-oct. 1 2010.

Abstract: A review is presented of work on multistatic, MIMO and networked radar, explaining the current high degree of interest in these subjects. The enhancement of target signatures in the forward scatter geometry is explained, and some of the principles of Passive Bistatic Radar. The challenge here is to identify applications which offer a clear advantage over conventional radar approaches. Finally, some newer, longer term ideas on networked radar as an intelligent, adaptive distributed sensor system are presented and discussed.

[477] B. Boudamouz, P. Millot, and C. Pichot. Through the wall mimo radar detection with stepped frequency waveforms. In *Radar Conference (EuRAD), 2010 European*, pages 400 – 402, 30 2010-oct. 1 2010.

Abstract: In this paper, we present through the wall (TTW) radar detection simulations with an emerging radar architecture which is the multiple-input multiple-output (MIMO) radar. The urban environment, especially in TTW detection, is very tough for radar detection. With the aim of improving the detection performances, we use several spaced antennas in transmission which gives a spatial diversity leading to different points of view of the scene. So as to keep diversity we choose linearly independant waveforms and more particularly we utilize the hyperbolic frequency hop codes. We first begin by introduce the problems and applications of TTW detection. Then we will present the geometric configuration of the scene and the wall attenuation and target modeling. After what, we will expose the waveforms used in transmission and the processing to perform detection. We finish with some preliminary results and conclude about this work.

[478] T. Aittomaki and V. Koivunen. Target detection and positioning in correlated scattering using widely distributed mimo radar. In *Radar Conference (EuRAD), 2010 European*, pages 403 –406, 30 2010-oct. 1 2010.

Abstract: Multiple-input multiple-output (MIMO) radars use different sources of diversity to improve the performance of the radar. A MIMO radar in which angular diversity is achieved by using widely distributed antennas has been proposed to reduce the impact of the fluctuations of the target radar cross-section. This type of system is also known as the statistical MIMO radar. Typically, it has been assumed that the scattering amplitudes of the signals received by different antennas are either fully correlated or independent depending on the configuration. However, the antennas may see similar aspects of the target in some situations leading to correlation in the scattering. In this paper, we show how the correlation of the scattering can be exploited to improve the probability of detection and positioning. This is achieved by using a parametric model for the correlation of the scattering. We also investigate how the correlation can be used for estimating the direction of arrival with an uncalibrated MIMO radar system.

[479] J. Klare and O. Saalmann. Mira-cle x: A new imaging mimo-radar for multi-purpose applications. In *Radar Conference (EuRAD), 2010 European*, pages 129 –132, 30 2010-oct. 1 2010.

Abstract: The research field of MIMO radar offers a bunch of new opportunities for various applications. Imaging MIMO radars can be used as a significant supplement to usual SAR and phased array radars and can extend the common applications for radar. MIRA-CLE X is an X-band MIMO radar consisting of 16 transmit and 14 receive antennas. During signal processing, 224 virtual antenna elements are generated to enable 2D radar imaging. This paper presents the radar system, the signal processing approach as well as a detailed analysis of first imaging results.

[480] Xiaoli Liu and Guisheng Liao. Joint dod and doa estimation using real polynomial rooting in bistatic mimo radar. In *Multimedia Technology (ICMT), 2010 International Conference on*, pages 1 –4, oct. 2010.

Abstract: An algorithm for joint direction-of-departures (DODs) and direction-of-arrivals (DOAs) estimation using real polynomial rooting in bistatic multiple-input multiple-output (MIMO) radar

is presented. Compared with the conventional spectral Capon method, the proposed approach estimates the angles by the alternating maximization (AM) algorithm and one-dimensional real polynomial rooting instead of two-dimensional angle search to reduce the computational burden. The novel real root-Capon method can perform well even without the prior knowledge of the initial values of unknown parameters which is a prerequisite to AM algorithm. Furthermore, the DODs and DOAs of targets can be paired automatically. Numerical examples validate the effectiveness of the algorithm.

[481] Niu Zhaoyang, Zhang Jianyun, and Zheng Zhidong. Angle estimation for bi-static mimo radar based on tri-iterative algorithm. In *Pervasive Computing Signal Processing and Applications (PCSPA), 2010 First International Conference on*, pages 1264 –1267, sept. 2010.

Abstract: The Bi-static MIMO (multiple-input multiple-output) radar signal modal is established in this paper. And the proper coefficient of the MF (matcher filter) is chosen in order to keep the noise output has the same statistical property as the noise input. To make the computational complexity lower and the convergence speed faster, the signal subspace is used as a dimension-reducing matrix. A novel cost function is proposed based on the LS (least squares), which is solved by using the Tri-Iterative Algorithm. Afterwards, a unique closed solution in each iteration which is posed a typical least square problem is derived and the receiving and the transmitting angles are estimated for bi-static MIMO radar. It is worth mentioning that the estimated angles can be paired automatically. Finally, Simulation results are presented to verify the effectiveness of the proposed method.

[482] Shenghua Zhou, Kuiying Yin, Tao Luo, and Hongwei Liu. Target deteciton algorithm for spatial diversity mimo radar with space partition. In *Image and Signal Processing (CISP), 2010 3rd International Congress on*, volume 9, pages 4152 –4155, oct. 2010.

Abstract: For spatial diversity multiple input multiple output (MIMO) radar, target echo signals received by its widely separated antennas may be semi-correlated and different in SNR. According to the correlation and SNRs of received target echo signals, a space partition based target detection method is proposed, which partition the surveillance volume into two sections, one using the coherent accumulating detector and the other using the incoherent accumulating detector. The partition method is shown to achieve an improved detection performance at a low computation cost.

[483] A. YazÄ±cÄ±, A.C. Hamurcu, and B. Baykal. The detection performance of neyman-pearson detector for mimo radar in k-distributed sea clutter. In *Signal Processing and Communications Applications Conference (SIU), 2010 IEEE 18th*, pages 165 –168, april 2010.

Abstract: Use of multiple transmit and receive antennas have become a popular research area in radar community after the success of the same concept in communication. It is shown by Fishler et al. in that multi-input multi-output (MIMO) radar has considerable advantages compared to traditional radar and phased array radar systems. In this paper, detection performance of MIMO radar using Neyman-Pearson detector is investigated in K-distributed sea clutter for a practical scenario. Also, spiki-ness of K-distributed MIMO radar clutter is discussed with respect to the number of nodes.

[484] D. Cerutti-Maori and J. Klare. Coherent mimo radar for gmti. In *Geoscience and Remote Sensing Symposium (IGARSS), 2010 IEEE International*, pages 1085 –1088, july 2010.

Abstract: In addition to imaging, coherent MIMO radars have a strong potential for detecting moving objects and estimating their parameters. This paper investigates different MIMO schemes based on spatial, waveform, and frequency diversity for their GMTI capability. The fully configurable MIMO radar MIRACLE X is taken as the baseline design for comparing the different approaches.

[485] A. Yazici and B. Baykal. Effect of quantization on mimo radar performance. In *Signal Processing and Communications Applications Conference (SIU), 2010 IEEE 18th*, pages 546 –549, april 2010.

Abstract: Multi-input multi-output (MIMO) radar systems have taken considerable attention among radar community in recent years. As stated in some publications MIMO radars have serious performance advantages compared to single-input single-output (SISO) radars. Although MIMO radars perform well theoretically, they have some practical problems. One of these problems is the data transmission rate required by MIMO radars. Quantization directly affects the amount of data to be transmitted. In this paper effects of quantization on MIMO radar performance is covered.

[486] Y. Kalkan and B. Baykal. Target localization methods for frequency-only mimo radar. In *Signal Processing and Communications Applications Conference (SIU), 2010 IEEE 18th*, pages 439 –442, april 2010.

Abstract: In Multi Input-Multi Output (MIMO) radar, the target localization is possible by using only the frequencies of received signals instead of using whole data on the received signals for moving targets. As target is moving, received frequency will be shifted as doppler frequency. Received frequencies which are scattered from non-manouvering and constant speed target, can be written in two dimensional (2D) space with respect to the target coordinates. A cost function can be defined by the help of these frequencies, and than by using grid search, local minimum of this cost function can be found in (x, y) coordinates. In this work, a new target localization method is poroposed for frequency-only MIMO radar.

[487] J. Klare, O. Saalmann, H. Wilden, and A.R. Brenner. Environmental monitoring with the imaging mimo radars mira-cle and mira-cle x. In *Geoscience and Remote Sensing Symposium (IGARSS), 2010 IEEE International*, pages 3781 –3784, july 2010.

Abstract: Several applications need imaging sensors for environmental monitoring which can continuously observe an area in a 24/7 mode independently from the weather and other atmospheric obscuration like dust and smoke. Imaging MIMO radar fulfills these requirements and enables the opportunity of low-cost and robust imaging systems by synthesizing many virtual antennas out of just a few real ones. MIRA-CLE is a fully configurable and expandable experimental MIMO radar in Ka-band while MIRA-CLE X works in X-band and is intended to be a low-cost experimental system for long range applications. This paper presents both MIMO radar systems and shows and discusses first imaging results of MIRA-CLE X.

[488] Yuanwei Jin, N. OrDonoughue, and J.M.F. Moura. Time reversal adaptive waveform in mimo radar. In *Electromagnetics in Advanced Applications (ICEAA), 2010 International Conference on*, pages 741 –744, sept. 2010.

Abstract: EM multipath propagation is common in radar and wireless communications. Most radar systems are designed assuming line-of-sight (LOS), not multipath. In this paper, we extend our prior work on Multi-Input Multi-Output (MIMO) radar in the absence of interference S.J. Anderson and W.C. Anderson. A mimo technique for enhanced clutter selectivity in a multiple scattering environment: Application to hf surface wave radar. In *Electromagnetics in Advanced Applications (ICEAA), 2010 International Conference on*, pages 133 –136, sept. 2010.

Abstract: The significance of multiple scattering processes whereby unwanted Doppler-spread energy can contaminate HFSWR remote sensing measurements has recently been reported. In this paper we present the results of quantitative calculations of the extent of the contamination, and then outline a solution based on the adoption of MIMO radar concepts which have been applied successfully in HF skywave radars.

[489] Changzheng Ma, Tat Soon Yeo, Qiang Guo, Chee Seng Tan, Pingjun Wei, and Guoxiong Xu. Zero correlation zone codes and extended zero correlation zone codes for mimo radar signal separation. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 2345 –2348, oct. 2010.

Abstract: Pseudo random codes are easily constructed and can be used in multiple-input multiple-output (MIMO) radar to provide for signal separation. However it has the drawbacks of high aperiodic cross-correlation and auto-correlation sidelobes. Fortunately, in some applications, codes with low correlations are needed only over a narrow window. In this paper, we introduce the Zero Correlation Zone Codes (ZCZC) which have zero correlations in a narrow zone. In other applications, the targets are stationary, which allows for using a long code sequence. In this case we propose an Extended Zero Correlation Zone Codes (EZCZC) where the zero correlation zone is extended to cover the whole sidelobes area. Design examples are given.

[490] Xiang-Ru Li, Zhao Zhang, Wu-Xing Mao, Xiao-Mo Wang, Jun Lu, and Wen-Sheng Wang. A study of frequency diversity mimo radar beamforming. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 352 –356, oct. 2010.

Abstract: Compared to traditional phased-array radar, multiple-input multiple-output (MIMO) radar can transmit multiple probing signals that are correlated or uncorrelated with each other. An interesting current research topic in MIMO radar is the frequency diversity MIMO (f-MIMO) radar. The frequency between two adjacent transmitted signals of f-MIMO radar are not identical but stepped uniformly at the same time. In this paper, a f-MIMO radar array processing model is developed. It is shown that the f-MIMO radar array processing can form a range-dimension beam, so it has the ability to distinguish targets in different ranges. The range resolution of array processing is derived, and then, the virtual array aperture of f-MIMO radar is also investigated.

[491] Xu Hao, He Xuezhi, Yin Zhiping, Wang Dongjin, and Chen Weidong. Compressive sensing mimo radar imaging based on inverse scattering model. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 1999 –2002, oct. 2010.

Abstract: From the view of inverse scattering imaging, the paper gives basic principle of MIMO radar imaging, then applies compressive sensing (CS) to two methods. The first method is sampling and receiving echoes randomly in both frequencies and channels. The second method is sampling echoes randomly only in frequencies, and controllable space intersection is done in channels to increase the practicability. Both methods can achieve high image resolution using few echo samples. The first method has better imaging quality, but the second method is more controllable. Ulteriorly, the simulation gives detailed analysis of imaging quality and reconstruction successful probability, which is beneficial to applications of CS to MIMO radar imaging.

[492] Hao-Wen Chen, Wei Zhou, Xiang Li, and Zhao wen Zhuang. Cramer-rao bounds for estimating velocity and direction with a bistatic mimo radar. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 2142 –2146, oct. 2010.

Abstract: We derive Cramer-Rao bounds (CRB) expressions for the velocity (Doppler shift), and direction of a point target using a bistatic multiple-input multiple-output (MIMO) radar in this paper. First, we introduce the signal and noise models which satisfy the space-time separability conditions. Then, general CRB expressions are derived for a narrowband signals with the above signal and noise models. We find that the directional parameters are uncoupled with Doppler shift for the space-time separable signal and noise models. However, the directional parameters are usually coupled with each other, i.e., the direction-of-departure (DOD) with direction-of-arrival (DOA) and the azimuth angles the elevation angles are ordinarily coupled. Fortunately, the uncoupled direction estimation can be gotten by the specifical antennas placement.

[493] Niu Zhaoyang, Zhang Jianyun, Mao Yunxiang, and Wang Wei. Study of array collocation for mimo radar based on beampattern synthesis. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 1931 –1934, oct. 2010.

Abstract: The beampattern of MIMO (Multiple-input Multiple-output) radar is the product of transmitter and receiver beam pattern. Exploiting uniform linear array, the beampattern has no grating lode when a certain relation between the space of transmitter element and receiver element is met. Moreover, this kind of collocation takes on maximum virtual array aperture. Exploiting non-uniform linear array, the beampattern will have better performance. Giving the restriction of array aperture and the number of element and constructing objective function based on minimum side lobe, we make use of GA (generic algorithm) to optimize the element position and then get the non-uniform linear array collocation scheme. Simulations verify the validity of the proposed method.

[494] Wang Yong-liang, Xie Wen-chong, Duan Ke-qing, and Zhang Xi-chuan. General clutter modeling for airborne radar. In *Signal Processing (ICSP), 2010 IEEE 10th International Conference on*, pages 2274 –2278, oct. 2010.

Abstract: Clutter returns in airborne radar applications spread in Doppler frequency because of platform motion. The clutter characteristics should be analyzed in detail for designing clutter

suppression algorithms. In this paper, clutter modeling method for conventional phased array airborne radar, multiple-input-multiple-output (MIMO) airborne radar, and hybrid MIMO-phased array airborne radar, all with arbitrary antenna array, is presented. Modeling of clutter intrinsic motion, sensor error, subarraying is also considered.

[495] K.V. Shanbhag, D. Deb, and M. Kulkarni. Mimo radar with spatial-frequency diversity for improved detection performance. In *Communication Control and Computing Technologies (ICCCCT), 2010 IEEE International Conference on*, pages 66 –70, oct. 2010.

Abstract: The Multiple Input Multiple Output (MIMO) radar concept exploits the independence between signals at the array elements unlike beamforming which presumes a high correlation between signals either transmitted or received by an array. Radar Cross Section (RCS) of a complex target varies with both transmitted frequency and target geometry. By widely separating transmit and receive antennas, MIMO radar systems observe a target simultaneously from different aspects resulting in spatial diversity, thus improving the detection performance. Also by utilizing different frequencies, independent RCS of the target can be observed, thus resulting in frequency diversity. In this paper, the spatial and the frequency diversities are studied together to bring out the combined benefits. The system proposed will not only have several antennas appropriately spaced but also several operating frequencies appropriately spaced, providing a better detection performance than conventional MIMO radar systems for the same transmission power. The simulation results exhibit a better detection performance of the proposed system as compared to MIMO radar systems with only spatial diversity.

[496] Young-Man Kim, Jung-Hun Oh, Anh-Duy Vu, Jin-Won Kim, Jun-Soo Jeon, Seung-Min Lee, and Jea-Il Han. Long range detection using a pdr sensor combined with mimo antenna. In *Information and Communication Technology Convergence (ICTC), 2010 International Conference on*, pages 450 –454, nov. 2010.

Abstract: The Pulse-Doppler radar (PDR) is a radar system capable of not only detecting the location of a fixed object, but also measuring its radial velocity by using the Doppler Effect. Taking these abilities, in this paper, we introduce a new PDR sensor which is combined with a Multiple-Input-and-Multiple-Output (MIMO) antenna system in order to enhance the detection range up to 120m. In the experiments at Kookmin University, the proposed sensor performed well to detect moving car at distance 130m - further than we had expected.

[497] Xuhua Huang, Jinmang Liu, and Xiangjun Li. The adaptive detector of mimo radar and its performance. In *Information Engineering and Computer Science (ICIECS), 2010 2nd International Conference on*, pages 1 –4, dec. 2010.

Abstract: Aiming at that the echo signal lies on the target characteristic in target detection of MIMO radar, namely the RCS of target determines the echo intensity, MIMO radar adaptive detector is based on the GLRT MIMO radar. It samplings in the radar receiver, makes the test be related to the SNR and sample size, and overcomes that the amplitude of echo effect detector's performance. then The better detector is achieved. The relative entropy, which is used to test the detection performance can represent the effect of the sample size on the detection performance. It is proved by the entropy that the MIMO detector is feasible and advanced.

[498] K. Ahmed, S. Kothuri, M. Patwary, and M. Abdel-Maguid. Subspace compressive glrt detector for airborne mimo radar. In *Communications (APCC), 2010 16th Asia-Pacific Conference on*, pages 302 –306, 31 2010-nov. 3 2010.

Abstract: In this paper, the design of a subspace compressive GLRT (SSC-GLRT) detector has been pursued for MIMO airborne radar system when the secondary sets of data are available in addition to the primary one. It is observed that with very reduced amount of measurement data at sub-Nyquist rate that is equal to the number of virtual bi-static radar in the presence of a single target, SSC-GLRT provides the same performance as the conventional GLRT with much larger length of the data, i.e., an order of magnitude higher given by the product of the number of elements in the received antenna array and coherent pulse interval (CPI). Therefore, SSC-GLRT is much energy efficient and useful in the scenario where the computational complexity becomes a burden. Also, this paper illustrates an elegant way of mapping the angular and Doppler domain to an one dimensional discrete vector for the formulation of compressive sampling (CS) based reconstruction of the signal subspace when it is unknown so that it can successively be used in SSC-GLRT. The simulation example further corroborates the effectiveness of the proposed SSC-GLRT detector.

[499] H. Godrich, A. Petropulu, and H.V. Poor. Power allocation schemes for target localization in widely distributed mimo radar systems. In *MILITARY COMMUNICATIONS CONFERENCE, 2010 - MILCOM 2010*, pages 846 –851, 31 2010-nov. 3 2010.

Abstract: Widely distributed multiple-input multiple-output (MIMO) radar systems offer parameter estimation improvement for target localization, proportional to the product of the number of transmitting and receiving radars and the total transmitted power. Thus far, power allocation has been uniformly distributed between the system transmitters. For a large number of radars, the achievable localization mean-square error (MSE), with full resource allocation, may extend beyond the system predetermined performance goals, such as target localization accuracy (i.e., minimum estimation MSE) and total power radiation. In this study, power allocation schemes are developed, taking into account system constraints. The first is concerned with minimizing the total transmitted power such that a predefined estimation MSE objective is met, while keeping the transmitted power at each station within an acceptable range. The second, optimally distributes a given power budget among all transmitting radars to maximize performance, i.e., minimize the attainable localization MSE. As the Cramer-Rao bound (CRB) is known to be asymptotically tight to the maximum likelihood estimator (MLE) MSE at high SNR, it is used as a metric for the estimation MSE. The CRB is derived for a signal model that incorporates the propagation path loss, the target radar cross section (RCS), and the transmitters' powers. It is shown that uniform or equal power allocation is not in general optimal and that the proposed allocation algorithms result in a local optimum that provided either better localization MSE for the same power budget or requires less power to establish the same performance in terms of estimation MSE. A physical interpretation of these conclusions is offered.

[500] Yao Yu, P.P. Athina, and H.V. Poor. Robust target estimation in compressive sensing based colocated mimo radar. In *MILITARY COMMUNICATIONS CONFERENCE, 2010 - MILCOM 2010*, pages 852 –857, 31 2010-nov. 3 2010.

Abstract: A colocated multiple-input multiple-output (MIMO) radar system is considered, in which the transmitters and receivers are nodes of a small scale wireless network. The sparsity of

targets in the illuminated space allows target detection based on compressive sensing (CS) techniques. A receive node compresses the received signal via a linear transformation, referred to in CS theory a measurement matrix. The compressed samples are subsequently forwarded to a fusion center, where an optimization problem is formulated and solved for target information. CS-based MIMO radar achieves the same localization performance as do traditional methods but with many fewer measurements. Unlike previous work, we consider the case in which the targets might be located across several range bins, and the delay of the first reflected signal is unknown and, due to the small number of compressed samples, cannot be estimated accurately. A new measurement matrix is proposed that is constructed based on the transmit signal waveforms and also accounts for all possible discretized delays of target returns within a given time window. It is shown that reduced bandwidth transmit waveforms can lead to a measurement matrix that improves signal-to-interference ratio (SIR), but on the other hand, using waveforms that are too narrowband increases the coherence of the sensing matrix, thus invalidating the conditions for the application of the CS approach. Therefore, the transmit waveforms must be chosen carefully to guarantee the desired performance.

[501] Lei Xu and Qilian Liang. Orthogonal pulse compression codes for mimo radar system. In *Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE*, pages 1 –5, dec. 2010.

Abstract: Inspired by recent advances in MIMO radar, we introduce orthogonal pulse compression codes to MIMO radar system in order to gain better target direction finding performance. We propose the concept and the design methodology for the optimized ternary pulse compression codes called the optimized punctured Zero Correlation Zone sequence-Pair Set (ZCZPS). According to codes property analysis, our proposed codes are able to provide the optimized autocorrelation and cross correlation properties during ZCZ. We also present a generalized MIMO radar system model using our proposed codes as pulse compression codes and simulate the target direction finding performance of the fluctuating and nonfluctuating system. The simulation results show that the more antennas used, the better target direction finding performance could be provided.

[502] A-Lei Chen, Dang-Wei Wang, and Xiao-Yan Ma. An improved bp algorithm for high-resolution mimo imaging radar. In *Audio Language and Image Processing (ICALIP), 2010 International Conference on*, pages 1663 –1667, nov. 2010.

Abstract: The back-projection (BP) algorithm is a popular imaging method. Nevertheless, there exists a difficulty that the cross-range resolution acquired by the standard BP algorithm is dependent on the bandwidth of transmitted signal when the BP algorithm is directly used to the multiple-input multiple-output (MIMO) radar for imaging a target in the cross-range direction without any variation. In this paper, an improved BP algorithm is presented for high-resolution MIMO imaging radar to avoid the difficulty associated with the standard BP algorithm. Furthermore, the theoretical expression of the cross-range resolution associated with the improved BP algorithm is given. Different from the standard BP algorithm, the cross-range resolution acquired by the presented BP algorithm can be independent on the bandwidth of transmitted signal since the presented algorithm can straight an integration curve and make the received echoes on the integration curve be focused by phase aligning to avoid the truncation error produced by the range resolution value. Simulations based on synthetic data are provided for testing the presented method.

[503] Qi Yang, Li Jun, Liu hongming, and Li huiyong. Analysis of anti-interception performance of mimo radar. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –3, dec. 2010.

Abstract: As a new radar system, MIMO radar has become the hotspot in radar research. Because the key point of radar's viability in battlefield is its RF stealth ability. Tough the analysis of radar transmit power and the LFM signal detect technique based on time-frequency analysis, this paper makes a discussion on the discrepancy of the anti-interception performance between MIMO radar and conventional phased array radar, and therefore draws some meaningful conclusions.

[504] Sun Ying, Zishu He, Hongming Liu, Li Jun, and Shangwei Gao. Binary orthogonal code design for mimo radar systems. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: Multiple Input Multiple Output (MIMO) radar can effectively improve radar performance by transmitting specially designed orthogonal signals. A novel algorithm is presented to design binary orthogonal code for MIMO radar system. The proposed algorithm employs the Walsh function to maintain the orthogonal property of signals. The binary orthogonal code set is obtained by executing synchronal random exchange in column and random selection from rows to coding template, with using Genetic Algorithm (GA) for optimization. The simulation results show that the algorithm is feasible.

[505] Chao Li, Hongming Liu, Jun Li, HuiYong Li, and Bin Wu. Parameter selection of mimo radar under the long time integration. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: Long time integration is a common work mode for multiple-input multiple-output (MIMO) radar. In this mode, the accumulation effect is seriously affected by range migration. To solve this problem, we derive an expression, which describes how the accumulation output changes with the target velocity, bandwidth, and other factors, based on the MIMO radar moving target echo model. This expression quantifies the relation between the range migration and the influence factors. It can be used to determine the range of the target velocity in which the motion compensation is needed. Further, through appropriate parameter selection, such as choosing a proper transmission bandwidth etc., the influence of the range migration on accumulation output is minimized. The correctness of the theoretical results is verified by simulations.

[506] Yongzhe Li, Zishu He, Jun Li, HuiYong Li, and Hongming Liu. A model of non-coherent airborne mimo space-time adaptive processing radar. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: Compared to single-input multiple-output (SIMO) radar, airborne multiple-input multiple-output (MIMO) space-time adaptive processing (STAP) radar transmits mutually orthogonal or non-coherent waveforms. The waveform diversity increases degrees of freedom (DOFs) of MIMO STAP radar and results in the variation of clutter characteristics. To make things worse, there exists many non-ideal factors in practical project that affect performance of MIMO STAP. Considering all such situations, we derive the covariance matrix of echo signals by utilizing waveform covariance matrix (WCM) and error covariance matrix tapering (CMT) to simplify the MIMO STAP in this paper. Signal to interference plus noise ratio (SINR)

performance simulation results verify that MIMO STAP radar has a better spatial resolution than SIMO radar generally and improving in orthogonality of transmitting waveforms can obtain a better SINR performance.

[507] Guolong Cui, Lingjiang Kong, Xiaobo Yang, and Jianyu Yang. Adaptive polarimetric mimo radar detection. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: This paper mainly deals with the target detecting problem using polarimetric Multiple Input and Multiple Output (MIMO) radar with unknown covariance matrix. And the GLRT-based receiver is devised by resorting to the two-step design procedure. Specifically, the GLRT is devised with known covariance, and then, a suitable estimate of covariance is obtained using secondary data to plug into the derived test. The performance is assessed by several numerical examples, and the results show that polarimetric diversity can be exploited to enhance the performance of detection. Moreover, the adaptive loss is acceptable.

[508] Yuyu Liao and Zishu He. Statistical mimo radar based on coherent signals. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: Multi-Input and Multi-Output (MIMO) radar was a new radar technology in the recent years, which used spatial diversity gain of the signal instead of coherent gain in traditional phased-array radar. Using the ideal point source model, this paper made an analysis of these two kind gain's contribution to radar detection system, which was divided into two classes: the contribution to system robustness and the contribution to improve the signal-to-noise ratio. Based on this, proposed that the MIMO radar's space diversity gain could make more contribution to signal-to-noise ratio, which rationality was showed by the modification of the statistical MIMO model. The above theory was verified by simulation.

[509] Shuangling Wang, Qian He, and Zishu He. Compressed sensing moving target detection for mimo radar with widely spaced antennas. In *Intelligent Signal Processing and Communication Systems (ISPACS), 2010 International Symposium on*, pages 1 –4, dec. 2010.

Abstract: The moving target detection based on compressed sending (CS) multiple-input multiple output (MIMO) radar with widely separated antennas is studied. The centralized processing is considered. The traditional centralized MIMO radar requires an exhaustive search on every possible two dimensional target velocity, resulting in huge computational complexity. In this paper, we adopt the CS technique to drastically reduce the computational burden and evaluate the reduction of the required complexity. We derive the moving target detector for the CS MIMO radar. The performance of the proposed detector is analyzed, and the receiver operating characteristic (ROC) curves are provided.

[510] A.A. Gorji, R. Tharmarasa, and T. Kirubarajan. A new co-located mimo radar system for multi-target tracking and localization. In *Information Fusion (FUSION), 2010 13th Conference on*, pages 1 –8, july 2010.

Abstract: Multiple Input Multiple Output (MIMO) radars are a new generation of radar systems that bring with them many benefits compared to traditional phased-array and multistatic radars.

Target localization using MIMO radars with co-located antennas has been recently discussed in the literature. It has been shown that the maximum number of targets that can be uniquely localized in one cell is bounded. This paper presents a new application of MIMO radars in Multi-Target Tracking (MTT) problems. Firstly, the previous model for co-located MIMO radars is modified in order to guarantee the observability in received measurements. Afterwards, it is shown that using prior information about the motion of targets relaxes the limitation on the number of uniquely localized targets. For filtering part, an Un-scented Kalman Filter (UKF) algorithm is used to update states of targets. Simulation results confirm the superiority of proposed approach in estimating states of multi-targets falling in the same resolution cell.

[511] Xiaojin Shi and Yunhua Zhang. Iterative dem retrieving from multi-baseline interferometric sar with mimo. In *Microwave Conference Proceedings (APMC), 2010 Asia-Pacific*, pages 1388 –1391, dec. 2010.

Abstract: In the recent years, there has been growing interest in exploiting multi-baseline synthetic aperture radar interferometry (MB-InSAR) to solve layover effects and phase unwrapping problem of long baseline. In this paper we propose a novel system concept for MB-InSAR based on Multiple-Input Multiple-Output (MIMO) configuration. Alamouti space-time coding scheme based on two transmitters is introduced into multi-baseline InSAR system. We investigate its performance and processing features based on our space-borne multi-baseline InSAR simulator and iterative multi-baseline data fusion algorithm. The simulation results shows that the received signal to noise ratio (SNR) and the precision of iterative multi-baseline data fusion algorithm are significantly improved under Alamouti scheme.

3.5 Conference papers published in 2011

[512] B. Chakraborty, J.J. Zhang, A. Papandreou-Suppappola, and D. Morrell. Waveform-agile mimo radar for urban terrain tracking. In *Digital Signal Processing Workshop and IEEE Signal Processing Education Workshop (DSP/SPE), 2011 IEEE*, pages 466 –471, jan. 2011.

Abstract: We investigate the problem of tracking a moving target in urban terrain using a multiple-input and multiple-output (MIMO) radar system. Our proposed method aims to maximize the target information using an optimal configuration of MIMO widely-separated radar sensors while exploiting multipath returns from all the sensors. Furthermore, we adaptively configure the parameters of the transmit waveforms of the MIMO system at each time step in order to minimize the overall mean-squared tracking error. We demonstrate our results using a realistic urban environment, by varying the regions of obscuration and the number of bounce path returns. An important advantage of the MIMO system is that, based on the radar configuration, it is possible to completely eliminate the obscuration regions.

[513] Y. Kochman and G.W. Wornell. Finite multi-coset sampling and sparse arrays. In *Information Theory and Applications Workshop (ITA), 2011*, pages 1 –7, feb. 2011.

Abstract: Signals with sparse but otherwise unknown frequency content are well-represented by multi-coset samples, and efficient algorithms can be used to recover the underlying sparsity structure. While such sampling is usually analyzed over a sampling interval sufficiently large that edge effects can be ignored, in this work we develop how to take into account finite-window effects in system design. Such considerations are particularly important in the context of antenna arrays, and we analyze the associated redundancy. Additionally, we describe an efficient MIMO radar implementation of multi-coset arrays. As an example application of our results, we develop a natural two-stage architecture for direction-of-arrival estimation in sparse environments using a multi-coset array over the available aperture.

[514] R.A. Coogle, J.D. Glass, L.D. Smith, P. Miceli, A. Register, P. West, and W.D. Blair. A mimo radar benchmarking environment. In *Aerospace Conference, 2011 IEEE*, pages 1 –10, march 2011.

Abstract: With the growing amount of research being devoted to the concept of multiple-input multiple-output (MIMO) radar, there has been a lack of a common simulation and benchmarking environment for determining the viability and cost-effectiveness of MIMO radar architectures and algorithms. To this end, GTRI has developed a MIMO Benchmark environment to serve this purpose, which is to be made publically available to researchers in order to compare the performance of MIMO techniques with those of more conventional phased array radar systems. This paper describes the problem that the MIMO Benchmark is intended to be used to assist in solving, in the form of a new challenge problem for the MIMO community, as well as providing a summary of the architecture of the MIMO Benchmark infrastructure.

[515] T. Backes and D. Smith. Waveform optimization in a mimo radar benchmark environment. In *Aerospace Conference, 2011 IEEE*, pages 1 –5, march 2011.

Abstract: Multiple-input and multiple-output (MIMO) radar systems have garnered significant interest due to their ability to generate additional target radar returns. These additional returns have the potential to improve tracking performance in terms of target tracking accuracy and resource use. This effort examines radar pulse control for target tracking optimization in a MIMO radar architecture. Specifically, an optimization algorithm based on the Cramer-Rao lower bound on the target state is implemented. The performance of the optimized tracker is compared to a conventional tracking algorithm in the Benchmark radar simulation environment. The difficulties in achieving significant performance improvements through MIMO techniques in a conventional radar system architectures are elucidated.

[516] J.D. Glass and L.D. Smith. Mimo radar resource allocation using posterior cramer-rao lower bounds. In *Aerospace Conference, 2011 IEEE*, pages 1 –9, march 2011.

Abstract: A technique is presented that will determine an efficient set of transmitters in a MIMO radar event based on tracking accuracy and energy consumption. The posterior Cramer-Rao lower bound (PCRLB) will provide the means of determining these optimal transmitters by placing a bound on the variance of the track state estimate. This is a predictive PCRLB since it is calculated before any measurements are taken. Optimal transmitters are chosen by minimizing a proposed cost function that incorporates the PCRLB, along with number of transmitters in the MIMO event. To account for measurement origin uncertainty, an information reduction factor (IRF) will be incorporated in the calculation of the PCRLB for each predicted measurement. Since the complexity of the cost calculation increases exponentially with the number of sensors, several approximations are made for the calculation of the PCRLB and IRF. The jacobian matrix for the sine space measurement equations are derived for use in the calculation of the PCRLB. This resource allocation scheme is evaluated using the GTRI/ONR MIMO Radar Benchmark with metrics including track completeness ratio and total cumulative energy consumption.

[517] D. Maì rquez, J. Valera, A. Camelo, C. Aceros, M. Jimeì nez, and D. Rodriguez. Implementations of cyclic cross-ambiguity functions in fpgas for large scale signals. In *Circuits and Systems (LASCAS), 2011 IEEE Second Latin American Symposium on*, pages 1 – 4, feb. 2011.

Abstract: This work presents theoretical formulations and algorithm development techniques for implementing the cross-ambiguity function on field programmable gate arrays (FPGA). Signal algebra operator techniques are utilized to formulate the cross-ambiguity function as a composition of cyclic mappings over finite dimensional Hilbert spaces. These formulations of linear operator compositions are proven to be essential to effect large scale FPGA implementations. Results are presented for Virtex 5 implementations of cross-ambiguity function operations using high order numeric sequences of up to 16384 samples in length. These results are being used in the development of a modeling framework for the study of MIMO radar waveform diversity design.

[518] Wen-Qin Wang. Mimo-based sar ground moving target detection approach. In *Intelligent Computation Technology and Automation (ICICTA), 2011 International Conference on*, volume 2, pages 608 –611, march 2011.

Abstract: This paper proposes a scheme of multiple-input and multiple (MIMO) synthetic aperture radar (SAR) for ground moving targets detection. The proposed approach employs MIMO configuration with multiple antennas in azimuth and orthogonal waveform diversity. After cancelling the clutter and estimating the along-track velocity of the moving targets with the proposed double-interferometry processing technique and estimating the Doppler parameters of the moving targets with a simplified fractional Fourier transform (SFrFT) algorithm, ground moving targets detection can then be obtained by jointly processing algorithm.

[519] S. Gogineni and A. Nehorai. Target estimation using compressive sensing for distributed mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 793 –797, nov. 2010.

Abstract: Distributed Multiple Input Multiple Output (MIMO) radar systems enable viewing the targets from different angles, thereby providing spatial diversity gain. In this paper, we propose an approach to accurately estimate the parameters (position, velocity) of multiple targets using such systems from fewer number of samples by employing compressive sensing. We also introduce a new metric to analyze the performance of the radar system. We show the improvement in performance over conventional Single Input Single Output (SISO) radar systems due to the spatial diversity offered by MIMO radar. We also demonstrate that the sampling rates can be significantly reduced by using compressive sensing at the receivers.

[520] J.M. Kantor and D.W. Bliss. Clutter covariance matrices for gmti mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 1821 –1826, nov. 2010.

Abstract: We examine the clutter covariance matrices for ground moving-target indicator (GMTI) multiple-input, multiple-output (MIMO) radar systems, and, in particular, discuss a potential suboptimal increase in their rank. This increase in rank will generically degrade the ability of a MIMO GMTI system to detect slowly moving targets. We first give a general theoretical analysis and then focus on simulated and experimental data for MIMO systems employing fast-time random, time-division multiple-access (TDMA), and Doppler-division multiple-access (DDMA) waveforms. We will show that for the TDMA/DDMA waveforms the clutter covariance matrix in a given Doppler bin is effectively rank 1 for both the simulated and experimental data.

[521] Changyu Sun and D.R. Fuhrmann. Joint estimation of target reflectivity and local oscillator phases in a mimo radar system with distributed assets. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 1986 –1990, nov. 2010.

Abstract: Synchronization across multiple distributed apertures is the standard assumption in proposed multiple-input multiple-output (MIMO) radar systems. However, perfect phase synchronization is difficult to realize. Assuming frequency synchronization, probably through a GPS system or reception of a beacon, we address the issue of unknown LO phases of local oscillators in a MIMO radar system, and consider the problem of joint estimation of target

reflectivity and LO phases. The bistatic target reflectivity is subject to a complex normal prior distribution given by a multiple point scatterer model and LO phases are assumed independent and identically distributed random variables.

[522] J. Salmi, S. Sangodoyin, and A.F. Molisch. High resolution parameter estimation for ultra-wideband mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 2129 –2133, nov. 2010.

Abstract: In this paper, remote vital sign detection using UWB MIMO radar is investigated. The UWB MIMO channel, which includes the test subject as well as other objects, is modeled as a superposition of propagation paths. Estimation of the path parameters, such as delays and directions, allows to identify and track the breathing pattern, and enable the localization of the target. Modification of the high-resolution RIMAX algorithm (iterative maximum-likelihood estimation scheme) together with a path detection scheme, enables estimation of delay variations of the diaphragm-reflected paths, that are much smaller than the Fourier resolution limits. Furthermore, it is illustrated that with a wideband array model, the requirements for antenna spacing are not as limited as for conventional narrowband array processing. The concept is demonstrated through a controlled experiment using an artificial breathing object in an anechoic chamber.

[523] J. Yu and J. Krolik. Quadrature slow-time mimo radar with experimental results. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 2134 –2137, nov. 2010.

Abstract: Multiple-input multiple-output (MIMO) radar requires orthogonal waveforms to be transmitted on each transmit element or subarray. One practical problem that arises is the complexity and expense of the hardware needed to implement MIMO radar. Slow-time MIMO waveforms, often referred to as SLO-MO waveforms, allow the implementation of MIMO radar without any hardware modifications to the receiver. However, generation of the SLO-MO MIMO waveforms on the transmitter typically requires a multichannel arbitrary waveform generator, variable RF phase shifters, or using multiple carrier frequencies. All of these options can be expensive, especially at microwave frequencies. This paper describes a technique to generate SLO-MO MIMO waveforms using low-cost passive frequency mixers with existing (non-MIMO) radar architectures. Passive frequency mixers are inexpensive and easy to add inline to existing radar transmitters. This paper presents the concept of double-sideband and quadrature MIMO slow-time radar, along with experimental results from the Duke S-band radar testbed.

[524] M. Zatman. The applicability of gmti mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 2138 –2142, nov. 2010.

Abstract: MIMO Radar has been proposed as a technique for improving the Minimum Detectable Velocity (MDV) performance of airborne radar systems. However, the increased pulse repetition frequency associated with waveform multiplexing techniques used in GMTI MIMO Radar increases the amount of range ambiguous clutter the radar must suppress, reducing the amount of clutter-free Doppler space available to detect targets and often degrading MDV performance. This paper evaluates this effect and quantifies the conditions where MIMO radar is advantageous, and

those where it is not. Results show that this form of MIMO radar is often a disadvantage at higher operating frequencies.

[525] B. Friedlander. Mimo-vsar: A high resolution radar system for imaging moving scenes. In *Signals, Systems and Computers (ASILOMAR), 2010 Conference Record of the Forty Fourth Asilomar Conference on*, pages 2143 –2147, nov. 2010.

Abstract: The Velocity SAR (VSAR) is a SAR-based sensor system for high resolution imaging of moving scenes such as the ocean surface. VSAR utilizes data collected by a multi-element SAR system, to extract information not only about the radar reflectivity of the observed area, but also about the radial velocity of the scatterers in each pixel. This is accomplished by making use of the phase information contained in multiple SAR images, and not just the magnitude information as in conventional SAR. Using this velocity information, the VSAR is able to compensate for the velocity distortion inherent in conventional SAR. MIMO-VSAR is an extension of VSAR employing multiple transmit antennas using orthogonal waveforms. The operating principle and basic design tradeoffs of MIMO-VSAR are presented herein.

[526] Frank Gumbmann and Lorenz-Peter Schmidt. Short range imaging with optimized sparse array. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: This paper presents a MIMO imaging system on the basis of a hybrid concept with synthetic aperture radar (SAR) and digital beam forming (DBF). By moving a multistatic linear array perpendicular to the array dimension a two dimensional aperture is sampled. The scope of application is the field of non destructive testing (NDT) and security systems. Thus the frequency range 75-90 GHz seems to be a good compromise between lateral resolution and penetration depth. A moderate number of transmit and receive channels is achieved by a sparse periodic array (SPA) design. Since this is a far field approach, ambiguities are not well suppressed in the near field point spread function of the sparse array. Therefore an optimized array was developed as well as a post processing algorithm on the basis of a notch filter. This notch filter is applied to attenuate the main part of the ambiguous energy in the doppler spectrum. Results are demonstrated with simulated and measured data.

[527] Michael C. Wicks, Yuhong Zhang, and Richard Schneible. A generalized inner product based algorithm for improved detection and discrimination of over resolved targets in mimo radar. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: A technique is proposed to achieve significantly better detection and discrimination for stationary or slow-moving range-Doppler over-resolved targets on or in close proximity to the ground (or sea surface). This technique is based upon a generalized inner product (GIP) approach to data analysis. This robust detector/discriminator separates radar returns from interference including ground clutter via a coherent process for separating target returns from the myriad of received signals. This GIP-based processing can be applied to single-receiver channel systems, multiple spatial channel systems, multiple polarization channel systems, systems with multiple spatial and polarization channels and MIMO distributed aperture radar.

[528] Hongbin Li and Braham Himed. Transmit subaperturing for mimo radars with co-located antennas. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: We present a transmit subaperturing (TS) approach for MIMO radars. A TS-MIMO radar offers a continuum of operating modes from the phased-array radar, which achieves the maximum directional gain but least interference rejection ability, to the omni-directional transmission based MIMO radar, which can handle the largest number of interference sources but offers no directional gain. Tuning of the TS-MIMO system can be made by changing the configuration of the transmit subapertures, which provides a direct trade-off between the directional gain and interference rejection power. The output SINR of the TS-MIMO radar is examined in an interference and training limited environment.

[529] Jens Klare, Olaf Saalmann, Helmut Wilden, and Andreas R. Brenner. First experimental results with the imaging mimo radar mira-cle x. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: MIMO radar for imaging is a quite new and promising research field with a big potential for various applications. Three different imaging radars based on the MIMO principle are currently developed at Fraunhofer FHR. This paper describes the ground based X-band MIMO radar MIRA-CLE X. This radar consists of 16 transmit and 14 receive antennas which are arranged in a special way to synthesize a fully and equally spaced virtual antenna array of 224 elements during signal processing. First image results of MIRA-CLE X are presented and discussed.

[530] Xing Tan, William Roberts, Jian Li, and Petre Stoica. A new sparse sensing approach for mimo radar imaging. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: Multiple-input multiple-output (MIMO) radar can provide higher resolution, improved sensitivity, and increased parameter identifiability compared to phased-array radar schemes. When a scene of interest contains only a limited number of targets, sparse signal recovery algorithms, including many l1-norm based approaches, can be used to perform MIMO angle-range-Doppler imaging. Herein, we present a regularized minimization approach to sparse signal recovery. Sparse Learning via Iterative Minimization, or SLIM, follows an lq-norm constraint, and can thus be used to provide sparser estimates, compared to the l1-norm based approaches, for MIMO radar imaging.

[531] Helmut Wilden, Jens Klare, Andreas Froehlich, and Michael Krist. Mira-cle, an experimental mimo radar in ka band. *Synthetic Aperture Radar (EUSAR), 2010 8th European Conference on*, pages 1 –4, june 2010.

Abstract: The experimental short range broadband surveillance radar system MIRA-CLE in Ka band is described in this paper. Based on the MIMO principle, the modular system consists of 16 transmitters and 16 receivers being arranged and excited in such a manner, that its cross range resolution is two times better compared to a 256 element conventional phased array. To improve the data acquisition rate for fast changing scenes, the waveform diversity method is applied. This means, each transmitter simultaneously transmits its individual modulated code being part of a set

of optimized orthogonal codes suitable for MIMO radar. The signal allocation to the individual transmit elements and the determination of the regularly spaced virtual RX phase centres are derived by signal processing. The technology of MIRA-CLE key components within the RF frontend is presented.

[532] K. Rezer, W. GropengieÃŸer, and A.F. Jacob. Particle swarm optimization of minimum-redundancy mimo arrays. In *Microwave Conference (GeMIC), 2011 German*, pages 1 –4, march 2011.

Abstract: Minimum-redundancy multiple-input multiple-output (MR-MIMO) antenna arrays - a class of thinned arrays - are introduced. The concepts of convolution array and correlation array are used for data processing required for radar applications but also for optimization of the element distribution in such arrays. An upper bound for the achievable thinning rate is estimated. Particle swarm optimization (PSO) is applied to optimize the element distribution of some linear, monostatic MR-MIMO arrays with up to 12 elements.

[533] Yang Yang and R.S. Blum. Broadcast consensus based phase synchronization for coherent mimo radar. In *Information Sciences and Systems (CISS), 2011 45th Annual Conference on*, pages 1 –6, march 2011.

Abstract: Multiple-input multiple-output (MIMO) radar can achieve improved localization performance by employing a coherent processing approach with proper antenna positioning. Different from the noncoherent counterpart, coherent processing entails the challenge of ensuring phase coherence of the carrier signals from different distributed radar elements. In this paper, we propose a broadcast consensus based algorithm for reaching a common notion of phase in coherent MIMO radar. This algorithm is distributed and iterative in nature. It does not require a priori establishment of the time synchronization, and is thus time asynchronous. We mathematically characterize this algorithm, and further study some statistical properties of the resulting phase synchronization error. Simulation results are presented to demonstrate the performance of the proposed algorithm, as well as to validate our theoretical analysis.

[534] Yang Yang and R.S. Blum. Some phase synchronization algorithms for coherent mimo radar. In *Information Sciences and Systems (CISS), 2011 45th Annual Conference on*, pages 1 –6, march 2011.

Abstract: Practical realization of the coherent processing in widely separated multiple-input multiple-output (MIMO) radar systems requires the development of implementable techniques to ensure a common notion of phase among all the distributed radar elements. In this work, we present two effective approaches to achieve phase synchronization in coherent MIMO radar systems. The first one is the master-slave closed-loop approach, which employs a master-slave architecture. This method is very simple, and is particularly suitable for fine phase synchronization. The second one is the round-trip algorithm, which employs an unmodulated beacon signal to travel through all the radar elements in a round-trip manner. These algorithms are both time asynchronous in nature, and they require no a priori establishment of either time or frequency synchronization. Under a similar analytical framework, we mathematically characterize each of these algorithms, and further derive and analyze the statistical properties of the corresponding phase synchronization error.

[535] Z.N. Rawas, Qian He, and R.S. Blum. Energy-efficient noncoherent signal detection for networked sensors using ordered transmissions. In *Information Sciences and Systems (CISS), 2011 45th Annual Conference on*, pages 1 –5, march 2011.

Abstract: Energy efficiency has been a topic of recent interest in networks employing wireless sensors used for signal detection. Energy efficient signal detection is of particular interest in systems where such sensors carry their own energy sources with a limited capacity. It has been demonstrated that ordering the sensor transmissions and halting them upon accumulating enough evidence can save transmissions (energy) without degrading the systems detection performance. We extend this concept to a system employing noncoherent signal detection where the hypothesis testing problem involves a log-likelihood ratio which can only take on nonnegative values. We propose a new algorithm for ordering the transmissions for such systems and show that the new algorithm tends to provide more significant savings than the existing methods, requiring as little as one sensor transmission in certain cases. We utilize MIMO radar as an example in our paper, and provide results demonstrating the savings achieved.

[536] Liu Weiwei, Cao Ning, Hao Lu, and Jurong Hu. Detection performance with improved principal component analysis for mimo radar. In *Electric Information and Control Engineering (ICEICE), 2011 International Conference on*, pages 4916 –4919, april 2011.

Abstract: Motivated by the development of MIMO communication, Multiple-Input Multiple-Output (MIMO) radar has drawn considerable attention. Currently, most articles about MIMO Radar analysis focus on angle diversity, the article investigates principal component analysis used in MIMO Radar detection, further studies the performance of transformation of logarithm as its improvement. The simulation results indicates that the method used in this paper can approach to the original target simulation results, meanwhile this method reduces computation complexity and saves computation time.

[537] F. Belfiori, N. Maas, P. Hoogeboom, and W. van Rossum. Tdma x-band fmcw mimo radar for short range surveillance applications. In *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on*, pages 483 –487, april 2011.

Abstract: The work presented in this paper was aimed at the design of a compact radar device to be used for private area surveillance applications. The radar is connected to a pan tilt zoom camera and it provides the camera system with high accuracy position information (bearing and range) of moving targets; in this way the camera can be steered to the point of interest and automatically zoom in on the target. The idea of combining a Multiple-Input Multiple-Output (MIMO) processing approach, with a Frequency Modulated Continuous Waveform transmission proved to be the most cost efficient in order to meet the final system requirements. A test board, suitable for various processing schemes, has been developed at TNO - Defence, Security and Safety in The Hague.

[538] Dang-Wei Wang, Zhen Lin, Jian-Cheng Zheng, and Xiao-Yan Ma. Efficient orientation estimation of mimo radar images: Method and results. In *Intelligent Systems and Applications (ISA), 2011 3rd International Workshop on*, pages 1 –4, may 2011.

Abstract: Estimating the orientation of multiple-input multiple-output (MIMO) radar images is a challenging problem because of the isotropic amplitude spectrum, an inadequate number of line

features and the existence of strong noise or clutter. To solve this problem, a scatterer template-based method is proposed in this paper. The key idea of the proposed method is that the inertia of the sampled image with the maximum energy, not the inertia of the original image, is used to estimate the orientation of the MIMO radar image. Because only part of the image at the stored parameter of high-energy scatterers is involved in the calculation of the inertia and because the noise and clutter outside the sampling locations is filtered, more robust performance can be obtained by the proposed method compared with the existed moment method. Numerical simulations are used to test the proposed method.

[539] Y. Kalkan and B. Baykal. Frequency based target localization methods for mimo radar. In *Signal Processing and Communications Applications (SIU), 2011 IEEE 19th Conference on*, pages 74 –77, april 2011.

Abstract: A new frequency based target localization method is proposed for MIMO radars which are widely separated. The performance of this new method is compared with other frequency based target localization methods. For target localization, time of arrival (TOA), angle of arrival (AOA) and frequency of arrival (FOA) informations can be used in cooperation. In general, TOA information is enough to localize a target. However, when the time resolution of the transmitted signals is not enough or good, i.e.; unmodulated CW radar, we can not rely on the TOA information to localize the target. On the other hand, if the frequency resolution of the transmitted signals is enough, only received frequencies can be used for finding the position of the target. Localization of a moving, non-maneuvering target is possible by using Doppler-shift measurements in MIMO radar systems. This is a nonlinear problem and it can be solved by grid searching. After defining suitable cost function for grid search, desired area can be searched grid by grid to find the position of the target in 2D space.

[540] Y. Kalkan and B. Baykal. Velocity estimation methods for frequency-only mimo radar. In *Signal Processing and Communications Applications (SIU), 2011 IEEE 19th Conference on*, pages 78 –81, april 2011.

Abstract: After finding position in 2D space, target velocity can be estimated by using found target position information and used cost function. In this paper, velocity estimation is achieved for pre-proposed target localization methods. For target localization, time of arrival (TOA), angle of arrival (AOA) and frequency of arrival (FOA) informations can be used in cooperation. When the time resolution of the transmitted signals is not enough or good,i.e.; unmodulated CW radar, we can not rely on the TOA information to localize the target. On the other hand, if the frequency resolution of the transmitted signals is enough, only received frequencies can be used for finding the position of the target. Localization of a moving, non-maneuvering target is possible by using Doppler-shift measurements in MIMO radar systems. This is a nonlinear problem and it can be solved by grid searching. After defining suitable cost function for grid search, desired area can be searched grid by grid to find the position of the target in 2D space. After target positioning is achieved, velocity of the target can be found by using predefined cost function.

[541] S.B. Akdemir and C. Candan. Moving target detection with mimo radar. In *Signal Processing and Communications Applications (SIU), 2011 IEEE 19th Conference on*, pages 106 –109, april 2011.

Abstract: The use of waveform diversity and angular diversity provides significant improvements in the performance of Multi Input Multi Output (MIMO) radar compared to the conventional radars and the phased array radar systems. One of these improvement areas is the success of moving target detection. In this paper, the moving target detection performance of a MIMO radar with a Neyman-Pearson detector which includes space time codes explicitly is investigated.

[542] M.L. Bencheikh and Yide Wang. Non circular esprit-rootmusic joint doa-dod estimation in bistatic mimo radar. In *Systems, Signal Processing and their Applications (WOSSPA), 2011 7th International Workshop on*, pages 51 –54, may 2011.

Abstract: In this paper, we investigate the exploitation of the Non-circularity of radar signal property in a bistatic MIMO radar to improve the performance of joint estimation of direction of arrival (DOA) and direction of departure (DOD) of targets using Combined ESPRIT-RootMUSIC techniques. Simulation results are carried out to illustrate the performance of the proposed approach.

[543] Pu Wang, Hongbin Li, and B. Himed. Distributed detection of moving target using mimo radar in clutter with non-homogeneous power. In *Systems, Signal Processing and their Applications (WOSSPA), 2011 7th International Workshop on*, pages 383 –387, may 2011.

Abstract: Previously, we studied moving target detection (MTD) using a distributed MIMO radar, where the multi-static transmit-receive configuration causes non-homogeneous clutter. By representing the non-homogeneous clutter in a low-rank subspace with different subspace coefficients for different transmit-receive pairs, a generalized likelihood ratio test (GLRT), which is referred to as the MIMO-GLRT, was introduced. The MIMO-GLRT, however, is a centralized detector requiring the distributed receivers to send their local observations to a fusion center, which performs parameter estimation and computes a global test variable. In this paper, we consider distributed detection for the moving target problem. The goal is to reduce the communication overhead as well as power/bandwidth consumptions from the receivers to the fusion center. We consider two distributed implementations of the MIMO-GLRT, with or without local data aggregation. Specifically, the one that performs local aggregation computes a single local test statistic at each receive antenna, by using the outputs of all matched filters (each matched to a waveform unique to one transmit antenna); meanwhile, the one that does not perform local aggregation computes multiple local test statistics, one for each matched filter output. In both cases, the local unquantized test statistics from all receive antennas are forwarded to the fusion center and non-coherently combined to form a final test variable. Simulation results are provided to illustrate the performance loss with respect to the centralized MIMO-GLRT and compare with another distributed MIMO moving target detector based on a homogeneous assumption.

[544] Mohammed Nabil El Korso, Remy Boyer, Alexandre Renaux, and Sylvie Marcos. Statistical resolution limit for source localization in a mimo context. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2756 –2759, may 2011.

Abstract: In this paper, we derive the Multidimensional Statistical Resolution Limit (MSRL) to resolve two closely spaced targets using a widely spaced MIMO radar. Toward this end, we perform a hypothesis test formulation using the Generalized Likelihood Ratio Test (GLRT). More precisely, we link the MSRL to the minimum Signal-to-Noise Ratio (SNR) required to resolve two closely spaced targets, for a given probability of false alarm and for a given probability of detection. Finally, theoretical and numerical analysis of the MSRL are given for several scenarios (known/unknown parameters of interest and known/unknown noise variance) including lacunar arrays.

[545] Qian He and Rick S. Blum. Mimo radar diversity with neyman-pearson signal detection in non-gaussian circumstance with non-orthogonal waveforms. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2764 –2767, may 2011.

Abstract: The diversity gain of a multiple-input multiple-output (MIMO) system adopting the Neyman-Pearson (NP) criterion is derived for a signal-present versus signal-absent scalar hypothesis test statistic and for a vector signal-present versus signal-absent hypothesis testing problem. The results are applied to a MIMO radar system with M transmit and N receive antennas, used to detect a target composed of Q random scatterers with possibly non-Gaussian reflection coefficients in the presence of possibly non-Gaussian clutter-plus-noise. It is found that the diversity gain for the MIMO radar system is dependent on the cumulative distribution function (cdf) of the reflection coefficients while invariant to the cdf of the clutter-plus-noise under some reasonable conditions. If the noise-free received waveforms at each receiver span a space of dimension M, the largest possible diversity gain is controlled by min (N M', Q) and the cdf of the magnitude square of a linear transformed version of the reflection coefficient vector. It is shown that properly chosen nonorthogonal waveforms can achieve the same diversity gain as orthogonal waveforms.

[546] Nguyen Duy Tran, Alexandre Renaux, Remy Boyer, Sylvie Marcos, and Pascal Larzabal. Mimo radar in the presence of modeling errors: A cramer-rao bound investigation. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2780 –2783, may 2011.

Abstract: In this paper, we study the impact of modeling error on the receiver of a MIMO radar. Following other works on classical array processing, we derive closed-form expressions of the Cramer-Rao bounds for an observation model of a widely spaced MIMO radar affected by modeling error. We show that, as the signal-to-noise ratio increases, the Cramer-Rao bound and the mean square error of the maximum likelihood estimator of the angle-of-arrival do not fall to zero (contrary to the classical case without error modeling) and converge to a fixed limit for which we give a closed-form expression. Moreover, we give a simple closed-form expression of the critical value of the signal-to-noise ratio where this limitation of performance appears.

[547] Arash Khabbazibasmenj, Aboulnasr Hassanien, and Sergiy A. Vorobyov. Transmit beamspace design for direction finding in colocated mimo radar with arbitrary receive array. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2784 –2787, may 2011.

Abstract: The transmit beamspace design problem for colocated multiple-input multiple-output (MIMO) radar is considered. We show that the MIMO radar transmit beampattern can be designed so that it is as close as possible to the desired one, the power is uniformly distributed across the transmit antennas, and most significantly, the rotational invariance property at the receive array with arbitrary geometry is satisfied. The latter enables a straightforward application of search-free direction of arrival estimation techniques such as ESPRIT in the unconventional case with the receive array of arbitrary geometry. The transmit beamspace design problem is cast as an optimization problem which is non-convex in general, but can be solved efficiently using the semi-definite programming relaxation technique.

[548] Aboulnasr Hassanien and Sergiy A. Vorobyov. Subspace-based direction finding using transmit energy focusing in mimo radar with colocated antennas. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2788 –2791, may 2011.

Abstract: In this paper, we consider the problem of direction finding in multiple-input multiple-output (MIMO) radar based on focusing the transmitted pulse energy within certain spatial sector(s). We propose a method for designing the transmit weight matrix based on maximizing the energy transmitted within the desired spatial sector and minimizing the energy disseminated in the out-of-sector area. The proposed transmit energy focusing results in the signal-to-noise ratio increase at the receive array which in turn leads to lower Cramer-Rao bound and improved direction of arrival estimation performance. Simulation results show the substantial improvements offered by the proposed transmit energy focusing based MIMO radar as compared to the traditional MIMO radar and the MIMO radar with receive beamspace post-processing.

[549] Tuomas Aittomaaki and Visa Koivunen. Widely distributed mimo radar beamforming for detecting targets with slow rcs fluctuations. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2792 –2795, may 2011.

Abstract: In a widely distributed MIMO radar, the transmitters and the receivers are distributed so that they see a target from different aspects. The scattering from the target is therefore different for each transmitter-receiver pair. It is commonly assumed that a set of orthogonal waveforms are transmitted and the scattered waveforms are then separated using a matched filter to achieve diversity. In this paper, we propose a beamforming method for the widely distributed MIMO radar. Orthogonal waveforms are used initially for probing the target, i.e. to obtain information about the the target and the channel and a single waveform is then transmitted so that the SNR in the receivers is increased. Numerical simulations demonstrate that this will increase the probability of detecting the target.

[550] Yimin D. Zhang and Moeness G. Amin. Mimo radar for direction finding with exploitation of time-frequency representations. In *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, pages 2760 –2763, may 2011.

Abstract: In this paper we consider the exploitation of spatial time-frequency distribution (STFD) in multiple-input multiple-output (MIMO) radar systems. STFD has been found useful in solving various array processing problems, such as direction finding and blind separation, where nonstationary signals are involved. Such treatment has been primarily limited to traditional array processing whereas its use in MIMO radar scenario has received less attention. The emphasis of this paper lies in the reexamination of the STFD framework in an MIMO radar platform for the processing of maneuvering targets with nonstationary signatures. Within this framework, we consider the use of joint transmit and receive apertures for the enhancement and improved estimation of time-frequency signature and the application of STFD in joint direction-of-departure (DOD) and direction-of-arrival (DOA) estimations. As a result, it becomes clear that STFD is effective in MIMO radar processing when the targets are of signatures that are highly localized in the time-frequency domain.

[551] J. Akhtar. Antenna selection for mimo radar transmitters. In *Radar Conference (RADAR), 2011 IEEE*, pages 018 –021, may 2011.

Abstract: Radar systems with widely separated transmitters and receivers offer advantages of spatial diversity as incoming echos can be observed originating through diverse aspect angles. This can be utilized to improve the overall sensitivity and performance of radar systems. This work introduces low-complexity antenna selection for MIMO radar systems where only a few of the available transmit antennas are selected. The antenna selection is carried out by making use of statistical radar information such as transmit antenna correlation and line-of-sight (LOS) reflectivity levels. The scheme is designed to ensure that the total available energy is only spread across the most viable antennas with independent diversity branches and strong LOS reflectors. Simulations are used to demonstrate that the use of statistical information and antenna selection can yield good performance compared to an all antenna system in many scenarios.

[552] Xiufeng Song, P. Willett, and Shengli Zhou. Detection performance for statistical mimo radar with identical and orthogonal waveforms. In *Radar Conference (RADAR), 2011 IEEE*, pages 022 –026, may 2011.

Abstract: This paper studies the detection performance of two different statistical MIMO radar models: one transmits orthogonal waveforms, the other identical. As for the latter, assuming there is no violation of peak power constraints, the allocation of power among transmitters is unimportant from the viewpoint of detection. For full power transmission, the latter model may outperform the former at medium or low SNR, but is inferior at high SNR. Since they both share the same antenna configuration, properly shifting the transmission strategies may alleviate detection loss of a statistical MIMO radar.

[553] Guolong Cui, Lingjiang Kong, Xiaobo Yang, and Jianyu Yang. Glrt design for polarimetric mimo radar in non-gaussian clutter. In *Radar Conference (RADAR), 2011 IEEE*, pages 106 –108, may 2011.

Abstract: This paper mainly deals with target detecting problem using polarimetric multiple input multiple output (MIMO) radars against non-Gaussian clutter. In general, spherically invariant random process (SIRP) describes the distribution of clutter in high resolution radar and in the lowing gazing angle cases. First, we develop the MIMO signal model to two polarimetric channels and SIRV clutter-dominated scenario, and then the generalized likelihood ratio test (GLRT) is derived. Several numerical examples is given, and the results show that the polarimetric diversity and the spatial diversity are all exploited to improve the detection performance, and it outperforms the conventional polarimetric phased-array counterpart.

[554] G.J. Frazer, Y.I. Abramovich, and B.A. Johnson. Mode-selective oth radar: Experimental results for one-way transmission via the ionosphere. In *Radar Conference (RADAR), 2011 IEEE*, pages 397 –402, may 2011.

Abstract: This paper reports results of an experimental program called the Mode Selection Experiment which was designed to demonstrate ionospheric propagation mode selectivity on transmit over a one-way skywave propagation path. This corresponds to the transmitter-to-target part of the two way propagation path used in OTHR. The purpose of the experiment was to show that MIMO radar techniques can be used to construct multiple simultaneous non-causal adaptive range dependent transmitter beams. Such beams are applied to selectively illuminate desirable ionospheric propagation paths while simultaneously nulling undesirable propagation paths and do so with a differing beampattern for each range cell in the OTHR range coverage.

[555] V. Pereira, E. Grivel, and J. Petitjean. Coloured transmission based on multicarrier phase coded signals in mimo radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 425 –430, may 2011.

Abstract: In radar processing, coloured transmission aims at improving the detection of targets that appear as fast as they disappear. It consists in simultaneously transmitting different waveforms using a wide beam. To differentiate the transmitted waveforms, various orthogonal coding schemes such as phase and frequency coding have been considered. In this paper, we suggest using in the MIMO radar case the so-called multicarrier phase coded signals (MCPC) initially introduced in SISO radar processing. This approach has the advantage of having better performances than phase coding based schemes. In addition, it has a lower computational cost than the frequency coding system.

[556] Y. Kalkan and B. Baykal. Target localization and velocity estimation methods for frequency-only mimo radars. In *Radar Conference (RADAR), 2011 IEEE*, pages 458 –463, may 2011.

Abstract: Target localization and the velocity estimation methods are proposed for frequency-only MIMO Radar with widely separated stations. For the target localization, time of arrival (TOA), angle of arrival (AOA) and frequency of arrival (FOA) informations can be used in cooperation. When the time resolution of the transmitted signals is not enough or good,i.e.; unmodulated CW radar, we can not rely on the TOA information to localize the target. On the other hand, if the

frequency resolution of the transmitted signals is enough, only received frequencies can be used for finding the position of the target. Localization of a moving, non-maneuvering target is possible by using the Doppler-shift measurements in MIMO radar systems. This is a nonlinear problem and it can be solved by grid searching. After defining suitable cost funtion for the grid search, the desired area can be searched grid by grid to find the position of the target in 2D space. After target positioning is achieved, velocity of the target can be found by using the predefined cost function.

[557] Jun Li, Guisheng Liao, and H. Griffiths. Bistatic mimo radar space-time adaptive processing. In *Radar Conference (RADAR), 2011 IEEE*, pages 498 –502, may 2011.

Abstract: Bistatic multiple-input multiple-output (MIMO) radar systems have the advantages of both bistatic radar and MIMO radar. In addition, the transmit angle can be obtained by processing the receive data. In this paper, bistatic MIMO and space-time adaptive processing (STAP) are applied to ground moving target indication (GMTI). It is shown that the clutter spectrum is a curve in 3-dimensions (transmit angle, receive angle and Doppler frequency) after compensation. The performances of single input multiple-output (SIMO) and MIMO cases are compared. The results show that the bistatic MIMO-STAP outperforms its SIMO counterparts in both signal interference and noise ratio (SINR) and SINR loss.

[558] B. Correll, J.M. Kantor, and D.W. Bliss. Waveform-dependent bayesian cramer-rao angle-estimation bounds and threshold snr estimates for mimo radars. In *Radar Conference (RADAR), 2011 IEEE*, pages 503 –508, may 2011.

Abstract: Multiple-input multiple-output (MIMO) radars operate by simultaneously transmitting multiple independent waveforms. This facilitates improved angle-estimation performance by enabling the use of sparse antenna arrays without the ambiguities that occur when sparse arrays are used in conventional radars. Angle-estimation performance can be characterized in terms of the local error-performance bound given by the Cramer-Rao bound and in terms of the threshold point given by the SNR at which the estimator deviates significantly from the Cramer-Rao bound. In this paper, we extend results of Bliss, Forsythe, and Richmond on angle-estimation performance as a function of transmit waveform covariance for a MIMO radar. The analysis described in the above work is dependent upon an estimate or test location of a target position. Here, we provide a framework for a Bayesian extension that incorporates knowledge of the priors on the target position probability density. This information affects both the Cramer-Rao bound and the threshold SNR. Consequently, it affects waveform and system optimization.

[559] C.Y. Chong, F. Pascal, and M. Lesturgie. Estimation performance of coherent mimo-stap using cramer-rao bounds. In *Radar Conference (RADAR), 2011 IEEE*, pages 533 –537, may 2011.

Abstract: Space-Time Adaptive Processing (STAP) is a recent technique used in airborne phased array radar to detect slow-moving targets embedded in an interference background such as jamming or strong clutter. Improved clutter mitigation by STAP enables these targets to be detected. With the use of MIMO configurations, the performance of the radar can be further enhanced, such as the angle-estimation performance and Minimum Detectable Velocity (MDV). In this paper, different coherent MIMO configurations are considered and their estimation performances are investigated in terms of the well-known Cramer-Rao bounds (CRB) which give

the lower bounds of the variances of the estimators of deterministic parameters. For the same Signal-to-Clutter Ratio (SCR), the configuration that maximizes the effective number of elements gives the lowest bounds. The bounds can be further lowered without causing additional ambiguities by increasing the element spacing in certain ways.

[560] M. Ravan, R.S. Adve, and R.J. Riddolls. Mimo fast fully adaptive processing in over-the-horizon radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 538 –542, may 2011.

Abstract: High frequency Over-the-Horizon Radar (OTHR) provides an economical means to track noncooperative air targets over large expanses of land and ocean. However, OTHR in Canada is confounded by the presence of radar clutter from the region of the aurora borealis. Given the time-varying nature of auroral clutter, this paper proposes joint adaptive transmit and receive beamforming as a key tool to deal with this clutter. This beamforming is an alternative adaptive process based on the previously proposed fast-fully adaptive (FFA) scheme extended to couple transmit and receive beamforming, specifically for slow-time multiple-input multiple-output (MIMO) radar. We test the efficacy of this algorithm using measured OTHR data.

[561] M. Akcakaya and A. Nehorai. Mimo radar sensitivity analysis for target detection. In *Radar Conference (RADAR), 2011 IEEE*, pages 633 –638, may 2011.

Abstract: For multi-input multi-output (MIMO) radar with widely separated antennas, we consider the effect of imperfect orthogonality of the received signals on detection performance. In practice, mutual orthogonality among the received signals cannot be achieved for all Doppler and delay pairs. We introduce a data model considering the correlation among the data from different transmitter-receiver pairs as unknown parameters. Based on the expectation-maximization algorithm, we propose a method to estimate the target, correlation, and noise parameters. We then use these estimates to develop a statistical decision test. Using the asymptotical statistical characteristics and the numerical performance of the test, we analyze the sensitivity of the MIMO radar with respect to changes in the cross-correlation levels of the measurements. In our numerical examples, we demonstrate the effect of the increase in the correlation among the received signals from different transmitters on the detection performance.

[562] J.J.M. de Wit, W.L. van Rossum, and A.J. de Jong. Orthogonal waveforms for fmcw mimo radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 686 –691, may 2011.

Abstract: Multiple input/multiple output (MIMO) radar system performance benefits from the capability to simultaneously transmit and receive multiple orthogonal waveforms. For pulse radars fitting orthogonal waveforms have been developed. These waveforms are however not necessarily suitable for frequency-modulated continuous-wave (FMCW) radar. The major benefit of the FMCW radar principle is that the bandwidth of the beat signal is generally much smaller than the signal bandwidth, relaxing sampling requirements. Preferably, this benefit should be preserved when applying orthogonal waveforms in an FMCW MIMO radar configuration. In this paper, orthogonal waveforms compatible with the FMCW radar principle will be discussed and tested by experiment or simulation.

[563] Jun Tang, Bo Tang, and Lizhong Zheng. Target models and waveform design for detection in mimo radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 798 –803, may 2011.

Abstract: In this paper, we propose a general target model for multiple-input multiple-output(MIMO) radar. Three types of targets are presented. For each type of target, we develop a corresponding optimum waveform designing method to optimize detection performance. Based on Chernoff-Stein lemma, we use relative entropy as the performance measure. We show that the optimum waveform designing method can obtain better detection performance than traditional orthogonal waveform designing method.

[564] J.P. Stralka, R.M. Thompson, J. Scanlan, and A. Jones. Miso radar beamforming demonstration. In *Radar Conference (RADAR), 2011 IEEE*, pages 889 –894, may 2011.

Abstract: Coherent multiple-input multiple-output (MIMO) radar is characterized by having a transmit antenna array and a receive antenna array located in a pseudo-monostatic configuration such that desired target returns from the far-field are coherent. Each element (or subarray) of the transmit array radiates an independent, ideally orthogonal, waveform. Such a radar offers the ability to digitally form beams, possibly adaptively, on both transmit and receive within the receive signal processor. The fundamental advantages of MIMO radar over modern single-input multiple-output (SIMO) radar can be demonstrated with a multiple-input single-output (MISO) radar. A MISO radar testbed with up to four transmit channels and a single receiver was built to evaluate the various classes of MIMO waveforms. Results of these tests are presented.

[565] M. Bucciarelli and D. Pastina. Multi-grazing isar for side-view imaging with improved cross-range resolution. In *Radar Conference (RADAR), 2011 IEEE*, pages 939 –944, may 2011.

Abstract: The use of multiple radar systems, carried by a set of air platforms flying in formation, is demonstrated to be able to provide side-view ISAR images of pitching and rolling targets with increased cross-range resolution. The multi-grazing ISAR technique is devised for two different cases: (i) multistatic case with a single platform carrying an active radar and the remaining equipped with receiving only devices, (ii) MIMO case with each platform carrying an active radar. The needed focusing technique is presented with the results obtained against simulated ISAR data; the performance analysis shows that the proposed technique is able to provide an increase of the cross-range resolution up to the number of radar systems in the multistatic case or even higher in the MIMO case. The multi-grazing ISAR is especially suitable for the application to ship target imaging in the presence of low sea state giving rise to side-views of poor quality when imaged with conventional ISAR.

[566] D.J. Rabideau. Doppler-offset waveforms for mimo radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 965 –970, may 2011.

Abstract: In a Multiple-Input, Multiple-Output (MIMO) radar, independent waveforms are transmitted from different locations, with the resulting reflections processed to form a "virtual antenna array" that is larger than the physical aperture of the radar. This paper examines the design of Doppler-offset waveforms for use in adaptive MIMO GMTI radar systems. Such waveforms provide good adaptive cancellation performance, but are also subject to strong range

and Doppler ambiguities. We analyze these ambiguities, and show how they relate to array topology and waveform design. Then, we describe a new waveform approach, called "Dithered DDMA," which enables high performance clutter cancellation over large range-Doppler regions without introducing ambiguous ranges or blind speeds, and without increasing the computational load on the MIMO processor.

[567] Jingxu Han and M.R. Inggs. Cumulative detection probability of stationary and moving targets by mimo radar. In *Radar Conference (RADAR), 2011 IEEE*, pages 974 –978, may 2011.

Abstract: Recently, Multiple-Input Multiple-Output (MIMO) radar attracts considerable attention. In this paper, the cumulative detection probability by MIMO radar is investigated. As the title implies, this paper consists of two parts. The first part studies on the cumulative performance of stationary targets. It is observed that the detection performance may be significantly improved by increasing cumulative time. In the second part, the cumulative detection probability of moving targets by MIMO radar is computed. As we known, it is difficult to acquire instantaneous speed or Doppler frequency of moving targets. Influenced by the fact that it is more difficult to detect or track far objects than ones are close to the observer, in terms of moving target detection, our proposed cumulative detection probability calculation is based on the average speed, or says travel distance during cumulative time. Various moving targets with different Radar Cross Section (RCS) are examined. Lastly, relevant Monte Carlo simulation results are provided.

[568] Li Li and J.L. Krolik. Vehicular mimo sar imaging in multipath environments. In *Radar Conference (RADAR), 2011 IEEE*, pages 989 –994, may 2011.

Abstract: In this paper, multi-input multi-output (MIMO) forward looking synthetic aperture radar (FL-SAR) is developed for imaging from a moving ground vehicle in urban multipath environments. Conventional SAR is often seriously degraded by ghost artifacts with the same direction of arrival and delays as direct path returns. In this paper, MIMO methods are used to improve SAR images by suppressing directions of departure which would otherwise be multipath scattered and added to direct path returns. Both conventional and adaptive MIMO SAR methods are presented and compared in a multipath imaging simulation. The results suggest MIMO SAR may offers substantial gains versus conventional SIMO imaging in urban settings.

[569] F. Foroozan, A. Asif, Yunwai Jin, and J.M.F. Moura. Direction finding algorithms for time reversal mimo radars. In *Statistical Signal Processing Workshop (SSP), 2011 IEEE*, pages 433 –436, june 2011.

Abstract: A time reversal (TR) based direction of arrival (DOA) estimation framework for multiple-input/multiple-output (MIMO) radars is presented. We develop minimum variance distortionless response (MVDR) and multiple signal classification (MUSIC) based DOA estimators for the TR/MIMO setup. The TR/MIMO estimation algorithms outperform their conventional counterparts in: (i) analytical Cramer Rao Bounds (CRB) comparisons, and; (ii) numerical Monte Carlo simulations for a range of signal to noise ratios that we tested.

[570] Z. Farshad and H. Amindavar. Detection performance of mimo radars in presence of k-distributed clutter using multi-dimensional saddle point approximation. In *Statistical Signal Processing Workshop (SSP), 2011 IEEE*, pages 441 –444, june 2011.

Abstract: Multiple Input Multiple Output (MIMO) radar is a useful tool to improve detection performance by introducing additional degree of freedom (DOF) to conventional radars at the expense of solving multi-dimensional random vectors calculation. In this paper, we develop a new multi-dimensional saddle point approximation-based approach to obtain the probability density function of multi-dimensional random vectors, which is nearly accurate especially in pdf tail regions. The proposed method is so effective to overcome the complexity of matrix calculations in determining random vector pdfs. We apply this approximated pdf to compare the detection performance of MIMO radars in the Neyman-Pearson sense against the presence of K-distributed clutter plus noise.

[571] B. Levitas, I. Naidionova, and J. Matuzas. Ultra-wide band radar imaging and live being detection research in lithuania. In *Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International*, pages 1 –4, june 2011.

Abstract: In this article we present recent achievements in UWB measurements in Lithuania. The main purposes of those measurements are to prove the possibility to detect objects behind non-metallic barriers and to characterize them. Different UWB measurements techniques (ISAR, SAR, MIMO - radar systems) allow to draw images of objects, as well as to analyze the small motions of objects and to measure the rate of respiration and heart beats. This work shows the possibility of using UWB radar systems in the rescue operations (live being detection), anti-terrorism (the detection of unauthorized objects under clothing) and medicine (remote monitoring of patients, detection of women's breast cancer).

[572] B. Levitas, J. Matuzas, and I. Naidionova. Ultra-wideband radar imaging and live-being detection research in lithuania. In *Microwave Symposium Digest (MTT), 2011 IEEE MTT-S International*, page 1, june 2011.

Abstract: In this article, we present recent achievements in UWB measurements in Lithuania. The main purposes of those measurements are to prove the feasibility of detecting objects behind non-metallic barriers and to characterize them. Different UWB measurements techniques (ISAR, SAR, MIMO - radar systems) allow us to draw images of objects, as well as to analyze small motions of objects and to measure the rate of respiration and heart-beat.

[573] Wentai Lei and Qianzhe Wang. Mimo radar 2-d real-time imaging algorithm and simulation. In *Mechanic Automation and Control Engineering (MACE), 2011 Second International Conference on*, pages 1394 –1396, july 2011.

Abstract: Conceptually, 2-dimentional(2D) imaging of radar target is a problem of 2D spatial spectrum filling of the target. Accordingly, MIMO(Multiple-Input Multiple-Output) radar real-time imaging technology is proposed in this paper. Firstly, MIMO radar 2D imaging model is established based on electromagnetic scattering integral equation. Secondly, the spatial sampling ability is analyzed from the concept of spatial convolution of the antenna elements. Thirdly, MIMO radar 2 D real-time imaging procedure is presented. Simulation results show the effectiveness of MIMO radar real-time imaging algorithm.

[574] Hai Deng. Adaptive signal processing for jammer suppression using mimo radar. In *Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on*, pages 289 – 292, july 2011.

Abstract: an innovative approach is proposed to suppress jammer signals in both mainlobe and sidelobe directions for adaptive target detection using MIMO radar.

[575] Hai Deng. Waveform design for mimo radar with low probability of intercept (lpi) property. In *Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on*, pages 305 –308, july 2011.

Abstract: A joint waveform and array signal processing approach is proposed to minimize MIMO radar antenna radiation power for best low probability of intercept (LPI) property in pre-selected directions and to achieve near-optimum target detection simultaneously. Some simulation results are presented.

[576] Songbai Wang, Jian Wang, Jianshu Chen, and Xiuming Shan. Optimalwaveform design for mimo radarwith low probability of interception. In *Digital Signal Processing (DSP), 2011 17th International Conference on*, pages 1 –5, july 2011.

Abstract: In this paper, we consider the waveform design problem of multiple input multiple output (MIMO) radar in the presence of an interceptor. By the joint considerations of high estimation accuracy and low probability of interception, we formulate the problem as maximizing the mutual information with a constraint on the Kullback-Liebler (KL) divergence. Then it is converted effectively to a convex optimization, which can be solved efficiently to give the optimal waveform. Simulation results show that there exits the optimal tradeoff between the estimation accuracy and the probability of interception.

[577] M.M. Hyder and K. Mahata. A joint sparse signal representation perspective for target detection using bistatic mimo radar system. In *Digital Signal Processing (DSP), 2011 17th International Conference on*, pages 1 –5, july 2011.

Abstract: The problem of detection of multiple targets using a bistatic MIMO radar system is posed as a joint sparse signal recovery problem. We explore the potential of MIMO systems to locate targets in noisy environment with limited number of time samples, while the transmitted signals are not necessarily mutually orthogonal. Explicit enforcement of a joint sparse representation is motivated by a desire to obtain a sharp estimate of the targets that exhibits robustness in noisy environment. Numerical experiments demonstrate that the proposed strategy outperforms existing algorithms.

[578] M. Dianat, M.R. Taban, and A.A. Tadaion. A new approach for target localization using maximum likelihood estimation in mimo radar. In *Electrical and Computer Engineering (CCECE), 2011 24th Canadian Conference on*, pages 000745 –000748, may 2011.

Abstract: In this paper, we propose a target localization method in Multiple Input Multiple Output (MIMO) radars with Widely Separated Antenna (WSA)s. Our proposed method is based on the Maximum Likelihood Estimation (MLE). We assume that the time delays between every transmitter-receiver pair antennas are available, maybe through a preprocessing estimation

method and the uncertainty on each time delay is modeled as a white Gaussian noise. Simulation results evaluate the performance of our proposed method comparing with the Cramer-Rao Lower Bound (CRLB).

[579] Huang Qian. Target detection of mimo radar. In *Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC), 2011*, volume 2, pages 1082 – 1084, july 2011.

Abstract: This paper mainly analyses the performance advantage of MIMO radar in target detection. Firstly, the basic concept of radar system and models of radar echo signal were introduced. The detection performance of MIMO radar was analyzed afterwards. Then, the relationships among detection probability, false-alarm probability and signal-to-noise ratio under the White Gaussian Noise were discussed. Finally, detection performance of MIMO radar was compared with that of traditional array radar.

[580] Jian Gong, Hongqing Lv, and Yiduo Guo. Multidimensional parameters estimation for bistatic mimo radar. In *Wireless Communications, Networking and Mobile Computing (WiCOM), 2011 7th International Conference on*, pages 1 –4, sept. 2011.

Abstract: A new multidimensional parameters (DODs: direction of departures: direction of arrivals, and Doppler frequencies) estimation method for bistatic MIMO radar via ESPRIT exploiting virtual arrays is presented. The proposed method uses the eigenvalues of constructed matrix to estimate DODs and Doppler frequencies and the eigenvectors to estimate DOAs. At the same time, the parameters are paired easily by the relationship between the eigenvectors. The performance of the proposed method is validated by the simulation results.

[581] V. Chernyak. Using mimo radars in multisite radar systems. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 691 –696, sept. 2011.

Abstract: The theoretical issues of using MIMO radars in multisite (multistatic) radar systems (MSRSs) are considered. It is shown that for both search mode and tracking mode MSRSs based on MIMO radars have significant advantages.

[582] A. Kirschner, S. Bertl, J. Guetlein, and J. Detlefsen. Comparison and tests of different virtual arrays for mimo radar applications. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 697 –702, sept. 2011.

Abstract: Traditionally well-known from communication applications, the multiple-input multiple-output principle (MIMO) has found its way into radar system theory in the last years. Different arrangements of transceivers equipped with orthogonal signals, lead to arrangements of virtual elements which is denoted as virtual array in the context of coherent MIMO approaches. In order to proof practical feasibility of ongoing theoretical considerations, experiments have been started and evaluated.

[583] J. Akhtar. Linear bi-pulse precoding for mimo radar transmitters. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 703 –708, sept. 2011.

Abstract: A conventional MIMO radar system with widely separated transmitters and receivers is designed to emit an independent orthogonal pulse from each of its transmitting antennas. This paper presents a pulse precoding scheme for MIMO radars where two pulses are jointly linearly coded across two transmitters to increase the overall system performance. The algorithm is specifically designed to link the gap between these two extreme cases of emitting a single pulse or two coded pulse in a smooth manner while ensuring that the number of waveforms in use is kept constant. The coding strategy makes use of statistical radar information emphasizing line-of-sight (LOS) reflectivity levels which introduce limited beamforming gain to the system. Simulations are used to demonstrate that the use of statistical information and pulse precoding can be beneficial even for widely separated antennas.

[584] J.O. Hinz, T. Fickenscher, A. Gupta, M. Holters, and U. Zolzer. Evaluation of time-staggered mimo fmcw in hfswr. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 709 –713, sept. 2011.

Abstract: This paper evaluates the performance of the time-staggered (TS) multiple-in-multiple-out (MIMO) Frequency Modulated Continuous Wave (FMCW) radar approach and compares it to a conventional phased-array approach to obtain a proof-of-concept. The approach combines stretch processed FMCW and colocated MIMO radar by using multiple time-staggered chirps. The advantages of forming virtual antenna elements can be seen as a flexible solution regarding antenna configuration for a mobile or space-limited High-Frequency Surface Wave Radar (HFSWR).

[585] M. Lesturgie. Some relevant applications of mimo to radar. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 714 –721, sept. 2011.

Abstract: After a brief introduction of existing MIMO systems, this paper attempts to define the basic properties of a MIMO - Multiple Inputs Multiple Outputs concept. Then the paper gives some directions to explore, in the fields of space time adaptive processing (STAP) for ground moving target detection and High Frequency Surface Waves Radar (HFSWR) for maritime surveillance. The last part of the paper deals with the choice of the codes. Fast time and slow time coding are considered. While orthogonal coding is desired in a MIMO system, the generalized ambiguity function is presenting as the unique tool to assess the efficiency of the codes.

[586] Hong Wang and Huaihai Guo. Hyperbolic localization method for mimo radar. In *Radar Symposium (IRS), 2011 Proceedings International*, pages 880 –885, sept. 2011.

Abstract: Classic localization methods in conventional radar cannot be used to multiple-input multiple-output radar directly. In this paper, we proposed a new localization model for MIMO radar system, which make hyperbolic location method can be extended to MIMO radar. TOAs equations are build from multipath between transmitters and receivers to estimate the target position. The equations are redundant since number of paths is more than number of target coordinates. Our new model makes full use of redundant paths to decrease the impact of TOA measurement errors and improve estimation accuracy. Then, we proposed a two-steps method to solve the overdetermined and nonlinear TOAs equations. Different with conventional Taylor

expansion method, which needs an initial position closed to the target and iterative process is necessary, we calculate the initial position in first step and use partly Taylor expansion and BLUE algorithm in the second step to obtain accurate results. GDOP performance of the new method is analyzed. CRLB of the proposed algorithm is derived as well and localization error of new algorithm is almost equal to CRLB which prove the value of the new method.

[587] P.F. Sammartino, D. Tarchi, and C.J. Baker. Mimo radar topology: A systematic approach to the placement of the antennas. In *Electromagnetics in Advanced Applications (ICEAA), 2011 International Conference on*, pages 114 –117, sept. 2011.

Abstract: Interest in MIMO radars has been growing lately because they keep performance close to a conventional antenna array, but make it possible, at the same time, to take advantage of several hardware benefits. There are a number of publications on the performance of MIMO radar systems so that their advantages/disadvantages against conventional electronic steered arrays have been investigated in details. However, no publications focus on the way of synthesizing an arbitrary array through appropriate transmit and receive arrays. Consequently this paper describes a method to find all the possible decompositions of an arbitrary linear antenna array into transmit and receive arrays employing the MIMO radar technique. In particular, this is achieved through a polynomial approach to array decomposition.

[588] B. Cordill, J. Metcalf, S.A. Seguin, D. Chatterjee, and S.D. Blunt. The impact of mutual coupling on mimo radar emissions. In *Electromagnetics in Advanced Applications (ICEAA), 2011 International Conference on*, pages 644 –647, sept. 2011.

Abstract: The effects of mutual coupling between antenna elements are considered with regard to the impact upon co-located MIMO radar emissions. Because this sensing scheme intentionally couples the spatial and fast-time (waveform) domains, it is shown that MIMO radar is sensitive to any electromagnetic mutual coupling effects that are not adequately characterized in the transmit array manifold. This sensitivity leads to mismatch that will degrade the radars sensitivity on receive.

[589] P.F. Sammartino, D. Tarchi, and G. Baldini. Wireless interference effects in mimo radars. In *Antennas and Propagation in Wireless Communications (APWC), 2011 IEEE-APS Topical Conference on*, pages 702 –705, sept. 2011.

Abstract: Interest in MIMO radars has been growing lately because they keep performance close to a conventional antenna array, but make it possible at the same time to take advantage of several hardware benefits. In this paper we focus our investigation on the effects of the interference of wireless communication systems in the band of the radar and we report the first results about this topic in literature. In addition, the full paper will report not only the results shown here, but also additional results about the cancellation of the interference.

[590] A.H. Narayanan, P. Brennan, F. Gillet-Chaulet, and K.W. Nicholls. Antarctic ice shelf 3d cross sectional profile imaging using mimo radar. In *Geoscience and Remote Sensing Symposium (IGARSS), 2011 IEEE International*, pages 186 –189, july 2011.

Abstract: Observation of the thickness of Antarctic ice shelves is vital for predicting the rise in sea levels caused by melting of the world's largest fresh water reservoir. This paper proposes a

ground-based radar system using a MIMO phased array antenna layout to accurately monitor thickness changes and provide 2 dimensional cross-range information of the ice shelf. The radar system used to collect data is a Step Frequency (SFCW) Radar using multiple transmitting and receiving antennas which operate orthogonally in time. The MIMO antenna layout is shown together with the beam pattern from the associated virtual array. The aperture synthesis of the MIMO array using digital beamforming technique is discussed. Results of the aperture synthesis, showing the cross-range and depth profile of the ice shelf to be observed will be shown. The study conducted using the MIMO antennas is part of a future plan to replace the SFCW Radar system with an FMCW system that will allow long term deployments to observe variability in the rate of change of the ice shelf thickness. One of the conclusions of the paper is that a linear version of the MIMO array will make more efficient use of the antennas than a 2D version of the array.

[591] Wen-Qin Wang and Jingye Cai. Ground moving target indication by mimo sar with multi-antenna in azimuth. In *Geoscience and Remote Sensing Symposium (IGARSS), 2011 IEEE International*, pages 1662 –1665, july 2011.

Abstract: Ground moving target indication (GMTI) is of great important for surveillance and reconnaissance. The representative GMTI technique of along-track interferometry (ATI) synthetic aperture radar (SAR) does not take into account the fact that the stationary clutter unavoidably corrupts the interferometric phase of the targets. In this paper, we aim at multiple-input and multiple-output (MIMO) SAR-based solution. We proposed a scheme of MIMO SAR which is different from normal MIMO radar for ground moving targets detection and imaging. This approach employs MIMO along-track antenna configuration and waveform diversity. The system schemes, signal models, and waveform diversity are investigated.

[592] B. Boudamouz, P. Millot, and C. Pichot. Through the wall radar imaging with mimo beamforming processing. In *Microwaves, Radar and Remote Sensing Symposium (MRRS), 2011*, pages 251 –254, aug. 2011.

Abstract: In this paper, we address the problem of Through The Wall (TTW) detection with the emerging radar concept that is the multiple-input multiple-output (MIMO) radar. At first near field and through the wall propagation effects on electromagnetic waves are addressed then a MIMO frequency signal model is given and the advantages of a MIMO scheme for the complex task of TTW detection is discussed. Then image formation with beamforming processing is derived. Finally, the proposed imaging method is implemented on numerical signals obtained by FDTD computations considering through cinder blocks walls propagation. The obtained images for scenarii with one or two targets are presented.

[593] Fufei Gu, Long Chi, Qun Zhang, Feng Zhu, and Ying Liang. An imaging method for mimo radar with sparse array based on compressed sensing. In *Signal Processing, Communications and Computing (ICSPCC), 2011 IEEE International Conference on*, pages 1 –4, sept. 2011.

Abstract: The number of antenna elements in MIMO (Multiple-Input Multiple-Output) radar is too many when imaging for moving targets with single snapshot. To a i m at solving the problem, an imaging method for MIMO radar with sparse antenna array is proposed. Firstly the configuration of sparse antenna array is analyzed. Then, combining Compressed Sensing theory, a

novel imaging method for MIMO radar with sparse array is put forward. Single snapshot imaging for moving targets is implemented by this method, which not only can avoid the difficulty of motion compensation aroused by the targets' maneuver, but also can reduce the number of antenna elements. Finally, the effectiveness of this method is validated by the simulation results.

[594] Lu Jie. The application of data fusion in mimo radar target detection. In *Internet Computing Information Services (ICICIS), 2011 International Conference on*, pages 598 – 600, sept. 2011.

Abstract: Multiple Input Multiple Output (MIMO) radar is a novel radar technique developed recently. In this paper, the principle of MIMO Radar based on collated antenna is presented and then the data fusion technique for MIMO radar is described. First, each elements of MIMO radar performs detection respectively, and then the results integrated in a center. At last the final detection result is get which includes all the information of each detector result.

[595] Lu Jie. The application of ica for mimo radar. In *Internet Computing Information Services (ICICIS), 2011 International Conference on*, pages 601 –603, sept. 2011.

Abstract: MIMO radar is a new radar technique developed recently. In this paper, a new signal processing method of independent component analysis (ICA) is presented. In the receiver, the ICA is employed to separate each of transmitted signals. And then, the signal is processed using conventional method such as DBF, MTD.

[596] Lu Jie. Resource management in mimo radar. In *Internet Computing Information Services (ICICIS), 2011 International Conference on*, pages 604 –606, sept. 2011.

Abstract: Scheduling is an important issue of radar resource management as there is a strong correlation between how tasks should be carried out and the time available to perform them. Multiple Input Multiple Output (MIMO) radar is a new radar technique. The problem of resource management in MIMO radar is important. In this paper, this problem is investigated.

[597] Ming Jin and Youming Li. Robust estimation of target reflection intensity in remote sensing application. In *Electronics, Communications and Control (ICECC), 2011 International Conference on*, pages 1014 –1015, sept. 2011.

Abstract: A robust algorithm for estimating target reflection intensity based on multiple-input multiple-output (MIMO) radar presented. The algorithm exploits the characteristic of MIMO radar signal model to estimate the reflection intensity. Unlike most robust algorithms such as Robust Capon Beamformer (RCB), our method requires no predetermined mismatch range between the actual and normal steering vectors. In addition, the proposed method can be applied to both monostatic and bistatic MIMO radars.

[598] Anh-Duy Vu, Jung-Hun Oh, Jea-Il Han, and Young-Man Kim. A detection and tracking system based on mimo doppler radar sensor. In *ICT Convergence (ICTC), 2011 International Conference on*, pages 85 –89, sept. 2011.

Abstract: We describe a system that can track a moving object in the range of 40 meters by using two MIMO Doppler radar sensors. Due to the low computing capability of the sensor node, it is

impossible to exactly determine the target's position. So we divide the sensing range into 4 10-meter long sections and develop a real-time tracking algorithm called Advanced Tracking Algorithm for Doppler Radar Sensors (ATAD) to point out which section the moving target is in. The algorithm automatically determines the threshold for detection at the initial period, adjusts this value during running time, and determines the relative location of the target in real-time.

[599] F. Ahmad, M.G. Amin, and Yeo-Sun Yoon. Multi-input multi-output synthetic aperture radar technology for urban area surveillance. In *Synthetic Aperture Radar (APSAR), 2011 3rd International Asia-Pacific Conference on*, pages 1 –4, sept. 2011.

Abstract: Multi-input multi-output (MIMO) radar is an emerging technology that has significant potential for advancing the state-of-the-art of modern radar. A MIMO radar deployed on a moving platform, with the signals coherently combined from pulse to pulse for imaging, is termed as MIMO synthetic aperture radar (SAR). Potential benefits of MIMO SAR include significant reduction in the system pulse repetition frequency, smaller losses when observing stationary and low-velocity targets, reduction of shadowing effects for 3D imaging, and realization of a synergistic MIMO SAR and ground moving target indication capability. In this paper, we provide a detailed review of the MIMO SAR technology, discuss its attributes, and highlight its potential for area surveillance, particularly in urban environments with dynamic complex terrains.

[600] J.H.G. Ender, A.R. Brenner, H. Essen, H. Wilden, D. Cerutti-Maori, A. Wahlen, and W. Johannes. Advances in radar imaging at fraunhofer-fhr. In *Synthetic Aperture Radar (APSAR), 2011 3rd International Asia-Pacific Conference on*, pages 1 –2, sept. 2011.

Abstract: The recent years mark a considerable progress in SAR techniques and systems. Radar imaging has been demonstrated at high frequencies and bandwidths never reached before. Miniaturized SAR systems have been developed which can be operated on board of small UAVs. Last but not least advanced imaging techniques have been demonstrated, e.g. bistatic SAR - even in a forward looking configuration, and new concepts of spatial temporal diversity based on the Multi-Input Multi-Output concept are arising (MIMO-SAR). A considerable set of these techniques and technologies have been developed at Fraunhofer-FHR in the last two decades. In this paper we will give an overview on the SAR research at FHR and introduce some of the institute's experimental systems.

[601] Xiang-Ru Li, Zhao Zhang, Wu-Xing Mao, Xiao-Mo Wang, and Jun Lu. A derivation of colocated mimo radar equation. In *Computational Problem-Solving (ICCP), 2011 International Conference on*, pages 674 –677, oct. 2011.

Abstract: Radar equation is a very important tool to evaluate a radar system, and an approximate derivation of colocated multiple-input multiple-output (MIMO) radar equation is presented in this paper. Firstly, we derive the Signal-to-Noise Ratio (SNR) improvement factor MN of the colocated MIMO radar array output compare to single-input single-output (SISO) radar array output employing coherent integration, where M is the number of orthogonal transmitted signals and N is the number of receive array elements. Secondly, we derive the array output's SNR expression from radar equation perspective. With the expression, we get the colocated MIMO radar equivalent array gain via comparing the array output's SNR expressions of colocated MIMO radar and SISO radar. Then we obtain the colocated MIMO radar equation without considering the antenna electromagnetic effect.

[602] S.K. Bolisetti, K. Ahmed, M. Patwary, and M. Abdel-Maguid. Compressive parametric glrt detector for airborne mimo radar. In *Wireless Communications and Signal Processing (WCSP), 2011 International Conference on*, pages 1 –5, nov. 2011.

Abstract: In this paper, an improved target detection algorithm for MIMO airborne radar has been proposed namely, Compressive Parametric Generalized Likelihood Ratio Test (CP-GLRT). The Parametric Generalized Likelihood Ratio Test (P-GLRT) and Generalized likelihood ratio test (GLRT) are also studied considering the availability of secondary data. The signal is assumed to be spatially and temporally colored. The noise signal is modeled as an auto-regressive process. Performance of the proposed CP-GLRT detector is compared with existing P-GLRT and GLRT detectors. Detailed comparative results have been obtained for different compression ratios as well as different number of samples. It is observed that by using compressive parametric GLRT, the computational burden on the system can be reduced. However this reduction in computational burden is achieved as a trade off with the performance of the detector. Moreover, the performance of the CP-GLRT can be improved by choosing an adaptive measurement matrix from the transmitted signal subspace.

[603] Hao-Wen Chen, Zhao kun Qiu, Lei Nie, Xiang Li, and Zhao wen Zhuang. Lorenz-based quasi-orthogonal waveforms for mimo radar systems. In *Radar Conference (EuRAD), 2011 European*, pages 289 –292, oct. 2011.

Abstract: It is well-known that it is very difficult to generate the ideal orthogonal waveforms. Commonly, the waveforms generated by Lorenz chaotic system are quasi-orthogonal. In this paper, the Lorenz-based chaotic waveforms are introduced to MIMO radar systems. Also, the principles of MIMO radar using Lorenz chaotic signals are analyzed briefly. Finally, numerical results demonstrate the effectiveness of Lorenz-based quasi- orthogonal waveforms for MIMO radar systems.

[604] P.W. Moo. Range-doppler migration in coherent mimo radar. In *Radar Conference (EuRAD), 2011 European*, pages 138 –141, oct. 2011.

Abstract: The detection performance of coherent MIMO radar with orthogonal waveforms is compared to that of a radar using a directed beam. For an accelerating target and Doppler processing detection, an analytical expression for probability of detection which explicitly accounts for range-Doppler migration is presented. It is shown that radar and target parameters should satisfy particular conditions in order to ensure that range- Doppler migration does not occur. Due to longer integration times, MIMO radar suffers degraded detection performance compared to that of a directed beam radar. Doppler migration due to target acceleration is the dominant cause of range-Doppler migration as the number of antenna elements increases.

[605] T. Fickenscher, A. Gupta, J. Hinz, M. Holters, and U. Zolzer. Mimo surface wave radar using time staggered fmcw chirp signals. In *Radar Conference (EuRAD), 2011 European*, pages 69 –72, oct. 2011.

Abstract: In order to distinguish between different signal paths, full orthogonal waveforms for each transmit antenna element is desirable for the concept of MIMO radar. We investigate time staggered Frequency Modulated Continuous Wave (FMCW) chirp signals with an individual successive temporal delay larger than the maximum round-trip time of the radar signal. This

concept is superior compared to those using time division multiplexing or multiple carrier frequencies in terms of unambiguous Doppler and bandwidth requirement, respectively. This is in particular important for long range marine surveillance using high-frequency surface wave radar where the frequency band is very congested and fast boats or helicopters have to be detected.

[606] F. Belfiori, L. Anitori, W. van Rossum, M. Otten, and P. Hoogeboom. Digital beam forming and compressive sensing based doa estimation in mimo arrays. In *Radar Conference (EuRAD), 2011 European*, pages 285 –288, oct. 2011.

Abstract: The paper presents different processing schemes that have been investigated in order to evaluate the direction of arrival (DOA) with a multiple-input multiple-output (MIMO) radar. Conventional digital beam forming (DBF) and super resolution algorithm (MUSIC) have been applied. The results provided by them have been compared with a compressive sensing (CS) processing of the virtual elements of the MIMO array. The possible reduction of the number of physical elements in the array, due to the application of CS techniques, has been also analyzed. Experimental validation has been carried out on a test board radar developed at TNO in the Netherlands.

[607] A.H. Narayanan, P. Brennan, R. Benjamin, N. Mazzino, G. Bochetti, and A. Lancia. Railway level crossing obstruction detection using mimo radar. In *Radar Conference (EuRAD), 2011 European*, pages 57 –60, oct. 2011.

Abstract: Level crossing obstruction detection is an important safety feature that is prominent in rail operations, with detection systems currently deployed use various radio and optical imaging technologies. This paper proposes a prototype radar system for level crossing obstruction detection which utilises the Multiple In Multiple Out principle. The radar system to be used is an FMCW radar which operates at 24.225 GHz. The millimetre operating wavelength enables a small MIMO patch antenna array for the radar system to be fabricated on the same substrate. The radar will also be mounted at a height of 4m looking downwards onto the crossing which will require ground clutter cancellation. The MIMO antenna array layout which shows the element positions and the beampattern from its associated virtual array is shown. A short description of the proposed radar system hardware layout is then given. The signal processing algorithm, which consists of Digital Beamforming and clutter removal, is discussed in the following section. Plans for further work to develop the radar system are provided at the end of the paper.

[608] O.A. Krasnov, Zongbo Wang, F. Van Der Zwan, and A. Yarovoy. A new bistatic radar system: Parsax + tara. In *Radar Conference (EuRAD), 2011 European*, pages 146 –149, oct. 2011.

Abstract: Combination of two existing S-band radars TARA and PARSAX into a multi-static system for weather and targets observation is discussed. The proposed combination of radars will provide unique back- and bistatic-scattered radar data simultaneously. The feasibility of the proposed combination has been verified experimentally. Analysis of the operational modes is performed and waveforms for MIMO operation are presented.

[609] P.F. Sammartino, J. Fortuny-Guasch, and D. Tarchi. Efficient signal processing in mimo radars. In *Radar Conference (EuRAD), 2011 European*, pages 13 –16, oct. 2011.

Abstract: An efficient way to process data of MIMO radars by means of FFT is here discussed. However, MIMO radars are here shown to suffer a discontinuous phase history across all the channels, due to their geometry, especially in the short-range. In turn, this would prevent the FFT-based algorithm to work correctly. Consequently, it is here shown that data of MIMO radars have to be pre-processed in order to allow an efficient FFT-based localization. For this purpose a sub-optimal algorithm is presented, discussed and tested against real data gathered by the JRC MIMO radar system.

[610] V. Riche, S. Meric, and E. Pottier. Study of receiver design in a mimo sar configuration. In *Radar Conference (EuRAD), 2011 European*, pages 297 –300, oct. 2011.

Abstract: In this paper, we are concerned on the receiver design and the different imaging possibilities for radar MIMO SAR. The transmission of pseudo-orthogonal waveforms gives many opportunities in reception on how to manage these different signals. We proposed to compare different resolutions and robustness for SAR measurements: SISO and MIMO. Moreover, we developed a SAR processing based on MIMO configuration by using the stolt interpolation.

[611] O. Gomez, P. Jardin, F. Nadal, B. Poussot, and G. Baudoin. Multiband waveform synthesis and detection for a wideband mimo radar. In *Microwaves, Communications, Antennas and Electronics Systems (COMCAS), 2011 IEEE International Conference on*, pages 1 –5, nov. 2011.

Abstract: In the context of wideband Multiple-Input Multiple-Output (MIMO) radar, this paper presents a waveform design technique using multiple frequency bands, satisfying a low Peak-to-Average Power Ratio (PAPR) constraint. We then adapt a Direction-of-Arrival (DOA) estimation technique, known as TOPS (Test of Orthogonality of Projected Subspaces) in the literature, to the received signals in a MIMO radar system.

[612] S. Gogineni and A. Nehorai. Adaptive waveform design for colocated mimo radar using sparse modeling. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 13 –16, dec. 2011.

Abstract: We consider the problem of multiple target estimation using a colocated Multiple Input Multiple Output (MIMO) radar system. We employ sparse modeling to estimate the unknown target parameters (delay, Doppler) using a MIMO radar system that transmits frequency-hopping waveforms. Further, we use the estimates of the target RCS values to adaptively design the amplitudes of the transmit waveforms during each hopping interval. We demonstrate the performance improvement using numerical examples.

[613] S. Gogineni and A. Nehorai. Polarimetric mimo radar target detection using game theory. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 17 –20, dec. 2011.

Abstract: Polarimetric radar systems allow the flexibility of transmitting arbitrarily polarized waveforms that match the scattering profiles of the target. Since different types of targets have varying profiles, the advantages of a polarimetric radar system can fully be exploited only when the type of target is accurately estimated. However, accurate estimation requires a significant amount of training data, which can be expensive. We propose a polarimetric design scheme for distributed Multiple Input Multiple Output (MIMO) radar target detection. We formulate the selection of transmit polarizations using a game theoretic framework by examining the impact of all possible transmit schemes on the detection performance with different available target profiles. This approach does not require training data, and we show a significant performance improvement due to the polarimetric design.

[614] D.R. Fuhrmann. Mimo radar signal processing for distributed phased arrays. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 1 –4, dec. 2011.

Abstract: We explore transmit signaling and receive signal processing strategies for a notional MIMO radar system consisting of widely distributed phased arrays. The assumptions are that within a phased array, there is a fixed rigid geometry and perfect phase synchronization, and there is a single look at the target. In constrast, between phased arrays there is imperfect phase synchronization and multiple views of the target. The relative advantages and disadvantages of coherent and orthogonal signaling in such a model are explored through simulation.

[615] Junhyeong Bae and N.A. Goodman. Widely separated mimo radar with adaptive waveform for target classification. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 21 –24, dec. 2011.

Abstract: In prior work, we have shown the advantage of adaptive waveforms for monostatic radar target recognition performance. In this paper, we extend our approach to the widely separated multi-input multi-output (MIMO) radar scenario. MIMO radar exploits a diversity of radar waveforms and target scattering to improve radar performance. We present an iterative information-based waveform design method that results in waveforms having narrow, disjoint bands so as not to interfere with each other. Applying a constant modulus constraint causes spectral spreading, but we study the impact of this spreading and find that the performance loss is minimal.

[616] Gongguo Tang and A. Nehorai. Computable performance analysis of block-sparsity recovery. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 265 –268, dec. 2011.

Abstract: In this paper, we employ fixed-point iteration and semidefinite programming to compute performance bounds on the basis pursuit algorithm for block-sparsity recovery. As a prerequisite for optimal sensing matrix design, computable performance bounds would open doors for wide applications in sensor arrays, MIMO radar, DNA microarrays, and many other areas where block-sparsity arises naturally.

[617] M. Strom and M. Viberg. Low papr waveform synthesis with application to wideband mimo radar. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 5 –8, dec. 2011.

Abstract: This paper considers the problem of waveform synthesis given a desired power spectrum. The properties of the designed waveforms are such that the overall system performance is increased. The metric used to evaluate the optimality of the synthesized time domain signals is the peak-to-average power ratio (PAPR). We discuss how to synthesize waveforms using the technique of partial transmit sequence (PTS). The key point is that the gradient can explicitly be derived from the objective function. Furthermore, the result is extended by allowing the power spectrum to deviate from its original shape, yielding a further reduction in the PAPR. The method is applied to derived power spectra for wideband multiple-input-multiple-output (MIMO) radar. It is shown that the proposed technique can achieve optimal or near optimal performance with PAPR below 0.5 dB.

[618] M. Strom, M. Viberg, and K. Falk. Transmit and receive filter optimization for wideband mimo radar. In *Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2011 4th IEEE International Workshop on*, pages 9 –12, dec. 2011.

Abstract: In this paper, we discuss the possibility to suppress interference for wideband multiple-input-multiple-output (MIMO) radar, using only the temporal properties of the signals. The idea is to use tunable filters each connected to a wideband waveform generator, and to derive the optimal power spectral density (PSD) of the resulting signals in a known environment. The metric used to evaluate the enhancement in the system performance is the signal-to-noise and interference ratio (SNIR), from which the optimal transmit and receive filter properties are derived. We discuss two optimization approaches: one alternating and one joint algorithm. Each method is separated into two cases: for a total power constraint and for an individual power constraint on the transmit filters, respectively. Numerical validation illustrates the possibility to suppress the interference in the temporal domain, without actually forming a spatial null in the direction of the interference.

[619] A. Al-Hamadi, R.S. Blum, and D. Nair. Lei Huang and Siliang Wu. High-resolution direction finding for mimo radar systems without eigendecomposition. In *Instrumentation, Measurement, Computer, Communication and Control, 2011 First International Conference on*, pages 941 –944, oct. 2011.

Abstract: By simultaneously transmitting and receiving multiple coded waveforms with multiple-input multiple-output (MIMO) configuration, the MIMO radar appears more attractive than the traditional phased array radar in performance. However, when applied in the MIMO radar system, the classical subspace-based methods for high-resolution DOA estimation are computationally prohibited as the observed covariance matrix is the Kronecker product of the transmit and receive covariance matrices, considerably increasing the size of the covariance matrix. To cure this problem, a computationally efficient subspace-based method for DOA estimation is addressed in this paper. The proposed method only needs vector-vector operations, and does not involve the covariance matrix calculation and its EVD or inversion operations. Therefore, the proposed method is computationally attractive for practical applications. Numerical results are included to illustrate the performance of the proposed method.

[620] ZhuLin Zong, Jianhao Hu, Lidong Zhu, and Haitao Jia. Hybrid-lfm signal design and detection performance analysis for formation-flying satellite radar system. In *Communications and Networking in China (CHINACOM), 2011 6th International ICST Conference on*, pages 1074 –1078, aug. 2011.

Abstract: Formation-flying satellite radars, as a kind of MIMO radars with widely-separated antennas, is a new technique developed recently. It offers the potential for diversity gain and spatial resolution gain through transmitting the orthogonal waveforms. In order to obtain diversity gain and spatial resolution gain and improve the detection performance, a hybrid-LFM signal for formation-flying satellite radar is proposed in this paper. The hybrid-LFM signal is composed of several sub-pulses with different frequency slope. In this model, the bandwidth of each sub-pulse and the frequency slope interval are important. Firstly, we investigate the signal processing of satellites' echo and present an efficient implementation of formation-flying satellite radar system. Then, the orthogonal performance of the hybrid-LFM signals and the detection performance of formation-flying satellite radar system are analyzed. In the end, we draw the conclusion from simulations that not only the Hybrid-LFM signals have good orthogonal performance, but also the formation-flying satellite radar system with hybrid-LFM signals can obtain better detection performance than that with OFDM-LFM signals.

[621] Xie Chao, Dangwei Wang, Xiaoyan Ma, and Wang Libao. The imaging method of airborne radar on hybrid sampling. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 8 –12, oct. 2011.

Abstract: This paper introduces a high resolution imaging method, which is based on hybrid sampling of the airborne MIMO radar, combined the single snapshot of MIMO radar with the synthetic aperture of SAR. The method represents an equivalent array algorithm that the PRF of the system can be reduced dramatically to the conventional SAR, such that large unambiguity areas we can get. Numerical simulations are provided to examine the validity of the proposed method.

[622] Zheng Zhidong, Zhang Jianyun, and Niu Chaoyan. Angle estimation of bistatic mimo radar in the presence of unknown mutual coupling. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 55 –58, oct. 2011.

Abstract: In this paper, a new joint the direction of departures (DODs) and the direction of arrivals (DOAs) estimation method in the presence of unknown mutual coupling for bistatic multiple-input multiple-output radar (MIMO) radar is presented. By setting the auxiliary elements on the both sides of the transmit and arrays, the effect of mutual coupling can be eliminated and the standard MUSIC can be utilized directly to estimate the DODs and DOAs. Simulation shows that the proposed method can get better estimation performance than the standard MUSIC with unknown mutual coupling and can be close to the performance of the standard MUSIC with known mutual coupling in the high SNR.

[623] Jun Li, Guisheng Liao, and H. Griffiths. Range-dependent clutter cancellation method in bistatic mimo-stap radars. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 59 –62, oct. 2011.

Abstract: In this paper, we investigate the problem of cancelling range-dependent clutter in bistatic radar by using multiple-input multiple-output (MIMO) techniques. The rotation and projection operations are applied directly to the received data samples to transform the range-dependent clutter to be range-independent. Only the velocities of transmitter and receiver are needed to aid the data processing. The method exploits the fact that the clutter spectra of bistatic MIMO radar are in a 3-dimension (3-D) plane when both transmitter and receiver are side-looking. Simulation and analysis show that the proposed method is easy to implement and can cancel the range-dependent bistatic clutter effectively.

[624] Xiaoli Liu and Guisheng Liao. Reduced-dimensional angle estimation in bistatic mimo radar system. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 67 –70, oct. 2011.

Abstract: An algorithm for reduced-dimensional angle estimation in bistatic Multiple-Input Multiple-Output (MIMO) radar system is presented. By utilizing the characteristic of Kronecker product, two-dimensional search of Capon/MUSIC can be reduced. The direction-of-arrivals (DOAs) and direction-of-departures (DODs) can be obtained by one-dimensional search and eigenvectors corresponding to the smallest eigenvalues, respectively. Furthermore, the angles of targets can be paired automatically. Simulations which demonstrate the analytical derivations are provided.

[625] Hong Jiang, Jian-Kan Zhang, and Kon Max Wong. Target localization for bistatic mimo radar in unknown correlated noise. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 71 –75, oct. 2011.

Abstract: In this paper, target localization for bistatic MIMO radar in unknown spatially correlated noise is investigated. In our model, both the transmitter and receiver arrays are divided into two subarrays. A novel target localization algorithm is proposed by jointly estimating the directions-of-departure (DODs) and directions-of-arrival (DOAs) for transmitter and receiver subarrays in unknown noise. The algorithm exploits the canonical correlation decomposition (CCD) and the joint estimation technology based on the shift-invariance properties of different subarrays obtaining the automatic pairing. In addition, the compact formulas of stochastic Cramer-Rao bounds (CRB's) for DOD and DOA estimation are derived. The simulations show that our method effectively improves the performance of estimation by eliminating the unknown correlated noise.

[626] Xiaowei Tang, Jun Tang, Bo Tang, Zhaozhao Gao, Xin Bi, and Jinsong Du. A new electronic reconnaissance technology for mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 79 –83, oct. 2011.

Abstract: MIMO (multiple-input multiple-output) radar has been recently introduced as an important new radar system which emits orthogonal waveforms to cover a wide surveillance space. Therefore, the electronic reconnaissance technology for MIMO radar is of great significance in the future war. In this paper, a new electronic reconnaissance mode and

identification algorithm for MIMO radar is proposed. In detail, a single reconnaissance aircraft is used to fly along a circumference of suspicious radar, collecting radiated signals on multiple positions. Furthermore, the collected data is analyzed and the number of orthogonal waveforms is estimated to detect and discriminate whether it's a MIMO radar. Studies show that the wider angle range the reconnaissance aircraft flies by, the better the estimation results will be. Accurate estimates can be achieved when the flying angle exceeds a certain threshold. In addition, the reconnaissance aircraft requires a longer flight when MIMO radar uses more orthogonal waveforms or the signal-to-noise ratio (SNR) is relatively low.

[627] L.H. Yuan, G. Zheng, and X.W. Li. Research on theory and technology of distributed mimo radar systems. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 87 –90, oct. 2011.

Abstract: The distributed MIMO radar system is presented on the basis of theory and technology of multiple input and multiple output (MIMO) radars. Firstly, the node radar in the distributed MIMO radar systems is introduced. Secondly, some technologies are analyzed such as antenna array, waveform design and precise simultaneous detection. Finally, simple analysis shows that this distributed MIMO radar system has good performance.

[628] Yilong Lu and Yue Tang. A low-cost mimo radar system concept based on single transmitter and single receiver. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 91 –94, oct. 2011.

Abstract: This paper presents a novel low-cost time-division multiplexing MIMO radar system concept by using only one transmitter and one receiver. For an MIMO radar system of M-element transmitting array and N-element receiving array, the number of required transmitters/receivers is reduced from N+M to 2 for considerable cost reduction.

[629] Wei Wang, Xianpeng Wang, and Xin Li. An angle estimation algorithm for mimo radar in the presence of colored noise fields. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 95 –98, oct. 2011.

Abstract: An angle estimation method for Multiple-Input Multiple-Output (MIMO) radar in the presence of colored noise fields is presented. In this method, the transmitter array is divided into two sub-arrays. Then a new correlation matrix can be constructed by the received data from two transmitter sub-arrays and reconstructed data. The influence of spatial colored noise can be eliminated by the cross correlation matrix and the angle can be estimated by ESPRIT-MUSIC. The parameters can be paired automatically and the angle estimation performance of the proposed method is better than other methods in low SNR. Simulation results are presented to verify the effectiveness of this method.

[630] Hao Cao, Tiezhen Jiang, and Xuyuan Chen. Array optimization for mimo radar by particle swarm algorithm. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 99 –103, oct. 2011.

Abstract: In this paper, in order to lower the maximum peak side-lobe of MIMO radar, sparse array optimization and particle swarm optimization(PSO) are used. By restricting the maximum and minimum spacing of the adjacent elements, symmetric, asymmetric array in the receiver and

in transmitter-receiver are experimented. The result of experimental simulation demonstrates that the PSO combing sparse array for suppressing side-lobe is effective.

[631] S.H. Zhou, H.W. Liu, Baochang Liu, and Kuiying Yin. Collocated mimo radar beamforming with two side adaptivity. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 104 –107, oct. 2011.

Abstract: We propose a beamforming algorithm for collocated multiple-input multiple-output (MIMO) radar with two side adaptivity capability such that more active and inactive interferences can be suppressed at a low computational complexity and a low sample number requirement. Signals only with jamming and noise signals are used as training samples to obtain the weighting vector for receiving beamforming. After receiving beamforming, signals that may contain targets of interest are range compressed and then pass the adaptive transmitting beamforming to suppress inactive interferences. Numerical experiments show that this algorithm can suppress more interferences than the MIMO Capon algorithm, at a lower computation cost than the MIMO two-side beamforming algorithm.

[632] Qian He, R.S. Blum, and Zishu He. Noncoherent versus coherent mimo radar for joint target position and velocity estimation. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 108 –111, oct. 2011.

Abstract: Recent research indicates that one can obtain improved MSE performance from employing a coherent processing approach in MIMO radar with properly placed antennas. This paper demonstrates that the magnitude of these gains decreases with an increase in the product of the number of transmit and receive antennas if the antennas for the noncoherent system are also suitably placed, using a placement which is generally different from the one for the coherent processing approach. In particular, the mean square error (MSE) of the noncoherent system approaches that of the coherent system when the product of the number of transmit and receive antennas is sufficiently large. A theorem is presented for the case of orthogonal signals in temporally and spatially white noise-plus-clutter, but numerical results for nonorthogonal signals and colored noise-plus-clutter follow a similar pattern.

[633] Long Sun, Kai Jiang, Bo cai Wu, and Jia long Ge. Mimo sar/mti system design and signal analysis for moving target indiction. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 116 –121, oct. 2011.

Abstract: Multiple-input multiple-output (MIMO) system is one of the major focuses on research activities for mobile communication. Since late 1990s active studies on MIMO radar system have been done as well. Inspired by recent advances in MIMO radar, the MIMO synthetic aperture radar (SAR) concept was advanced. In this paper,the contradiction between azimuth antenna size (or azimuth resolution) and radar detection range in near space high speed platform SAR/MTI system is analyzed. The technique of multiple -input multiple-output,which can be used to resolve the contradiction, is used in SAR imaging mode. Subsequently, a novel space-time equivalent reconstruction method, which can get a high Performance of detection and location in MTI mode, is presented.

[634] Jingxu Han and M. Inggs. Detection performance of mimo passive radar systems based on fm signals. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 161 –164, oct. 2011.

Abstract: This paper analyses the use of commercial Frequency Modulation (FM) broadcasting signals to configure a Multiple Input Multiple Output (MIMO) parasitic (passive) radar system. The postulated system utilises multiple transmitters of opportunity, operating at multiple frequencies, with spatially distributed receivers. By utilising the Neyman-Pearson hypothesis, this paper addresses detection issues for such a MIMO parasitic radar system. Closed-form expressions for calculating the probability of detection with a given probability of false alarm has been derived. Lastly, Monte Carlo simulation results confirming the theoretical derivations are presented.

[635] Jie He, Da zheng Feng, N.H. Younan, and Hui Lv. Bi-capon beamforming for mimo radar: A correlation matrix-based method. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 335 –338, oct. 2011.

Abstract: In this paper, a bi-Capon beamforming (BCB) algorithm for MIMO radar based on a simplified correlation matrix is investigated. By vectorising the received data matrix and its transpose and iteratively optimizing two lower dimensional weight vectors, the bi-Capon beamforming (BCB) method can significantly decrease the computational complexity and the training samples requirement. Simulation results are presented to demonstrate the effectiveness of the proposed method.

[636] Minglei Yang, Baixiao Chen, Guimei Zheng, and Xiaofang Dang. Reduced-dimensional esprit algorithm for mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 347 –349, oct. 2011.

Abstract: A reduced-dimensional (RD) ESPRIT algorithm is proposed to reduce the dimension of the received data and to estimate the DOAs of multiple targets for arbitrary MIMO radar linear array configuration. It exploits the rotational invariance property of the RD virtual array and has much lower computational complexity than the methods of the same kind.

[637] D. Pastina, F. Santi, and M. Bucciarelli. Multi-angle distributed isar with stepped-frequency waveforms for surveillance and recognition. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 528 –532, oct. 2011.

Abstract: The exploitation of data acquired by a multiplatform system has been demonstrated to be able to increase the cross range resolution of ISAR images of rotating targets. In this paper we focus on Distributed-ISAR (D-ISAR) making use of stepped-frequency waveforms, obtaining a high range resolution through a synthetic range-profile processing. Both scenarios, multistatic or MIMO are considered: in the multistatic case one sensor of the formation transmits and the remaining just receive, while in the MIMO case each platform carries an active radar and receives echoes from all the transmissions. A suitable set of waveforms is proposed for the MIMO case and the required focusing technique is shown and tested against simulated D-ISAR data. Moreover, for the multistatic case, the proposed concept and processing scheme are validated by using a set of real data acquired in anechoic chamber.

[638] Junliang Qu, Xu Jia, Yingning Peng, and Xiutan Wang. Optimal waveform design for mimo radar detection with clutter and noise. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 559 –563, oct. 2011.

Abstract: In this paper, we introduce KL-divergence into MIMO radar waveform design to jointly resist clutter and noise. We derived the optimal waveforms which could match the target echoes and resist the background interference. Moreover, the energy allocation way is also used as the solution for distributing more energy into target channel and lower energy into inference channel. Finally, this paper shows the detection performance of optimal waveforms compared with other waveforms. Finally, numerical simulation results are provided to demonstrate the effectiveness of the proposed optimal waveforms.

[639] Xu Wang, Hongwei Liu, Junkun Yan, Liangbing Hu, and Zheng Bao. Waveform design with low sidelobe and low correlation properties for mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 564 –567, oct. 2011.

Abstract: MIMO radar can transmit different signals via different antennas, which enables flexible designs of transmit beampattern. At present, the most methods for beampattern design focus on the spatial performance. In this paper, an approach is proposed to design MIMO radar waveform with beampattern having low sidelobe level and low spatial cross-correlation level, and with the spatial signals having low temporal correlation properties. Numerical examples are presented to demonstrate the effectiveness of the proposed algorithm.

[640] K. Shadi, F. Behnia, and B. Aghili. Copula method constant modulus waveform synthesis for mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 568 –571, oct. 2011.

Abstract: MIMO radar is a new promising research area. In MIMO radar in compare to conventional phase array radar each radar antenna can transmit arbitrary waveform. This degree of freedom in waveforms design brings numerous benefits for MIMO radar. But to deploy these benefits, a waveform optimization problem should be solved. One of the most important criteria in designing waveforms is achieving prescribed correlation matrix. In this paper we propose a novel stochastic method based on copula for constant modulus waveform synthesis to obtain a given correlation matrix. This method is compared to existing methods for pros and cons. Simulation is carried to verify the theoretical results.

[641] Anxi Yu, He Feng, Dong Zhen, Sun Xilong, and Ma Xile. Design and implement of a spaceborne mimo sar simulation software. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 887 –890, oct. 2011.

Abstract: Radar signal models and software architecture for spaceborne MIMO SAR simulation are designed in this paper. Spaceborne MIMO SAR signal simulation is separated into several monostatic and bistatic signal simulation tasks. A parallel task decomposition method based on cluster computer environment is proposed to solve the problem of the large requirement of computation and memory. Finally, a typical spaceborne MIMO SAR simulation is executed and experiment results are presented.

[642] Tian Jin, Lou Jun, Qian Song, and Zhimin Zhou. Landmine bistatic scattering function estimation from virtual aperture radar image. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 938 –941, oct. 2011.

Abstract: Virtual aperture formed by multiple-input multiple-output (MIMO) array can obtain the high-resolution image, which contains bistatic scattering information instead of monostatic scattering information and thus can improve the discrimination performance of virtual aperture radar. In this paper, a bistatic scattering function estimation method is proposed to extract the landmine bistatic scattering information from the forward-looking virtual aperture ground penetrating radar image. The imaging model of virtual aperture is developed firstly. Based on the imaging model, the bistatic scattering function of a suspected object is estimated on the virtual aperture image of the suspected object using the space-wavenumber processing. The experimental results show that the proposed method can offer the bistatic scattering information to discriminate landmines from clutter.

[643] Yunhe Cao, Zijing Zhang, Fengzhou Dai, and Rong Xie. Fast doa estimation for monostatic mimo radar with arbitrary array configurations. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 959 –962, oct. 2011.

Abstract: A fast direction of arrival (DOA) estimation method is presented in this paper for monostatic multiple-input multiple-output (MIMO) radar with arbitrary array configuration. In order to avoid spectral peaks search in the multiple signal classification (MUSIC) algorithm and reduce the computational complexity, the proposed method uses manifold separation and polynomial rooting technique to estimate DOAs of the targets for the monostatic MIMO radar with arbitrary array configurations. The proposed polynomial rooting DOA estimation algorithm provides a lower computation complexity and a better resolution performance than the conventional MUSIC method. Finally, simulation results are presented to verify the effectiveness of the method.

[644] Ma Peng, Zhang Ke, and Zhang Jianyun. Detection performance of non-coherent mimo radar with phase synchronization errors. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 963 –966, oct. 2011.

Abstract: Phase synchronization errors (PSEs) are practically inevitable for non-coherent MIMO radar with widely separated antennas, so in this paper a two-step generalized likelihood ratio test (2s-GLRT) algorithm to target detection under PSEs. The expectation-maximization (EM) algorithm and detection criterion are employed to estimate the channel parameter and acquire target detector respectively. Simulation results verify the correctness of algorithm.

[645] Dang-Wei Wang, A-Lei Chen, Jun-Quan Yuan, and Xiao-Yan Ma. Sparsity-based mimo radar imaging method. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 1, pages 967 –970, oct. 2011.

Abstract: The matched filter, as a popular method, has been widely used to image a target in the radar society. Nevertheless, there exists an important difficulty that the resolution of the image produced by the filter can be changed with the variation of the target's distance. In this paper a distinct imaging algorithm through the exploitation of the sparsity of the received echoes is presented for the multiple-input multiple-output (MIMO) radar imaging application against the

difficulty involved in the matched filter. Furthermore, the constrained conditions for the array size and element interval are also presented. Different from the imaging algorithm based on the matched filter, the iterative greedy algorithm is used to image a target in this paper. Due to the exploitation of the sparsity of the received echoes, the cross-range resolution of the proposed algorithm can be higher over the given spatial scope. Numerical simulations are provided for testing our imaging algorithm.

[646] Feng Xun, Wang Shou-yong, Yang Jun, Du Peng-fei, and Zhu Xiao-bo. Mimo radar signal separation algorithm in non-gaussian clutter. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 979 –983, oct. 2011.

Abstract: This paper addresses the problem of MIMO radar signal separation with traditional matched filtering (MF) in dependent non-Gaussian clutter, and a fractional lower order generalized sidelobe canceller (FLO-GSC) is proposed. In the proposed method, the dependent clutter and the undesired transmitting signals are regarded as interference. By using the fractional lower order statistics of the received signals based on the rule of minimum mean square error (MMSE), the FLO-GSC model is derived. Finally, simulations are given for the MIMO radar signal separation in SG-Alpha stable distribution clutter. The results show that the proposed method is efficient for MIMO radar signal separation in dependent non-Gaussian clutter.

[647] Juting Wang. Adaptive detection and sidelobe signal rejection for mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 984 –988, oct. 2011.

Abstract: Antenna beam pattern in MIMO radar systems, like any other radar, exhibits sidelobes. Naturally it is possible for clutter and other sort of interference to be detected accidently via these sidelobes. This has the effect of mis-aligning the main beam steering vector and reducing detection performance. In addition, the performance is dependent on the precision of the array calibration process. This paper examines the competing effects of both those components. Specifically, we examine adaptive processing that operates across the whole MIMO system aiming to reduce sidelobe clutter, restore the steering vector to its true position and hence maximize signal to clutter ratio and therefore detection performance. The MIMO version of an Adaptive Detector with Conic Acceptance and Rejection (ADCAR) is developed, resorting to a generalized likelihood ratio principle. Constant False Alarm Rate (CFAR) properties of the detector are demonstrated. The performance of the MIMO- ADCAR is numerically evaluated. The results show the proposed detector is capable of achieving a compromise between sensitivity of mainlobe signal and rejection of sidelobe signal.

[648] Juting Wang. Angle estimation of coherent targets for bistatic mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 989 –992, oct. 2011.

Abstract: Angel estimation is considered for bi-static MIMO radar in the case where there exist both coherent and incoherent targets. Firstly, the bis-tatic MIMO radar data model is introduced and data covariance matrix is given. secondly, a matrix is formed using a column of the bi-static MIMO radar data covariance matrix. The rank of the formed matrix is only related to the number of the targets. Finally, the estimation of signal parameter via rotational invariance techniques (ESPRIT) algorithm is applied on the formed data matrix to estimate the direction of departure (DOD) and the direction of arrival (DOA). The numerical results show the effectiveness of the method.

[649] Xing Shi and Xiang Long Peng. Radar embedded communication technology study. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 1000 –1003, oct. 2011.

Abstract: Because of significantly merit in anti-jamming, potential performance, multifunction and integration, the technique and application of dual-use of radar and communication has been paid a special attention recently. This paper describer importance and latest techniques of radar embedded communication, analyses commonness and difference of Joint radar and communication. Based on rapid development of relative techniques, an concept of radar embedded communication with combining of multiple-input multiple-output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) was presented. Radar performance and communication capacity was studied. The prospect and further work are putt forward.

[650] Yongzhe Li, Zishu He, Hongming Liu, and Jun Li. A new stap method for mimo radar based on joint digital beam forming and joint domain localized processing. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 1107 –1110, oct. 2011.

Abstract: Multiple-input multiple-output (MIMO) radar has drawn unprecedented attention and becomes a main focus of research in the radar field. In this paper, we develop a novel STAP scheme for MIMO radar. The scheme takes advantage of the signals extracted by the matched filter (MF) bank which cascades with each receiver antenna element and forms a group of joint transmit-receive beams. A general sidelobe canceller (GSC) is derived to implement the adaptive matched filter (AMF) CFAR detection by employing a data level multistage wiener filter (DMWF) algorithm. This scheme reverses the unavailability of the phased-array-efficient joint-domain localized (JDL) algorithm for MIMO radar. Moreover, it adapts to MIMO radar with arbitrary ratio between transmitter and receiver element space. Even better, it needs less computed amount. We evaluate the validity of algorithm in terms of comparing the probability of detection performance and improving factor (IF) between phased array (PA) and MIMO radar.

[651] Wu-Xing Mao, Zhao Zhang, and Xiang-Ru Li. Ubiquitous mimo radar energy integration detection based on range synthesis. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 1760 –1763, oct. 2011.

Abstract: During such long-term time, the problem of target range-walk, Doppler-slide, beam-crossing must be considered, in the processing of the ubiquitous multiple-input multiple-output (MIMO) radar energy integration detection. Commonly, keystone transform is adopted for the completion of the migration compensation, and then the integration is finally carried out by motion target detection or joint time-frequency analysis, the result of energy integration is limited to the migration compensation. An improved long-term energy integration method is proposed, it makes use of range synthesis for avoiding the processing of the migration compensation. The effectiveness of new method is conformed by the simulation results.

[652] Yi-Duo Guo, Yong shun Zhang, Ning ning Tong, and Di Shen. Spatial localization of quasi-stationary targets using bistatic mimo radar. In *Radar (Radar), 2011 IEEE CIE International Conference on*, volume 2, pages 1788 –1791, oct. 2011.

Abstract: Quasi-stationary targets (QST) represent a class of nonstationary targets in which the statistics of their echoes are locally static over a short period of time, but exhibit differences from

one local time frame to another. A novel algorithm is proposed for spatial localization of quasi-stationary targets using bistatic MIMO radar. The proposed algorithm exploits the character of quasi-stationary targets and the rotational0 invariance property of ESPRIT to estimate the two-dimensional direction of departures (2-D DODs) and two-dimensional direction of arrivals (2-D DOAs) of quasi-stationary targets, so the targets can be localized in a 3-D plane. The algorithm does not refer to multi-dimensional nonlinear peak search, so that the computational load of the algorithm is low, and the estimated parameters of the targets can be paired automatically. The theoretical analysis and simulation results show the proposed method is effective.

[653] Guang Hua and S. Abeysekera. Collocated mimo radar waveform coding using costas and quadratic congruence arrays. In *Information, Communications and Signal Processing (ICICS) 2011 8th International Conference on*, pages 1 –5, dec. 2011.

Abstract: Multiple-input-multiple-output (MIMO) radar with collocated antennas transmits orthogonal waveforms to allow the received echoes to be used efficiently for range and Doppler estimation. The orthogonality of the transmitted waveforms should hold for both time shifts and frequency shifts. This paper, for the first time, extends two time-frequency hopping coding methods - the Costas Array Coding (CAC) and the Quadratic Congruence Coding (QCC), which were commonly used in single-input-single-output (SISO) radar and sonar applications, to MIMO scenario, and formulate the novel optimization problems. By decomposing the MIMO ambiguity function (AF), we analyze their auto-ambiguity functions (AAF) and cross-ambiguity functions (CAF). Linear frequency modulation (LFM) signal is used for the coding. Simulation shows that MIMO radar is superior to conventional single-input-single-output (SISO) radar in terms of sidelobe reduction, and the delay resolution can be significantly improved by increasing the coding dimension.

[654] K. Shadi and F. Behnia. Transmit beampattern synthesis using eigenvalue decomposition in mimo radar. In *Information, Communications and Signal Processing (ICICS) 2011 8th International Conference on*, pages 1 –5, dec. 2011.

Abstract: MIMO radar is the next generation radar which transmits arbitrary waveforms at each one of its apertures. It has been shown that design of waveforms for MIMO radars in order to synthesize a desired spatial beampattern is mapped into a waveform correlation matrix (R) design in the narrowband case. Searching for desired R has been modeled as a convex optimization problem which demands considerable processing power. There are also some close form solutions for special cases like rectangular beampatterns. Here we deal with the problem from a matrix eigenvalue theory perspective and show how close form solutions can be found for more general cases relaxing high computational power demand. Our proposed method also fulfills uniform elemental power, targets decorrelation and low Side Lobe Level.

3.6 Conference papers published in 2012

[655] G.V.K. Sharma and K.R. Rajeswari. Four-phase orthogonal code design for mimo radar systems. In *Communications (NCC), 2012 National Conference on*, pages 1 –4, feb. 2012.

Abstract: MIMO (Multiple-Input Multiple-Output) Radars have received considerable attention over the last decade due to their enhanced performance potential. Unlike phased array radar, MIMO radar transmits orthogonal waveforms via its transmitting antennas to improve separability of individual returns at the receiver elements. In this paper, an alternate method for generating four-phase sequences with good autocorrelation and cross correlation properties is proposed. The advantages of the proposed scheme include constant envelope, finite alphabet, large family and efficient structure for generation.

[656] Wei Wang, Xianpeng Wang, and Jinshan Yan. Angle estimation for monostatic mimo radar based on multistage wiener filter. In *Computer Science and Network Technology (ICCSNT), 2011 International Conference on*, volume 1, pages 200 –203, dec. 2011.

Abstract: In this paper, an angle estimation algorithm for monostatic Multiple-Input Multiple-Output (MIMO) radar based on Multistage Wiener Filter (MSWF) is present. Firstly, a reduced dimensional transformation matrix can be utilized to transform the high dimensional received signal data into low dimensional one. Then the signal subspace can be obtained by forward recursion of the Multistage Wiener Filter. The root polynomial of direction of arrival (DOA) estimation can be constituted by signal subspace, and the DOA can be obtained by root-MUSIC. The proposed method avoids not only the estimate of the covariance matrix and its eigendecomposition, but also the angle searching. Thus, the proposed method has lower computational complexity. Simulation results show that the proposed algorithm has better estimation performance than other methods.

[657] R. Feger, C. Pfeffer, C.M. Schmid, M.J. Lang, Z. Tong, and A. Stelzer. A 77-ghz fmcw mimo radar based on loosely coupled stations. In *Microwave Conference (GeMiC), 2012 The 7th German*, pages 1 –4, march 2012.

Abstract: In this work the realization of a frequency-modulated continuous-wave (FMCW) multiple-input multiple-output (MIMO) radar for the 77-GHz frequency band is presented. The proposed system consists of two separate radar units only loosely synchronized by the ramp trigger signal. To realize the separation of each transmitter's signal at reception, as it is required for the MIMO principle, a delayed ramp start of the slave station is implemented leading to different output frequencies for each transmitter. Since the delay caused by the ramp trigger is estimated in each measurement, the required accuracy of the ramp start timing is only defined by the maximum achievable sampling frequency of the used analog-to-digital converter. Due to the derived signal processing algorithms a coherent measurement with the two stations can be realized without requiring an RF link between them.

[658] T.D. Backes and L.D. Smith. Array design in a linear phased-subarray mimo radar. In *Aerospace Conference, 2012 IEEE*, pages 1 –6, march 2012.

Abstract: Much attention has been given to multiple input multiple output radar systems due to their potential for better performance in detection and angular resolution and measurement accuracy. However, MIMO radar's capabilities come with serious costs. These costs come in the overall system implementation and in considerations for real world applications. A hybrid system, where not all radiating elements transmit orthogonal waveforms and all elements are steerable in terms of phase shift, may be able to provide some of the advantages of a MIMO radar system while mitigating costs. One application where a hybrid system may make sense is in a target tracking radar, where the application demands a high signal to noise ratio. This paper examines one application of this hybrid architecture to the problem of main beam discrimination of targets.

[659] R.A. Coogle, J.D. Glass, L.D. Smith, and W.D. Blair. Tracking with mimo radar: A baseline solution. In *Aerospace Conference, 2012 IEEE*, pages 1 –9, march 2012.

Abstract: This paper describes a baseline target tracking system implemented using the GTRI/ONR Multiple-Input Multiple-Output (MIMO) Radar Benchmark platform. MIMO radar systems have been garnering a significant amount of attention for their potential to improve overall radar performance in comparison to existing systems. While there is much in the current literature regarding the performance and parameter design of MIMO radar target tracking systems, there is little that describes a complete target tracking solution. Such a solution would integrate measurement processing, data assignment, and track filtering into a single unit. The MIMO tracker described in this paper aims to provide a starting point for such tracking solutions. Although naive in some respects, this MIMO tracker provides a comparison tool for new MIMO target tracking algorithms. The results of running the tracker with the scenarios provided in the GTRI/ONR MIMO Radar Benchmark are also presented.

[660] J.D. Glass and A.D. Lanterman. Mimo radar target tracking using the probability hypothesis density filter. In *Aerospace Conference, 2012 IEEE*, pages 1 –8, march 2012.

Abstract: Target tracking in a widely spread multiple input multiple output (MIMO) radar system requires joint processing of several measurements from multiple sensors. The probability hypothesis density (PHD) filter provides a promising framework to process these measurements, since it does not require any measurement-to-track associations. Furthermore, the PHD filter naturally handles a multi-target environment because of the lack of explicit data association. We implement a PHD filter in the GTRI/ONR MIMO Benchmark, and compare results against the Benchmark's default solution. We assume a linear Gaussian target model so that the posterior target intensity at any time step is a Gaussian mixture (GM). Under this assumption, the PHD filter has closed-form recursions and target state extraction is simplified. This paper focuses on our implementation of the GM-PHD filter in the MIMO Benchmark, along with practical issues such as track labeling and applying the filter for the case of multiple sensors.

[661] T. Strohmer and B. Friedlander. Some theoretical results for compressed mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 739 –743, nov. 2011.

Abstract: We consider a MIMO radar system and derive a theoretical framework for the recoverability of targets in the azimuth-range-Doppler domain via compressive sensing type recovery algorithms. In particular we prove bounds on the achievable resolution and number of detectable targets in the presence of additive noise. Furthermore our theory reveals that even weak targets can be recovered reliably with the proposed approach.

[662] Duc Vu, Luzhou Xu, and Jian Li. Mimo sar based ground moving target indication. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 868 –872, nov. 2011.

Abstract: We investigate a framework for the detection of ground moving targets using a Multiple-Input-Multiple-Output (MIMO) radar system. We look at how phase histories collected from a MIMO Synthetic Aperture Radar (SAR) system can be used for target detection in a Ground Moving Target Indication (GMTI) mode while SAR images are being formed. We propose the usage of the recently developed Iterative Adaptive Approach to detect movers and estimate their velocities in the post-Doppler domain. We show how the waveform diversity afforded by a MIMO radar system enables its superiority over its Single-Input-Multiple-Output (SIMO) counterpart.

[663] T. Aittomaki, H. Godrich, H.V. Poor, and V. Koivunen. Resource allocation for target detection in distributed mimo radars. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 873 –877, nov. 2011.

Abstract: A distributed multiple-input multiple-output (MIMO) radars using transmitters and receivers distributed over a large area can offer improved target detection, estimation, and tracking capabilities. In order to achieve best performance, it is necessary that the use of resources is optimized in such a radar system. In this paper, we consider the optimization of the transmit power of the transmitters for the purpose of target detection. We derive the optimal Neyman-Pearson detector without assuming whiteness of noise or independence of scattering and formulate the problem of optimizing the probability of detecting targets in an area of surveillance. Numerical examples are provided to demonstrate the effectiveness of the method.

[664] Pu Wang, Hongbin Li, and B. Himed. Centralized and distributed tests for moving target detection with mimo radars in clutter of non-homogeneous power. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 878 –882, nov. 2011.

Abstract: In this paper, we study moving target detection (MTD) using a distributed MIMO radar, where the multi-static transmit-receive configuration causes non-homogeneous clutter. By representing the non-homogeneous clutter in a low-rank subspace with different subspace coefficients for different transmit-receive pairs, we first propose a centralized detector, the MIMO generalized likelihood ratio test (MIMO-GLRT), which requires the distributed receivers to send all their local observations to a fusion center. To reduce the communication overhead as well as power/bandwidth consumptions from the receivers to the fusion center, we consider two

distributed implementations of the MIMO-GLRT, with or without local data aggregation. In both cases, the local unquantized test statistics from all distributed receivers are forwarded to the fusion center. Simulation results are provided to illustrate the performance loss with respect to the centralized MIMO-GLRT and compare the proposed detectors with another distributed MIMO moving target detector based on a homogeneous assumption.

[665] K.B. Stewart, M.T. Frankford, J.T. Johnson, and E. Ertin. Mimo radar target measurements. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 1067 –1071, nov. 2011.

Abstract: Widely-spaced Multiple-Input Multiple-Output (MIMO) radar seeks to exploit an angular diversity of measurements in order to improve target detection performance. Such systems have been predicted to outperform equivalent phased-array configurations given a suitably low-noise environment. However, these predictions have been based on the use of a target model comprising a finite area filled with an infinite number of uncorrelated point-source scatterers, and the applicability of such models when applied to realistic MIMO radars and targets remains to be demonstrated. An extended target model is offered in which scattering amplitudes in the random target are correlated as a function of spatial proximity. This model is evaluated for its utility in describing the average radar profiles of two targets: a numerically-simulated helicopter and an experimentally measured unmanned aerial vehicle. Results demonstrate a limited applicability of the new target model but serve to verify several predictions concerning the target detection performance of MIMO radars when compared to phased arrays.

[666] A.P. Petropulu, Yao Yu, and Junzhou Huang. On exploring sparsity in widely separated mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 1496 –1500, nov. 2011.

Abstract: The scenario of widely separated multi-input multi-output (MIMO) radar is considered. For a small number of targets, the target returns are sparse in the target space. First, a decoupled Lasso approach is proposed, which by exploiting the structure of the basis matrix decomposes the large size problem into a number of smaller size problems, thus reducing computational complexity. Second, it is shown that by reordering the columns of the basis matrix, group sparsity can be introduced to the returns. This structure can be exploited by a group Lasso approach to achieve significant performance gains.

[667] B. Friedlander. On the role of waveform diversity in mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 1501 –1505, nov. 2011.

Abstract: MIMO radar employs multiple antennas to simultaneously transmit diverse waveforms, as well as multiple antennas to receive the radar returns. This paper studies the role of waveform diversity in MIMO radar as separate and distinct from the role of the multiple transmit antennas. This is done by comparing a MIMO radar system to a scanning phased-array radar which uses the same transmit and receive arrays but only a single waveform. The performance characteristics of the two systems are compared in detail for single pulse operation as well as multi-pulse operation with coherent integration. Both element-space and beam-space systems are considered.

[668] M. Rossi, A.M. Haimovich, and Y.C. Eldar. Global methods for compressive sensing in mimo radar with distributed sensors. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 1506 –1510, nov. 2011.

Abstract: We study compressive sensing methods for target localization in MIMO radar. While much attention has been given to compressive sensing of signal measurements in the time domain, this work focuses on the spatial domain. We propose a framework in which the target localization with distributed, active sensors is formulated as a nonconvex optimization. By leveraging a sparse representation, we devise a branch-and-bound type algorithm that provides a global solution to the nonconvex localization problem. It is shown that this method can achieve high resolution target localization with a highly undersampled MIMO radar with transmit/receive elements placed at random. A lower bound is developed on the number of required transmit/receive elements required to ensure accurate target localization with high probability.

[669] M. Scharrenbroich, M. Zatman, and R. Balan. Cooperative radar techniques: The two-step detector. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 1975 –1979, nov. 2011.

Abstract: In this paper we analyze a two-step detection scheme for use in distributed sensor systems (e.g. statistical MIMO radar). The scheme arises when a data rate restriction forces each of the distributed systems to sensor their detection statistics before sharing. We present the Neyman-Pearson (NP) two-step detection rule for the Swerling 2 target model case and expressions for the overall probability of detection and false alarm. We then analyze the performance of the Swerling 2 NP two-step detector, which requires a priori knowledge of the target SNR, and provide empirical evidence that it appears to be only weakly dependent on this a priori knowledge.

[670] S. Krishnamurthy, D.W. Bliss, and V. Tarokh. Sidelobe level distribution computation for antenna arrays with arbitrary element distributions. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 2045 –2050, nov. 2011.

Abstract: This paper discusses the conditions in which the sidelobe level distribution can be calculated in closed form for arrays with randomly located antenna elements with arbitrary element probability distributions. By using the number of times a beampattern crosses a certain level in an upward direction, sidelobe level distributions are found for beampatterns with angle-dependent and angle-independent statistics. The evaluation of the probability of exceeding a given peak sidelobe is investigated as a function of the antenna array spatial position variance in the asymptotic limit of a large number of antennas. Examples are presented including a multi-input multi-output (MIMO) radar illustration.

[671] B. Friedlander. On spatial processing in mimo radar. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 2075 –2079, nov. 2011.

Abstract: We develop a signal model for MIMO radar which takes into account delay and Doppler mismatch due to the fact that scatterers do not generally lie in the center of delay/Doppler resolution cells, as is commonly assumed in the literature on this subject. This

mismatch may cause a distortion of the array manifold thus impacting the results of array processing functions such as beamforming, null steering, and direction finding.

[672] P.B. Tuuk and A.C. Sharma. Sensor calibration errors in compressive distributed-aperture radar sensing. In *Signals, Systems and Computers (ASILOMAR), 2011 Conference Record of the Forty Fifth Asilomar Conference on*, pages 2117 –2121, nov. 2011.

Abstract: As unmanned platforms become more common, the desire for lightweight, low-power, inexpensive radar systems has increased. One such solution is a distributed-aperture, multiple-input, multiple-output (MIMO) radar. This allows simple, lightweight antennas to work cooperatively as a larger array. Typically, this setup requires a large amount of communications bandwidth, reducing its utility. Herein, we explore compressed sensing techniques as a solution. A model was developed to derive performance curves for detection of targets in range-angle-Doppler space. We explored in the impact on performance versus the accuracy to which the locations of the sensors are known and the precision to which they can be time synchronized. Our results show that the compressed sensing process is not brittle to errors of this type.

[673] David Wilcox and Mathini Sellathurai. Maximum likelihood sub-arrayed mimo radar receiver. In *Sensor Signal Processing for Defence (SSPD 2010)*, pages 1 –5, sept. 2010.

Abstract: There has been recent interest in MIMO radars which employ sub-arrays at the transmitter. This architecture allows a trade-off between the coherent beamforming gain of a phased array antenna and the transmit beampattern diversity offered by a MIMO radar with full transmit diversity, while maintaining a relatively simple implementation in the transmit hardware. In this work we study the maximum likelihood (ML) receiver for a transmit sub-arrayed MIMO radar, for estimating the direction of arrival of multiple targets. We develop the likelihood function for an orthogonal sub-arrayed MIMO radar for receiver architectures with and without a matched-filter bank. The maximisation of these likelihood functions form multi-dimensional optimisation problems which can be solved using a variety of sub-optimal numerical algorithms.

[674] Guodong Qin and Baixiao Chen. Doa estimation in mimo radar based on coherent siganl-subspace method. In *Wireless Mobile and Computing (CCWMC 2011), IET International Communication Conference on*, pages 25 –28, nov. 2011.

Abstract: MIMO radar in this paper uses sparse-array to transmit the FMCW signals of multiple carrier frequencies, and an array to receive the echoes. Due to transmit signals of multiple carrier frequencies, the Doppler frequency of the received signals after separated is not in a Doppler cell, and then the traditional supper-resolution algorithms work ineffectively, the parameters of the target can't be obtained. One method is presented in this paper. Firstly the data of different frequency is transformed into the data of the same frequency using focusing transformation, and then the spatial spectrum estimation algorithms are applied. The simulation results indicate the validity of the methods presented in this paper.

[675] He Gang, Bai Peng, Peng Wei-dong, Su Xi, Lin Ji-fu, and Zhang Xi-chuan. Influence of emitting waveforms' correlation on clutter suppression performance of mimo radar. In *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*, pages 2651 –2654, april 2012.

Abstract: Aiming at the constraints imposed on MIMO radar's clutter suppression performance by emitting waveforms' correlation, Based on the theoretical derivation of output SINR and improvement factor's expression, simulation results confirm that the proposed improvement factor can effectively promote the clutter suppression performance of airborne MIMO radar.

[676] S.B. Akdemir and C. Candan. Mismatched filter design in mimo radar. In *Signal Processing and Communications Applications Conference (SIU), 2012 20th*, pages 1 –4, april 2012.

Abstract: It was shown in the literature that MIMO radar can resolve much more targets in the angle than phased array radars. In order to resolve targets close to each other in range, waveforms, whose side-lobes of the autocorrelation function are low, are designed by using pulse compression techniques or mismatched filters are used at the receiver. In this paper, an integrated side lobe level filter which was originally developed for conventional radars is adapted to MIMO radar. In addition, a new mismatched filter design procedure is developed for the reduction of peak side lobe level.

[677] Y. Kalkan and B. Baykal. Cramer rao bound for target localization with mimo radar. In *Signal Processing and Communications Applications Conference (SIU), 2012 20th*, pages 1 – 4, april 2012.

Abstract: For target localization with radar, time of arrival (TOA), angle of arrival (AOA) and frequency of arrival (FOA) informations can be used in cooperation. In general, TOA information is enough to localize a target. Moreover, if the target velocity should be estimated, the target velocity is able to estimated by using doppler frequency. In this paper, the Cramer-Rao Bound (CRB) is shown for Multi Input, Multi Output (MIMO) radar with widely separated antennas case. CRB's are compared for different targets and transmitter-receiver configurations.

[678] A.P.G. Ariza, R. Muller, R. Stephan, F. Wollenschlager, A. Schulz, M. Elkhouly, C. Scheytt, U. Trautwein, J. Muller, R.S. Thoma, and M.A. Hein. 60 ghz polarimetric mimo sensing: Architectures and technology. In *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, pages 2578 –2582, march 2012.

Abstract: Millimeter-Wave (mm-W) is considered a potential technology for high-data rate wireless transmission and for high-resolution short-range radar, due to the 7-9 GHz bandwidth at the 60 GHz unlicensed band available worldwide. Developing ultrawideband architectures including multiple-input-multiple-output (MIMO) antenna systems at mm-W offer many advantages including jointly optimized analogue and digital signal processing at carrier frequency and baseband. This allows for flexible antenna designs and reduced losses, as many passive structures can be avoided at both sides of the link. Besides, based on flexible polarimetric approaches, the polarimetric propagation of electromagnetic waves can be exploited. In this paper we present a 60 GHz polarimetric MIMO system architecture, which includes analogue miniaturized frontends designed and manufactured by multi-layer packaging technologies. Such

architecture permitted the design of compact MIMO radar and multi-dimensional channel sounding. The MIMO approach allows not only polarimetric filtering and fully polarimetric/directional signal processing to increase the signal-to-clutter-plus-noise ratio of mm-W radar systems, but also the full characterization of wireless channels including multipath with orthogonal polarizations.

[679] A.P.G. Ariza and R.S. Thoma. Polarimetric ultrawideband mimo radar for security check points: Detecting and classifying suspects carrying wires. In *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, pages 1733 –1736, march 2012.

Abstract: The polarimetric scattering signatures of targets have been considered as potential source of information for target classification in radar. Besides, the use of ultrawideband (UWB) and multiple-input-multiple-output (MIMO) real-time systems offers additional advantages jointly with polarimetric antennas. Such systems allow extracting high resolution impulse responses and polarimetric covariance information of targets from different aspect angles. This paper presents the application of a polarimetric-UWB-MIMO radar system for detection and classification of suspects in security check points, with special focus in detecting suspects carrying wires by applying multivariate statistics. The classification process has been based on the Mahalanobis distance between different targets and has shown high success rate in a reference anechoic scenario.

[680] M. Helbig, M. Kmec, J. Sachs, C. Geyer, I. Hilger, and G. Rimkus. Aspects of antenna array configuration for uwb breast imaging. In *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, pages 1737 –1741, march 2012.

Abstract: Microwave UWB radar and imaging provides perspectives for early-stage breast cancer detection. We present an experimental MIMO setup for breast phantom trials based on M-sequence radar technology and electrically short antennas (bowtie dipoles). This approach combines short impulse responses, sufficient fidelity and very small antenna dimension and allows array construction with sufficient number of antennas around the breast. Obtained imaging results will be presented and aspects regarding the array configuration will be discussed.

[681] U. Prechtel, V. Meenakshisundaram, B. Schoenlinner, V. Ziegler, H.-P. Feldle, and A. Meusling. Short-range mimo radar system considerations. In *Antennas and Propagation (EUCAP), 2012 6th European Conference on*, pages 1742 –1745, march 2012.

Abstract: This paper gives a short overview of EADS research on system concepts for short range MIMO imaging radar and its potential applications in security. Basic approaches and constraints for image reconstruction are discussed. Additionally some simulation and measurement results are presented.

[682] J. Akhtar. Combined transmitter selection and pulse precoding for mimo radar systems. In *Radar Conference (RADAR), 2012 IEEE*, pages 0151 –0155, may 2012.

Abstract: This paper presents a pulse precoding technique combined with antenna selection for widely distributed MIMO radar systems. The scheme selects a subset of antennas for transmission and jointly linearly coded pulses are emit in order to offer a MIMO system making maximum usage of any available information. The selection and coding procedure is constructed on slowly

time-varying statistical radar knowledge such as antenna correlation and stationary / line-of-sight scatterers. Transmitting pulses from a few selected antennas ensures that signals are only emit from the most viable emitters while pulse coding introduces additional information-limited beamforming gain. Simulations are used to demonstrate that combining these techniques can offer substantial advantages.

[683] F. Belfiori, W. van Rossum, and P. Hoogeboom. Random transmission scheme approach for a fmcw tdma coherent mimo radar. In *Radar Conference (RADAR), 2012 IEEE*, pages 0178 –0183, may 2012.

Abstract: In this paper the authors analyze the use of Time Division Multiple Access (TDMA) applied to coherent Multiple-Input Multiple-Output (MIMO) radar systems. One of the main limitations in exploiting the orthogonal condition in the time domain for MIMO radars is the reduction of the unambiguous Doppler interval. With respect to frequency modulated continuous waveform (FMCW) systems, the authors present a possible solution which is based on the introduction of a random selection of the active transmitter. The analytical representation of the signal model is described and the simulated results of the proposed approach are shown.

[684] G.L. Charvat, J. Goodwin, M. Tobias, J. Pozderac, and J. Peabody. Detection algorithm implementation and measured results for a real-time, through-wall radar system using a tdm mimo antenna array. In *Radar Conference (RADAR), 2012 IEEE*, pages 0240 –0246, may 2012.

Abstract: Locating moving targets inside of buildings would greatly improve the situational awareness of the urban war fighter. A real-time, through-wall radar system was developed that plots the location (in down range and cross range) of moving targets at the video frame rate of 10.8 Hz behind an opaque wall. This is achieved by coupling an ultrawideband (UWB) S-band frequency modulated continuous wave (FMCW) radar, which uses a spatial frequency analog range gate, with a time division multiplexed (TDM) multiple-input multiple-output (MIMO) antenna array. Real-time imagery or detections are plotted on the radar screen, providing the war fighter with an immediate picture of the situation behind an unknown wall.

[685] T. Webster, Liwei Xu, and M. Cheney. Antenna beam patterns in mimo radar. In *Radar Conference (RADAR), 2012 IEEE*, pages 0332 –0337, may 2012.

Abstract: This paper deals with the development of an appropriate multistatic or multiple-input-multiple-output (MIMO) radar ambiguity function. Earlier work analyzed the case of isotropic antennas; in this work, we show how to include antenna beam patterns into the model. We consider the case of fixed sensors and a general distribution of objects, each undergoing linear motion; thus the theory deals with imaging distributions in phase space. We outline the derivation for a model for the data that is appropriate for narrowband waveforms in the case when the targets are moving slowly relative to the speed of light. From this model, we develop a phase-space imaging formula that can be interpreted in terms of filtered backprojection or matched filtering. For this imaging approach, we derive the corresponding phase-space ambiguity function or point-spread function. We show plots of the phase-space ambiguity function for various geometries.

[686] R.A. Coogle, L.D. Smith, and W.D. Blair. Debiased coordinate conversion of bistatic radar measurements. In *Radar Conference (RADAR), 2012 IEEE*, pages 0383 –0388, may 2012.

Abstract: The introduction of biases into monostatic radar measurements as a result of conversion from sine space coordinates into Cartesian coordinates is a well-known problem. Specifically, this problem occurs in long-range radars or radars with high range resolution. However, the biases have only been determined with regard to monostatic radars. With a possible resurgence in bistatic radar, specifically since in certain cases, a Multiple-Input-Multiple-Output (MIMO) radar system can be formulated in terms of bistatic radar pairs, understanding the biases as a result of such coordinate conversions becomes important. In this paper, we present the equations for transforming bistatic measurements into Cartesian coordinates, as well as derive expressions for the biases in the mean and covariance that result.

[687] Tianxian Zhang, Lingjiang Kong, Xiaobo Yang, and Jianyu Yang. Knowledge-aided bayesian glrt design of mimo radar in heterogeneous clutter. In *Radar Conference (RADAR), 2012 IEEE*, pages 0399 –0403, may 2012.

Abstract: This work addresses the problem of adaptive multiple-input multiple-output (MIMO) radar detection in heterogeneous clutter. We first derive the generalized likelihood ratio test (GLRT) based on the two-step design procedure. Then, considering with the Bayesian framework and the prior knowledge about the clutter, we adopt the Maximum A Posteriori (MAP) estimator of the clutter covariance matrix and extend the knowledge-aided Bayesian technique to MIMO radar detection. Finally, various simulation results and comparison with respect to other conventional technique are presented to demonstrate the effectiveness of the knowledge-aided Bayesian technique, especially in presence of a small amount of secondary data.

[688] Pu Wang, Hongbin Li, and B. Himed. Recursive moving target detection with distributed mimo radar in clutter with non-homogeneous power. In *Radar Conference (RADAR), 2012 IEEE*, pages 0504 –0509, may 2012.

Abstract: Our previous study addresses moving target detection (MTD) using a distributed multiple-input multiple-output (MIMO) radar in clutter with non-homogeneous power. The developed detector, referred to as the MIMO-GLRT detector, assumes perfect knowledge of the clutter subspace and uses the assumed clutter subspace to construct a projection matrix which is required to compute the test statistic. In this work, we take into account uncertainties on the clutter subspace, i.e., the subspace dimension is not known a priori, and develop a recursive version of the MIMO-GLRT detector by integrating a computationally efficient updating algorithm for the subspace projection matrix from one iteration to another, together with a generalized Akaike Information criterion (GAIC) for the subspace dimension selection. Simulation results with a synthesized dataset and a general clutter dataset are provided to demonstrate the performance degradation of the standard MIMO-GLRT detector when an over-estimated or under-estimated clutter subspace is used, and show that the recursive MIMO-GLRT detector is able to mitigate such degradation by choosing a proper clutter subspace directly from the received signals.

[689] O. Gomez, F. Nadal, P. Jardin, G. Baudoin, and B. Poussot. On wideband mimo radar: Detection techniques based on a dft signal model and performance comparison. In *Radar Conference (RADAR), 2012 IEEE*, pages 0608 –0612, may 2012.

Abstract: Wideband Multiple-Input Multiple-Output (MIMO) radar systems have improved performance compared to narrowband systems, including higher resolution and better parameter estimation. In this context, this paper presents a DFT signal model and adaptations of narrowband detection techniques to this model. Next, the performance of these techniques is evaluated after transmitting wideband probing signals designed by the Spectral Focusing Beampattern synthesis Technique (SFBT).

[690] G.J. Frazer. Simplified processing for time-staggered mimo waveforms with interference reduction properties. In *Radar Conference (RADAR), 2012 IEEE*, pages 0801 –0805, may 2012.

Abstract: A simplified radar processing scheme for multiple-input multiple-output (MIMO) radar is presented. The scheme uses a single matched filter to process all K waveforms in the MIMO waveform set however requires that K range gates are computed rather than a single range gate as in single waveform radar. The scheme assumes the MIMO waveform set is comprised of time-staggered waveforms and there are mild assumptions on the scatterer response that have been validated for the high frequency skywave radar case using an experimental MIMO skywave transmitter system. Results from this experimental system have shown that the simplified MIMO processing scheme described also has radio frequency interference rejection properties. An example from the experimental system demonstrates both ionospheric mode selection using MIMO radar and interference rejection.

[691] M.N. Majd, M.M. Chitgarha, M. Radmard, and M.M. Nayebi. Probability of missed detection as a criterion for receiver placement in mimo pcl. In *Radar Conference (RADAR), 2012 IEEE*, pages 0924 –0927, may 2012.

Abstract: Using multiple antennas at the transmit and receive sides of a passive radar brings both the benefits of MIMO radar and passive radar. However one of the obstacles arisen in such configuration is the receive antennas placement in proper positions so that the radar performance is improved. Here we just consider the case of positioning one receiver among multiple illuminators of opportunity. Indeed it is a start for the solution of optimizing the geometry of the multiple receivers in a passive radar.

[692] G. Krieger, M. Younis, S. Huber, F. Bordoni, A. Patyuchenko, J. Kim, P. Laskowski, M. Villano, T. Rommel, P. Lopez-Dekker, and A. Moreira. Digital beamforming and mimo sar: Review and new concepts. *Synthetic Aperture Radar, 2012. EUSAR. 9th European Conference on*, pages 11 –14, april 2012.

Abstract: Spaceborne Synthetic Aperture Radar (SAR) is a unique tool for large scale Earth observation, but the current generation of SAR sensors suffers from some fundamental limitations with regard to their imaging and mapping capabilities. To overcome these limitations, several new instrument architectures and SAR imaging modes have been suggested that employ digital beamforming (DBF), multiple aperture data recording and MIMO SAR techniques. This paper provides a critical review of these techniques and makes some suggestions for further

improvements. Special attention is given to advanced DBF and MIMO SAR concepts for ultra-wide swath imaging.

[693] Matthew C. Edwards and Evan C. Zaugg. Design of a compact, modular, multi-frequency band, multi-mode, multi-channel synthetic aperture radar. *Synthetic Aperture Radar, 2012. EUSAR. 9th European Conference on*, pages 44 –47, april 2012.

Abstract: Compact, flexible synthetic aperture radar (SAR) systems have proven their utility on a number of manned and unmanned aircraft. These systems can be even more useful when configured with multiple frequency bands, multiple channels, and/or multi-mode operation. This paper presents the design of a compact, modular, multi-frequency, multi-mode, multi-channel SAR. The modular design increases flexibility, allowing for an arbitrary number of transmit and receive channels, facilitating multiple-input, multiple output (MIMO) operation.

[694] Debora Pastina, Fabrizio Santi, Marta Bucciarelli, and Pierfrancesco Lombardo. 2d-mimo sar/isar imaging of moving targets with reconfigurable formation of platforms. *Synthetic Aperture Radar, 2012. EUSAR. 9th European Conference on*, pages 223 –226, april 2012.

Abstract: In this paper we propose a new technique to exploit the data simultaneously acquired by multiple radar sensors carried by multiple air platforms to increase the resolution of radar images of moving targets. Using orthogonal waveforms that occupy the same bandwidth in the range frequency domain, a 2D-MIMO SAR/ISAR system is configured. The system is based on a formation of platforms which can be configured with proper cross-track displacements to achieve ground range resolution improvement (MIMO SAR) and proper along track displacements to achieve cross-range resolution improvement (MIMO ISAR). The proposed technique allows to achieve a maximum theoretical 2D resolution cell improvement factor significantly greater than the number of flying platforms, by jointly exploiting both the monostatic and the bistatic acquisitions. The 2D-MIMO SAR/ISAR technique could be suitable to the application of ship target imaging using a reconfigurable formation of platforms for maritime surveillance in wide sea areas.

[695] Zhenqing Hong, Peng Ma, Zhong Rui Huang, and Jian Yun Zhang. Adaptive beamforming for mimo radar with sidelobe control based on second order cone programming. In *Information Science and Technology (ICIST), 2012 International Conference on*, pages 384 –388, march 2012.

Abstract: The beampattern of the traditional MVDR beamformer for MIMO radar always has unacceptably high sidelobe levels, especially when the transmit antennas are located more than a half wavelength apart from each other. To overcome this shortcoming, we proposed a new adaptive beamforming algorithm with sidelobe control for MIMO radar. Our method minimizes the power of interferences and noise, while maintaining distortionless response in the direction of target of interest and keeping the sidelobe levels lower than some prescribed threshold value. The second order cone (SOC) formulation of our proposed beamformer is derived which can be easily solved using the well-established interior point method. Simulation results show that our proposed beamformer has substantially lower sidelobe levels than the traditional MVDR one. Both theoretical analyses and simulation results validate the effectiveness of the proposed algorithm.

[696] Xue-Song Yang, J. Salmi, A.F. Molisch, Shi-Gui Qiu, Seun Sangodoyin, and Bing-Zhong Wang. Trapezoidal monopole antenna and array for uwb-mimo applications. In *Microwave and Millimeter Wave Technology (ICMMT), 2012 International Conference on*, volume 1, pages 1 –4, may 2012.

Abstract: Ultra-wideband (UWB) antenna arrays are important for UWB communications, positioning, and radar. Antenna efficiency as well as omnidirectionality of the antenna pattern are important for these applications. This paper introduces and investigates a new printed array consisting of trapezoidal monopole antennas. The antenna elements have good impedance matching and omni-directional radiation pattern in the frequency range of interest, namely 2.2 GHz -7.5 GHz. Since a uniform linear array (ULA) of these elements shows severe pattern distortions at higher frequencies, we propose an interleaved uniform rectangular array (iURA). The iURA achieves a lower mutual coupling and thus improved omni-directionality of the radiation pattern. Furthermore, by comparing the ambiguity functions of a virtual iURA with that of a virtual ULA, it is found that, even though without considering the mutual coupling, the iURA has a better angular resolution performance than the ULA. We conclude that the iURA is more suitable than the ULA for UWB-MIMO applications.

[697] Jian Dong, Jie Yang, Wentai Lei, Ronghua Shi, and Ying Guo. Antenna array design in mimo radar using cyclic difference sets and simulated annealing. In *Microwave and Millimeter Wave Technology (ICMMT), 2012 International Conference on*, volume 1, pages 1 –4, may 2012.

Abstract: In this paper, the antenna array design problem in minimum redundancy MIMO radars is addressed, which seeks to maximize the virtual array aperture for a given number of transmitting and receiving (Tx/Rx) elements. A hybrid optimization method combining cyclic difference sets (CDSs) with simulated annealing (SA) is proposed for the optimal design of Tx/Rx antenna arrays. Numerical results are also presented, showing large variety in array configurations and notable improvement in the spatial resolution.

[698] Pu Wang, Hongbin Li, and B. Himed. Target velocity estimation and crb with distributed mimo radar in non-homogeneous ar-modeled disturbances. In *Radar Symposium (IRS), 2012 13th International*, pages 109 –112, may 2012.

Abstract: In this paper, we examine the target velocity estimation with distributed multi-input multi-output (MIMO) radars in non-homogeneous environments, where the disturbance signal (clutter and noise) exhibits non-homogeneity in not only power but also covariance structure from one transmit-receive antenna pair to another as well as across different test cells. Specifically, a set of distinctive auto-regressive (AR) models are used to model such non-homogeneous disturbance signals for different transmit-receive pairs. The maximum likelihood (ML) estimator for the target velocity parameter is developed. Corresponding Cramer-Rao bounds, in both the exact and asymptotic forms, respectively, are examined to shed additional light to the problem. Numerical results are presented to demonstrate of the effectiveness of the proposed method.

[699] T. Rommel, A. Patyuchenko, P. Laskowski, M. Younis, and G. Krieger. Development of a mimo radar system demonstrator - calibration and demonstration of first results. In *Radar Symposium (IRS), 2012 13th International*, pages 113 –118, may 2012.

Abstract: Multi-Modal Radar Systems (MMRS) using Digital Beam-Forming (DBF) concept offer higher operational flexibility and improved performance compared to the conventional radar systems using analog beam steering. In particular, Synthetic Aperture Radar (SAR) based on DBF concept overcomes the fundamental limitation of classical SAR systems delivering high resolution and simultaneously wide swath images. This paper presents a laboratory prototype of the next generation MMRS system - a reconfigurable Multiple Input Multiple Output (MIMO) radar demonstrator based on the DBF architecture. The hardware configuration of the demonstrator is described in detail, and the system calibration and signal processing procedures are considered. The first measurement results confirming its functional capabilities are presented and discussed.

[700] A. Zwanetski and H. Rohling. Continuous wave mimo radar based on time division multiplexing. In *Radar Symposium (IRS), 2012 13th International*, pages 119 –121, may 2012.

Abstract: A radar system with multiple transmit and receive antennas (MIMO) is considered in this paper. A specific linear frequency modulated continuous wave (FMCW) signal is applied in this case, which allows a simultaneous and unambiguous measurement of target range and radial velocity even in multiple target situations. This frequency modulated signal is transmitted alternately by each transmit antenna. This means that each transmit antenna has exclusive access to the radio channel inside a very small time slot while all other transmit antennas are switched off. Each transmit antenna uses the same waveform however in an intertwined way. In this case all transmit signals are mutually orthogonal and no interferences will occur. The radar echo signal is processed in each receive antenna simultaneously. Due to the orthogonality of all transmit signals each receive antenna can separate perfectly all signals transmitted by different antennas. This transmit signal structure and the time division multiplexing (TDM) procedure is the basis for a MIMO radar system design described in this paper. The radar system will have a high azimuth angle resolution and a large artificial receive antenna aperture.

[701] F. Belfiori, W. van Rossum, and P. Hoogeboom. Array calibration technique for a coherent mimo radar. In *Radar Symposium (IRS), 2012 13th International*, pages 122 –125, may 2012.

Abstract: In this paper we present a technique to estimate the calibration coefficients of a coherent Multiple-Input Multiple-Output (MIMO) array radar built on a printed circuit board (PCB). Due to the integrated structure and the MIMO nature of the system, a direct measurement of each antenna element behavior cannot be performed. The proposed method is based on the evaluation of the calibration parameters from the signal reflected by dominant targets, located at different range bins, and it does not require the a priori knowledge of their angular positions. Experimental validation of the presented technique has been done and the related results are illustrated.

[702] T. Brenner, J. Hardejewicz, M. Rupniewski, and M. Nalecz. Signals and data fusion in a two-band radar. In *Radar Symposium (IRS), 2012 13th International*, pages 15 –18, may 2012.

Abstract: The paper addresses important problems related to detection of small RCS targets. The probability of detection of such targets can be improved by fusion of non-coherent signals and/or plots from a few independents radars (channels) working in different bands. As an example a two-band radar system working simultaneously in S and C bands is considered. Its antennas are placed back to back. The paper describes the concept, similar to the MIMO method described in Maoxin Cai, Hongming Liu, Jun Li, and Zishu He. Evaluation of the anti-interception method for mimo radar. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: The performance of RF stealth is of significant importance for military radar because of the threat of an electromagnetic interference or an antiradiation missile. What is more, a useful method that can evaluate the RF stealth is needed urgently. In this paper, we proposed a method to evaluate the performance of RF stealth for MIMO radar. We provide a model to calculate the probability of intercept and analyze the factors that affect the probability of intercept. Simulation results show that the proposed model is efficient and valuable.

[703] Juanjuan Zhang, Hongming Liu, Jun Li, and Chunlin Han. Research on the mono-pulse phase comparison angle measurement algorithm of mimo radar. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: Mono-pulse angle measurement technology is being widely used for its simple structure and high accuracy. In this paper, we propose a mono-pulse phase comparison angle measurement algorithm applied to virtual array transformed equivalently from MIMO radar. Based on the principle of improving the accuracy of angle measurement, we adopt amplitude weighting to optimize this algorithm that we achieve higher accuracy compared with mono-pulse phase comparison angle measurement algorithm applied to actual array of MIMO radar. Simulation results verify the validity of this algorithm.

[704] Shaowei Yang, Zishu He, Hongming Liu, Jun Li, and Ting Cheng. An analysis of anti-tdoa positioning capability for mimo radar. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: The advantages of MIMO radar with orthogonal signals in anti-TDOA (Time Difference of Arrival) are discussed. First the cross-correlation between signals received by two receivers in different directions relative to MIMO radar is analyzed. It shows that the cross-correlation changes with the angle difference in certain value of which the two signals are even completely uncorrelated. Then a detailed analysis of angle-range coupling is presented based on uniform linear transmit array (ULTA) when Stepped Frequency Division Linear Frequency Modulation (SFDLFM) signals are used. The angle-range coupling will ultimately lead to the positioning deviation, thus contributing to the radar RF stealth.

[705] Xiang Duan, Hongming Liu, Jun Li, and Zishu He. Clean algorithm based direct-path-interference and multi-path-interference suppression in bistatic mimo radar. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: Transceiver arrays of Bistatic MIMO Radar are separated in airspace, which transmit orthogonal signals in space, forming a wide, low-gain transmit beam. With the DBF technique, the receiver can form multiple integrated transmit and receive beams. As multiple orthogonal signals are transmitted, direct-path interference and multi-path interference are combination of multiple signals, and meanwhile, considering the correlativity of target signal and interference, the methods such as transmit nulling, sidelobe cancellation and subspace-projection are inapplicable. The method of CLEAN algorithm based direct-path interference and multi-path interference suppression is proposed in this paper with the characters of this radar and the lack of existing methods considered. This method suppresses the direct-path and multi-path interference, highlighting the weak target signal by stripping strong interference signals layer by layer. Simulation results prove the validity of the method.

[706] Wei Zhang, Zishu He, Hongming Liu, and Jun Li. Comparisons of anti-jamming property of array configurations for mimo radar with the same virtual array. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: The comparisons of anti-jamming of array configurations for MIMO radar with the same virtual array is made. It is found that the degrees of freedom of clutter are same for the array configurations which have the same virtual array when there' s no jammer exist. If there are jammers exist, the clutter rank vary much depending on the numbers of transmitter, receiver no matter the transmitting array is set to be sparse configuration or receiving array is set to be sparse configuration. With the help of this conclusion, we can design an optimal array configuration when there are jammers which usually exist..

[707] Cheng Luo, Jun Li, Hong Ming Liu, and Zi Shu He. Compensation method for envelop migration of mimo radar high speed moving target based on transmit signal pre-process. In *Microwave and Millimeter Wave Circuits and System Technology (MMWCST), 2012 International Workshop on*, pages 1 –4, april 2012.

Abstract: According to the echo envelop migration of MIMO radar translational moving target with a high speed, the characteristic of the echo is analyzed, then a novel compensation method, based on transmit signal pre-process, is proposed. The method makes envelops of echo pulses automatic alignment in the fast-slow time domain. At the receiver, combining the Fractional Fourier transmit (FrFT), two index phases caused by the acceleration can be compensated, so the Doppler shift can be compensated simultaneously. The method requires tiny calculating quantities, and it is easy to achieve, moreover there's no SNR-loss in the process. The results of simulation verified the validity of the method presented.

[708] S. Kraut and D.W. Bliss. Analyzing the impact of mimo radar on tracking association error. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 161 –164, june 2012.

Abstract: We present a methodology for quantifying the effect of MIMO radar on tracking association performance. Two general factors affecting contact-to-track association are included. The first is a decrease in measurement error, in both Doppler and azimuth. The second is an increase in detection probability (due to enhanced discrimination of slow-moving targets from the clutter ridge), which effectively decreases the average time interval between track updates. The approach quantitatively evaluates the decrease in the probability of a track association error with a MIMO radar, to efficiently assess the design trades of system parameters.

[709] Yao Yu, A.P. Petropulu, and H.V. Poor. Power allocation for cs-based colocated mimo radar systems. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 217 –220, june 2012.

Abstract: It has been shown that in colocated multi-input multi-output (MIMO) radar systems the sparsity of targets in the illuminated space can be exploited by compressive sensing (CS) techniques to achieve either the same localization performance as traditional methods but with significantly fewer measurements, or significantly improved performance with the same number of measurements. In the colocated CS-based MIMO radar context, this paper proposes a power allocation scheme that distributes the system total transmit power among the transmit antennas in an optimal fashion that leads to improved detection performance. In particular, the allocation scheme minimizes the coherence between the target returns from different search cells, or equivalently, the coherence of the columns of the sensing matrix.

[710] Y.D. Zhang, M.G. Amin, and B. Himed. Altitude estimation of maneuvering targets in mimo over-the-horizon radar. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 257 –260, june 2012.

Abstract: Target altitude estimation is an important problem in over-the-horizon radar (OTHR) systems for target tracking and classification. Narrow signal bandwidth and rich propagation environment in OTHR render this problem difficult and challenging. In this paper, we develop a novel technique that allows accurate altitude estimation for a maneuvering target during its ascending or descending flight. The proposed technique considers a multiple-input multiple-output (MIMO) OTHR platform and utilizes the difference in the Doppler signatures generated in a micro-multipath propagation environment. The separability of the multi-component Doppler signatures in the time-frequency domain is used to individually estimate the elevation angles of these paths, which are otherwise infeasible to obtain, due to their small angular separation. The estimated elevation angle information is then used to achieve a reliable estimate of the target altitude.

[711] W. Rowe, J. Karlsson, Luzhou Xu, and Jian Li. Untangling multipath returns in mimo radar via waveform diversity. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 29 –32, june 2012.

Abstract: In some radar operating environments multipath clutter is the dominant source of interference. Since the multipath clutter may hide the desired target returns, an effective method

of clutter suppression is required. MIMO radar systems can discriminate multipath returns from target returns by estimating the directions of departure and arrival. Multipath clutter suppression using the conventional beamformer is not effective when the multipath returns are much stronger than the target returns. However, effective multipath clutter suppression can be achieved by using an adaptive transmit beamformer in conjunction with an adaptive receive beamformer while still illuminating the entire scene. This work explores the simulated performance of a MIMO radar system with two adaptive filtering algorithms: Iterative Adaptive Approach and Sparse Learning via Iterative Minimization. Simulation results show that these algorithms effectively suppress multipath returns at the cost of increased computational complexity.

[712] Yuewen Wang, A.N. Akansu, and A. Haimovich. Generalized dft waveforms for mimo radar. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 301 –304, june 2012.

Abstract: Recently, the Generalized Discrete Fourier Transform (GDFT) with nonlinear phase was introduced to improve the traditional Discrete Fourier Transform (DFT). We take advantage of the phase shaping function (PSF) of GDFT framework to optimize auto- and cross-correlation properties of OFDM frames used to generate radar waveforms. The superior performance of the GDFT MIMO radar waveforms over multifrequency complementary phase coded (MCPC) and Oppermann code families are presented in this paper. GDFT MIMO radar waveforms may be employed in the future as an efficient upgrade to the DFT based technologies.

[713] M. Scharrenbroich, M. Zatman, and R. Balan. Performance of a practical two-step detector for non-fluctuating targets. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 313 –316, june 2012.

Abstract: In this paper we analyze a two-step detection scheme for use in distributed sensor systems (e.g. statistical MIMO radar). The scheme arises when a data rate restriction forces each of the distributed systems to censor their detection statistics before sharing. We present the Neyman-Pearson (NP) two-step detection rule for a non-fluctuating target model (Swerling 0), which is non-linear and requires a priori knowledge of the target SNR. We then analyze the performance of a practical two-step detection rule under the non-fluctuating target model.

[714] S. Gogineni and A. Nehorai. Sparsity-based mimo noise radar for multiple target estimation. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 33 –36, june 2012.

Abstract: We solve a multiple moving-target estimation problem using a colocated multiple-input multiple-output (MIMO) radar system. Each antenna of the radar array transmits noise waveforms to achieve high resolution. These waveforms are further covered by codes that are inspired from code division multiple access (CDMA) to exploit code diversity. We formulate the measurement model using a sparse representation in an appropriate basis to estimate the unknown target parameters (delays, Dopplers) using support recovery algorithms. We demonstrate the performance of the proposed system using numerical simulations.

[715] S.L. Marple. Suas for 8-channel gmti radar using alternative high performance non-smi stap algorithm. In *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2012 IEEE 7th*, pages 417 –420, june 2012.

Abstract: GTRI is developing an 8-channel X-band experimental radar for a small unmanned aircraft system (SUAS) for adaptive multi-channel, MIMO, and waveform diversity test bed studies. New adaptive algorithms, one of which is covered in this paper, are also part of the test bed. Estimation of the statistical covariance matrix forms a central role in radar detection and adaptive beamforming algorithm. For example, the optimal (adaptive) linear combiner (beamformer) weights for a radar sensor array are expressed in terms of the inverse of the multi-channel (MC) covariance matrix for MIMO problems. Rather than form an estimate of the covariance matrix directly from the available data and inverting (sample matrix inversion Yanyun Xu, Shiyou Wu, Jinjin Shao, Jie Chen, and Guangyou Fang. Life detection and location by mimo ultra wideband radar. In *Ground Penetrating Radar (GPR), 2012 14th International Conference on*, pages 80 –84, june 2012.

Abstract: The detection of micro-motion of human body such as respiration or heartbeat is an effective way to detect the life trapped in rubble. In this paper, the micro-motion of life is regarded as a moving target which can be detected by life detection algorithm and located by Ultra-wideband (UWB) radar imaging method based on Multiple-Input Multiple-Output (MIMO) system.

[716] Zhaofa Zeng, Jing Li, Ling Huang, and Fengshan Liu. Improvement of target imaging quality by multi-polarization mimo gpr. In *Ground Penetrating Radar (GPR), 2012 14th International Conference on*, pages 119 –124, june 2012.

Abstract: As for the conventional ground penetrating radar (GPR) system, the detection result is seriously affected by the antenna directionality, the target scattering sections (RCS) and multi-polarization characteristics of electromagnetic wave. The MIMO (Multiple-Input and Multiple-Output) array antenna GPR technology can overcome the influence of RCS, electromagnetic polarization and improve the quality of target imaging effectively. In this paper, we put forward the MIMO GPR technology based on the plane wave like (PWL). It uses the conventional radar system with multiple antennas and takes the plane wave like as transmit resource. It has higher stability and signal-to-noise ratio (SNR). The multi-polarization detection mode can obtain more precise waveform of incident wave. Combining with multi-polarization phase information of target signal, we can obtain more precise location parameters of target and improve the detection accuracy. In addition, because the antenna interval is far less than wavelength of source signal, the multi-polarization and multi-input signal can compress the width of target response polarized wave and increase the target-range resolution. The result of simulation and experiments demonstrate that the MIMO GPR with multi-polarization detection mode has higher target imaging accuracy than that of the conventional GPR system.

[717] V.U. Reddy. Signal design for a specified transmit beampattern, spatial ambiguity function for mimo radar: A brief review of recent results. In *Applied Electromagnetics Conference (AEMC), 2011 IEEE*, pages 1 –4, dec. 2011.

Abstract: In phased-array radars, the transmitted waveforms from its different antenna elements are fully correlated resulting in a focused beampattern. On the other hand, MIMO (multiple-input

multiple-output) systems with transmit array containing colocated elements produce omni-directional beampattern with uncorrelated waveforms transmitted from its antennas. In some applications, it might be desirable to synthesize a beampattern that is between these two extremes so that wide focus areas can be formed without wasting power in the directions that are of no interest. In this paper, we present a brief review of recent results on the signal design. Specifically, we first introduce briefly the transmit beampattern and spatial ambiguity function, and then illustrate through examples how the zero-lag cross-correlation matrix of the transmitted signals, R, impacts the transmit beampattern. Next, we describe the beampattern/spatial ambiguity function design, through the design of R, as an optimization problem, and illustrate this with a few examples. Once the desired R is found, synthesis of the waveforms from R, subject to certain practical constraints, will be outlined.

[718] Steffen Lutz, Klaus Baur, and Thomas Walter. 77 ghz lens-based multistatic mimo radar with colocated antennas for automotive applications. In *Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International*, pages 1 –3, june 2012.

Abstract: With the fast development of highly integrated 77 GHz SiGe-MMICs, cost effective and reliable radar systems are feasible to significantly increase driving safety in all vehicle classes. New features have to be implemented in these sensors to fulfill the ascending requirements for future systems. Important demands will be the detection and separation of multiple targets in a range cell and the exact measurement of angles in azimuth and elevation. In this paper we present a new lens based 77 GHz MIMO radar system with SiGe MMICs. The center of attention in our investigations is the comparison between conventional lens based radar configurations and lens based MIMO radar configurations.

[719] Kamil Rezer, Christian Klickow, and Arne F. Jacob. Thinned mimo frame-arrays for radar imaging. In *Microwave Symposium Digest (MTT), 2012 IEEE MTT-S International*, pages 1 –3, june 2012.

Abstract: Thinned multiple-input multiple-output (MIMO) frame-arrays are proposed for 3-dimensional imaging radars. Their elements are placed on the perimeter of a square, thus allowing for simplified front-end architectures. A synthesis method for large arrays is described. A deconvolution algorithm is implemented for image enhancement. The principle is verified with a 12-transceiver array in a Ka-band radar.

[720] Guang Hua and S.S. Abeysekera. Colocated mimo radar transmit beamforming using orthogonal waveforms. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 2453 –2456, march 2012.

Abstract: Multiple-input-multiple-output (MIMO) radar transmit beamforming mainly relies on designing transmitted signals with an appropriate covariance matrix. The signals can be designed using a two-step method which first optimizes the covariance matrix and then searches for the signals accordingly. A more efficient way is to synthesize transmitted signals by designing a weight matrix given a set of orthogonal waveforms, which makes use of both MIMO waveform diversity and phased-array transmit gain. In this paper, we propose a method to design the transmit beampattern by solving a semidefinite programming (SDP) problem. Then the eigen-decomposition of the optimal covariance matrix yields the weight matrix. Therefore it is called the SDP-EIG method. As a result, the overall transmitted waveforms are obtained more simply

and efficiently, and the number of orthogonal signals required to form a desired beam reaches its minimum.

[721] A.A. Gorji, R. Tharmarasa, and T. Kirubarajan. Widely-separated mimo vs. multistatic radar for target localization. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 2461 –2464, march 2012.

Abstract: This paper considers the localization performance of MIMO radars with widely-separated antennas. A Multiple-Hypothesis (MH) based algorithm is proposed for multiple target localization problems where targets become unobservable in certain pairs of transmitters and receivers. In addition, the performance of MIMO radars in localizing multiple-scatterer targets is compared to that of multistatic radar systems. Finally, simulation results are provided in order to demonstrate the capability of MIMO radars in localizing multiple-scatterer targets.

[722] Xiufeng Song, P. Willett, and Shengli Zhou. Optimal power allocation for mimo radars with heterogeneous propagation losses. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 2465 –2468, march 2012.

Abstract: A multiple-input multiple-output (MIMO) radar can improve system performance with waveform and spatial diversities. Mathematically, the multiple independent waveforms increase the dimension of signal space, so optimal transmission power allocation deserves investigation. The majority of the literature prefers to omit the effect of propagation attenuation, and considers the receiving gain vectors to be independently and identically distributed (i.i.d.) in power allocation. In this paper, we integrate the propagation losses into MIMO radar signal model, and investigate the power allocation problems under three popular criteria: maximizing the mutual information, minimizing the minimum mean square errors, and maximizing the echo energy. As their objective functions are either convex or concave, the optimal strategies are theoretically guaranteed.

[723] Changchang Liu, Jin Yan, and Weidong Chen. Sparse self-calibration by map method for mimo radar imaging. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 2469 –2472, march 2012.

Abstract: Multiple-input multiple-output (MIMO) radar is expected to achieve good inversion performance by utilizing space diversity technology. However, traditional imaging methods often fail owing to the practical constraints that the available transmitters and receivers are very few and the number of snapshots is very limited. More seriously, the unavoidable position errors of the transmitters and the receivers would further deteriorate the imaging results. In this paper, by exploiting the sparse priority of the target, the sparse self-calibration by maximum a posterior probability method (SSC-MAP) is proposed to provide high resolution image and realize accurate position calibration at the same time. Numerical simulations verify the effectiveness of the proposed method.

[724] Xiufeng Song, P. Willett, Shengli Zhou, and P.B. Luh. The power game between a mimo radar and jammer. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 5185 –5188, march 2012.

Abstract: The interaction between a smart target and a smart MIMO radar is investigated from a game theory perspective. Since the target and the radar form an adversarial system, their interaction is modeled as a two-person zero-sum game. The mutual information criterion is used to formulate the utility functions. The unilateral, hierarchical, and symmetric games are studied, and the equilibria solutions are derived.

[725] Qian He, R.S. Blum, and Z.N. Rawas. Ordering for energy efficient communications for noncoherent mimo radar networks. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 5189 –5192, march 2012.

Abstract: In order to reduce the number of transmissions between a set of sensors and a fusion center in signal detection applications, we propose an algorithm based on ordering and halting the transmissions wisely, which can reduce the data transmission, and thus expended energy and data rate, without sacrificing signal detection performance. Here we consider the specific case of noncoherent signal detection, where the log-likelihood ratio turns out to be nonnegative, with independent observations form sensor to sensor. For this specific case, we design a new ordering algorithm which provides very large savings for some example MIMO radar systems considered for almost all false alarm probabilities and signal-to-noise ratios (SNRs). While these savings are demonstrated numerically, we also prove analytically that savings of (N - 1)/N 100probabilities and sufficiently large distance measures, a generalization of SNR, for a very large class of signal detection problems which employ N total sensors.

[726] T. Aittomaki and V. Koivunen. Target velocity estimation with distributed mimo radar using multiple pulse repetition frequencies. In *Acoustics, Speech and Signal Processing (ICASSP), 2012 IEEE International Conference on*, pages 5201 –5204, march 2012.

Abstract: In this paper, we propose estimating the velocity of a target using a widely distributed multiple-input multiple-output radar that employs multiple pulse repetition frequencies. In a MIMO radar, it is possible to use different PRFs in different transmitters without added complexity. This allows one to increase the number of pulses for estimation without decreasing the unambiguous range or increasing the time the target needs to be illuminated. We derive a maximum likelihood estimator for the velocity of the target under the assumptions that the scattering is independent and noise spatially and temporally white.

[727] A.A. Gorji, T. Kirubarajan, and R. Tharmarasa. Antenna allocation for mimo radars with collocated antennas. In *Information Fusion (FUSION), 2012 15th International Conference on*, pages 424 –431, july 2012.

Abstract: This paper deals with the antenna allocation problem in Multiple-Input Multiple-Output (MIMO) radar systems with collocated antennas. After deriving the Cramer-Rao Lower Bound (CRLB) as the cost function, the optimal distribution of antennas is found by applying the relevant operators to the CRLB. A convex optimization algorithm is then proposed to find the optimum distribution of antennas that achieves the optimal CRLB. It is also shown that the optimization problem can be simplified to the well-known Semi-definite Programming (SDP) for

a single target scenario. Using a number of simulations, it is shown that the localization algorithm also leads to superior results when the optimal antenna configuration is used.

[728] B. Mathelier, D.S. Kiran, and V.U. Reddy. Synthesis of waveforms from zero-lag cross-correlation matrix with specified constraints and power levels. In *Signal Processing and Communications (SPCOM), 2012 International Conference on*, pages 1 –4, july 2012.

Abstract: In MIMO radar applications, zero-lag cross-correlation matrix of the transmitted waveforms is designed for a desired transmit beampattern and spatial ambiguity function. The transmitted waveforms are to be synthesized from this matrix subject to certain constraints. Recently, Jian Li et al. A. Merline and S.J. Thiruvengadam. Mmse based waveform design for mimo radar with per antenna power constraint. In *Signal Processing and Communications (SPCOM), 2012 International Conference on*, pages 1 –5, july 2012.

Abstract: The design of MIMO radar waveform to minimize mean square error (MSE) in estimating the target impulse response subject to per antenna power constraint is addressed here. The optimal solution for waveform design employs waterfilling that uses Sum Power Constraint (SPC) at the transmitter, results in wide power variations across the transmit antennas. So a more realistic p-norm power constraint that jointly meets both the average per-antenna power constraint (PAPC) and the average sum power constraint to bound the dynamic range of the power amplifier at each transmit antenna is considered here. The optimal solution is obtained using Karush-Kuhn-Tucker (KKT) approach. It is shown that the detection performance of the system with both sum and per antenna power constraint is better than considering only the sum power constraint.

[729] M. Jabbarian and H. Khaleghi Bizaki. Target tracking in pulse-doppler mimo radar by extended kalman filter using velocity vector. In *Electrical Engineering (ICEE), 2012 20th Iranian Conference on*, pages 1373 –1378, may 2012.

Abstract: The superiority of multiple-input multiple-output (MIMO) radars over conventional radars has been recently shown in many aspects. The target tracking in MIMO radars is one of these aspects that has not been considered thoroughly yet. These radars consist of many transmitters and receivers located far from each other. In this scenario, the MIMO radar is able to observe different aspects of the target. One of the advantages of these radars is exploitation of Doppler frequencies from different transmitter-target-receiver paths. The extracted Doppler frequencies can be used for estimation of target velocity vector so that, the radar can be able to track the targets by use of its velocity vector with reasonable accuracy. In this paper, the pulse Doppler processing in MIMO radars is considered. The measurement of the velocity vector of the target and its counterpart errors is taken in to account. The extended Kalman target tracking by using its velocity vector is considered too. Besides, its performance is compared with those of MIMO target tracking without using the velocity vector and conventional radars. The simulation results show that the MIMO radars using velocity vector have superior performance over conventional radars in fast maneuvering target tracking.

[730] Jie Wang, Longyong Chen, Xingdong Liang, Wen Hong, and Lideng Wei. Mimo fmcw sar system using beat-frequency division waveforms. In *Imaging Systems and Techniques (IST), 2012 IEEE International Conference on*, pages 367 –370, july 2012.

Abstract: Special attention has been devoted to the lightweight, cost effective frequency modulated continuous wave (FMCW) synthetic aperture radar (SAR) in recent years. However, FMCW SAR is not feasible in the case of wider swath or higher Doppler bandwidth, because the loss of range resolution is dramatic and the system sampling rate is high. By using the technique of multi-input multi-output (MIMO), the pulse repetition frequency (PRF) of the system can be reduced dramatically without causing azimuth ambiguities. Consequently, the sweep cycle is increased, the system sampling rate is reduced, the loss of range resolution is negligible and the transmitter-receiver isolation is sufficient. The orthogonal signal transmitted in the system is beat-frequency division waveform. As the bandwidth of the beat signal is much smaller than the signal bandwidth and radio frequency (RF) carrier frequency, the difference between the transmitted signals wavelength is negligible, and the residual phase error caused by compensating phase shift can be ignored. Theoretical analysis and simulation results illustrate the feasibility of this system.

[731] F. Ahmad and M.G. Amin. Wall clutter mitigation for mimo radar configurations in urban sensing. In *Information Science, Signal Processing and their Applications (ISSPA), 2012 11th International Conference on*, pages 1165 –1170, july 2012.

Abstract: Strong front wall returns tend to obscure indoor targets and render through-the-wall target detection difficult and challenging. Among the various techniques proposed for wall clutter mitigation under monostatic radar operation is subspace projection. This technique uses the strength of the wall EM reflections relative to that of the target to separate the wall subspace from the target subspace. In this paper, we present analyses of the subspace projection approach for suppressing wall clutter and preserving indoor targets in multi-input multi-output (MIMO) through-the-wall radar imaging systems. We highlight the similarities and the differences in performance of the subspace technique under MIMO and monostatic configurations. Supporting results based on simulated and experimental data are provided.

[732] A. Guruswamy, V.U. Reddy, and R. Blum. Mimo radar under general waveform correlations/antenna spacing: Optimum detectors, detection performance and waveform design. In *Information Sciences and Systems (CISS), 2012 46th Annual Conference on*, pages 1 –6, march 2012.

Abstract: The performance of a multiple-input multiple-output (MIMO) radar is highly dependent on the relative positioning of the transmitter and receiver elements as well as the choice of transmitter waveforms. MIMO radars with either closely spaced antennas or widely separated antennas have been well studied in literature. In this paper, we study the general case where the transmit and receiver antennas have arbitrary separations, while also assuming that the transmit waveforms are arbitrarily correlated with one another. Under this setting, we derive closed form expressions for the optimal Neyman-Pearson detector and the detector signal-to-noise ratio (SNR). It is also shown that for radars with widely separated antennas, orthogonal waveforms maximize detector SNR at high received SNRs. Simulation results are presented demonstrating the nature of the optimal transmit waveforms for various antenna separations. A new scalar measure to characterize the nature of the waveform correlation matrix and the channel covariance matrix is also introduced.

[733] M. Rossi, A.M. Haimovich, and Y.C. Eldar. Spatial compressive sensing in mimo radar with random arrays. In *Information Sciences and Systems (CISS), 2012 46th Annual Conference on*, pages 1 –6, march 2012.

Abstract: We study compressive sensing in the spatial domain for target localization using MIMO radar. By leveraging a joint sparse representation, we extend the single-pulse framework proposed in Guangchen Fan and Weibo Deng. Mimo radar transmit beampattern synthesis based on genetic algorithm. In *Millimeter Waves (GSMM), 2012 5th Global Symposium on*, pages 445 – 448, may 2012.

Abstract: MIMO radar is an emerging technology that is attracting the interest of researchers. Each element for MIMO radar systems can transmit an arbitrary waveform, which leads to more flexibility for signal optimization and transmit beampattern synthesis. Here we propose a new method to synthesis MIMO radar transmit beampattern based on Genetic Algorithm. By employing Genetic Algorithm to select the best set of polyphase coded signals, we can approximate a desired beampattern which can hardly be achieved by its phased-array radar counterpart.

[734] G.A. Rankin, A.Z. Tirkel, L.Q. Bui, and N.W.D. Le Marshall. Radar imaging: Conventional and mimo. In *Communications and Electronics (ICCE), 2012 Fourth International Conference on*, pages 171 –176, aug. 2012.

Abstract: Our group has developed two diverse radar sensors with practical applications: an imaging radar at 94 GHz for Unmanned Aerial Vehicle (UAV) take-off and landing and a radar based termite detector at 24 GHz. These two sensors operate in vastly different environments. One relies on the weak radar returns from ground clutter to form a high fidelity image. The other detects the movement of termites hidden inside building materials at extremely short distances. Currently, our approach is moving away from classical radar towards Multiple Input Multiple Output (MIMO) radar. This paper presents the sensor implementations and recent results. The aircraft radar is still a demonstration system, whilst the termite detector is a mature product.

[735] Zhi Tian and E. Blasch. Compressed sensing for mimo radar: A stochastic perspective. In *Statistical Signal Processing Workshop (SSP), 2012 IEEE*, pages 548 –551, aug. 2012.

Abstract: Compressed sensing for MIMO radar can potentially enhance spatial resolution and improve anti-jamming capability by virtue of multiple transmitter and receiver antennas, and at the same time reduces the number of samples needed by making use of the inherent sparsity property of most radar scenes. Existing work along this line adopts a deterministic model for the radar signals, which may not be effective to cope with fading propagation and signal correlation in practical scenarios. This paper takes a stochastic approach by modeling the target scenes as random processes that are possibly correlated. A new stochastic framework of compressed sensing for MIMO radar is developed for reconstructing useful statistics of the random target scenes using a small number of samples. The proposed approach directly extracts the useful statistics for estimation without reconstructing the random signals; as a result, it is computationally more efficient and requires a smaller number of samples than existing deterministic approach to compressed sensing.

[736] Xiufeng Song, P. Willett, Shengli Zhou, and J. Glaz. Mimo radar detection with heterogeneous propagation losses. In *Statistical Signal Processing Workshop (SSP), 2012 IEEE*, pages 776 –779, aug. 2012.

Abstract: A multiple-input multiple-output (MIMO) radar can utilize distributed antennas to improve detection performance. Some existing works model bistatic path gains as identically and independently distributed random variables, and the known distinct features between propagation paths are neglected. Based on the bistatic radar equation, a path gain is a product of target reflection gain and propagation loss. Since the latter depends on geometry and system parameters, the true path gains are not necessarily identically distributed. In this paper, the propagation loss is incorporated into the MIMO radar signal model and the binary hypothesis test is explored. The test statistic is a sum of weighted Chi-square random variables under either hypothesis, and its distribution is a Gamma mixture. The probabilities of detection and false alarm can be explicitly obtained. In addition, a saddlepoint approximation based performance analysis is suggested, and it may be less sensitive to numerical errors, particularly when weighting coefficients are similar.

[737] N.D. Tran, R. Boyer, A. Renaux, S. Marcos, and P. Larzabal. Theoretical multidimensional resolution limit for mimo radar based on the chernoff distance. In *Statistical Signal Processing Workshop (SSP), 2012 IEEE*, pages 780 –783, aug. 2012.

Abstract: In this paper, we study the behavior of the theoretical multidimensional resolution limit (TMRL) for two closely spaced targets in the context of MIMO Radar with two scenarios: transmitting array and receiving array are widely spaced and collocated. Particularly, we apply the Stein's lemma which links the Chernoff distance and a given probability of error to derive closed-form expression of the TMRL for these models. The theoretical analysis provides interesting characteristics of the TMRL while numerical simulations show that the TMRL is better when amplitudes of two targets are not identical.

[738] Wenbing Dang, A. Pezeshki, S. Howard, and W. Moran. Coordinating complementary waveforms across time and frequency. In *Statistical Signal Processing Workshop (SSP), 2012 IEEE*, pages 868 –871, aug. 2012.

Abstract: In this paper, we consider a MIMO radar consisting of multiple collocated transmit/receive elements, where each transmit/receive pair operates at a different subcarrier frequency. Each transmit element is assumed to be waveform agile, meaning that it can select its waveform across time from a waveform library on a pulse by pulse basis. We consider a waveform library consisting of simply two component waveforms. The component waveforms are Golay complementary and are obtained by phase coding a narrow pulse with a pair of Golay complementary sequences. We show that by properly sequencing Golay complementary waveforms across time and frequency we can annihilate the range sidelobes of the radar point-spread function inside a desired Doppler interval around the zero-Doppler axis. This enables us to extract weak targets, which are located near stronger reflectors.

[739] Tie Jun Cui. Metamaterials - from new concepts to applications. In *Electromagnetics; Applications and Student Innovation (iWEM), 2012 IEEE International Workshop on*, pages 1 –2, aug. 2012.

Abstract: For a long time, the natural materials have been classified into two types: crystals and noncrys-tals, until Daniel Shechtman discovered quasicrystals in 1982, who won the Nobel chemistry prize in 2011 for this work. In fact, crystals and noncrystals are composed of periodically-distributed and randomly-distributed atoms, while quasicrystals have a third material state between crystals and noncrystals: which are non-periodic structures of atoms with certain rules instead of random. Hence the two factors to affect natural material properties are the atoms themselves and the spatial arrangements of atoms. Quasicrystals have brought a lot of new features of materials and found applications in steel armour, non-stick frying pans, and devices in cars for recycling waste heat into electricity. However, it is very hard to control atoms themselves and their spatial arrangements to get more material properties. Metamaterials provide us a freedom to tailor the material properties, both for electric and magnetic. Metamaterials are composed of periodic or non-periodic structures of artificial atoms or particles , which have a size of subwavelength scale. The flexible design of single artificial particles, the feasible arrangements of such particles, and the high anisotropy make it possible to control the material properties as desired: metamaterials can be used to realize the effective permittivity and/or permeability which cannot be achieved in nature. Hence they have either unique features with unusual physical phenomena (such as negative refraction, invisibility cloak, optical illusion, etc.) or superior performance than the natural materials. In this talk, I will focus on microwave metamaterials and introduce their counterparts to crystals, noncrystals, and quasicrystals: homogeneous metamaterials, random metamaterials, and inhomogeneous metamaterials. For all three cases, I will introduce the new concepts and important experiments and ap- lications in microwave frequencies conducted in my group, including the invisibility cloaks, electromagnetic black hole, radar illusion devices, power combination for omnidirectional radiations, planar gradient-index lenses, flattened Luneburg lens, Maxwell fisheye lens, high-gain Vivaldi antennas, and decoupling device for MIMO system.

[740] M. Hein, M. Helbig, M. Kmec, J. Sachs, F. Scotto di Clemente, R. Stephan, M. Hamouda, T. Ussmueller, R. Weigel, M. Robens, R. Wunderlich, and S. Heinen. Ultra-wideband active array imaging for biomedical diagnostics. In *Antennas and Propagation in Wireless Communications (APWC), 2012 IEEE-APS Topical Conference on*, pages 367 –370, sept. 2012.

Abstract: Ultra-wideband active array imaging has proven extremely valuable for biomedical diagnostics. At the same time, the underlying technologies have achieved a high degree of maturity. Across institutions, we have merged our expertise in M-sequence radar systems, antennas, low-noise and high-power circuitry, to devise an UWB MIMO radar system for breast tumour localisation. Recent progress in UWB imaging and hardware for active antenna arrays is presented.

[741] Dali Liu, Yuntao Liu, and Huizhi Cai. Orthogonal polyphase code sets design for mimo radar using tabu search. In *Intelligent Control, Automatic Detection and High-End Equipment (ICADE), 2012 IEEE International Conference on*, pages 123 –127, july 2012.

Abstract: Orthogonal polyphase code sets with low aperiodic autocorrelation sidelobe peak (ASP) values and aperiodic cross-correlation peak (CP) values, can be used in multiple input multiple output (MIMO) radar systems to reduce the interference between different signals. Tabu Search (TS) algorithm is proposed to optimize such orthogonal polyphase code sets with good autocorrelation and cross-correlation properties. The phase values of designed sequences are randomly distributed, which results in good properties of polyphase code sets. Some of the synthesized results are presented, and the properties of the sequences are shown to be better than those of sequences designed by other algorithms. Some relations of performances of polyphase code sets to the code length and the set size are discussed.

[742] G. Collins. A generalized mimo design technique for broadband doherty power amplifiers based on complex network synthesis methods. In *Integrated Nonlinear Microwave and Millimetre-Wave Circuits (INMMIC), 2012 Workshop on*, pages 1 –3, sept. 2012.

Abstract: Multistandard requirements for wireless infrastructure are driving the need for broadband PAs capable of achieving performance across several bands. Additionally, radar and satellite communications are requiring broadband performance with devices that can be deployed in a broad number of applications. A generalized design technique is presented here that aims to address this need. The MIMO approach accounts for the matching networks of the peaking and carrier amplifiers in a comprehensive manner. The Doherty PA has been a favorite candidate for delivering power and efficiency in narrowband designs. The design technique presented here encompasses the both the carrier, peaking and combining networks of the Doherty PA. This methodology is applicable to N-way Doherty PAs of different structures and can be extended to switched mode PA design as well as reconfigurable PAs.

[743] D. Deb, R. Bhattacharjee, and A. Vengadarajan. Mimo radar: Analysis of snr, beamwidth and sidelobe level. In *Antennas and Propagation (APCAP), 2012 IEEE Asia-Pacific Conference on*, pages 17 –18, aug. 2012.

Abstract: MIMO radar provides improvements in different system parameters but suffers from SNR and sidelobe level (SLL) degradation. It is shown in this paper that the improvement in beamwidth for fully filled transmit-receive array is achievable only if degradation in peak SLL is acceptable. It is also shown that improvement in beamwidth becomes evident only for sparse array at transmit-receive. SNR degradation for different configurations are also evaluated and it is shown that the same can not be compensated fully by increasing Time-on-Target (TOT). Hence the process of parameter improvements is generally a tradeoff and this paper brings out the interdependence that exist while making such tradeoff.

[744] Wen-Qin Wang and Huaizong Shao. Phased-mimo radar with frequency diversity for increased system flexibility. In *Signal Processing, Communication and Computing (ICSPCC), 2012 IEEE International Conference on*, pages 16 –19, aug. 2012.

Abstract: Phased-multiple-input multiple-output (MIMO) radar enjoys the advantages of MIMO radar in diversity gain without sacrificing the main advantage of phased-array radar in coherent

transmit gain. However, a limitation of the phased-MIMO radar is that the beam steering is fixed in an angle for all the ranges. This limits the system performance to mitigate non-desirable range-dependent interferences. To overcome this disadvantage, this paper proposes a flexible phased-MIMO radar with frequency diversity. This approach divides the transmit antenna array into multiple subarrays that are allowed to overlap, each subarray coherently transmits a distinct waveform, which is orthogonal to the waveforms transmitted by other subarrays, at a distinct transmit frequency. Each subarray forms a range-dependent beam and all beams may be steered to different ranges or directions. The subarrays jointly offer flexible operating modes such as MIMO radar, phased-array radar, and phased-MIMO radar.

[745] Wei Wang, Yuehua Ma, and Xin Li. Transmit beampattern synthesis for sub-arrayed mimo radar. In *Signal Processing, Communication and Computing (ICSPCC), 2012 IEEE International Conference on*, pages 1 –4, aug. 2012.

Abstract: Sub-arrayed multiple-input multiple-output (MIMO) radar is a new architecture of MIMO radar, which can exploit jointly the benefits of the coherent processing gain and waveform diversity, and has received extensive attention of researchers. An approach to synthesize the desired transmit beampattern for sub-arrayed MIMO radar is proposed in this paper. The essence of this approach is that the transmit beampattern is equal to the weighted sum of sub-arrays' beampatterns. First the beam-pattern of each sub-array with certain steering direction and low side lobe level is obtained by using traditional constrained optimization technique. Then under the constant total transmit energy constraint, convex optimization technique is utilized to design the optimal weight of each sub-array's beampattern, so that the synthesized beampattern can approximate the desired transmit beampattern exactly. Both analytical and simulation results validate the effectiveness of the proposed approach.

[746] E. Malz, R.S. Thoma, R. Zetik, P. Semashko, and A.P.G. Ariza. Polarimetric ultrawideband radar principles and applications. In *Ultra-Wideband (ICUWB), 2012 IEEE International Conference on*, pages 407 –411, sept. 2012.

Abstract: In this article we give an overview about the principles of polarimetric Ultrawideband Radar. Starting from the state of the art and a summary of the theory we analyze the calibration principles of polarized UWB Radar Data, we investigate possible imaging algorithms and we list important applications. Finally we show an example, to detect certain targets using a polarimetric MIMO UWB radar by doing an analysis of the radar cross section (RCS) of the individual targets.

[747] A. Bhat, A. Feinberg, Chujen Lin, R. Mone, E. Turner, M. Tracy, and J.P. Browning. Software defined, plug-and-play (pnp) radar transceiver for phased-array applications. In *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE*, pages 1 –2, july 2012.

Abstract: Digital Radar Transceivers providing precise digital control over waveform amplitude, frequency and phase is critical for modern Phased Array Radar systems. A Plug-and-Play (PNP) Transceiver was developed to support the Air Force's objective to develop a Hybrid Multiple Input Multiple Output (MIMO) Phased Array Radar (HMPAR) system, where the full array is partitioned into multiple sub-arrays which can be driven by mission specific waveforms. This PNP Radar Transceiver has been integrated with the Lockheed Martin's Portable Search and Target Acquisition Radar (PSTAR) antenna array. Advanced Radar capabilities including

transmit-receive digital beam-steering, direct digital L-band receiver and real-time digital signal processing with the integrated system have been successfully demonstrated. This paper discusses the overall PNP Radar Transceiver concept and highlights the successful phased-array test results when integrated with the PSTAR array.

[748] Lilin Guo, Tan Ma, and Hai Deng. Optimization of antenna excitation phases for transmit beam nulling with mimo radar. In *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE*, pages 1 –2, july 2012.

Abstract: In this article, the excitation phases of the antenna arrays of MIMO radar are optimized via minimizing the transmit beam power in certain pre-selected directions. A novel algorithm, adopted from the Fletcher's new variable metric method (VMM), is employed for antenna phase optimization. The simulation results demonstrate the effectiveness of the algorithm.

[749] Yanqing Zhu, Jie Chen, Wei Yang, and Pengbo Wang. Analysis of channel capacity for mimo sar model. In *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pages 4003 –4005, july 2012.

Abstract: MIMO radar can be considered as a particular communication system, which enjoys similar profits to the MIMO communication theory. Based on the information theory, the concept of channel capacity was introduced into the MIMO radar system. In this paper, the capacity expressions for MIMO SAR system were derived. As is shown in the simulation results, the channel capacity of the MIMO SAR depends on the number of the antennas, channel character and radar system parameters. The capacity of MIMO SAR increases with pulse repetition frequency and decreases with range and velocity. Furthermore, the larger the antenna number is, the more information can be obtained from the echoes. Meanwhile, the MIMO SAR capacity is larger than phase array SAR in high SNR.

[750] Wen-Qin Wang. Ofdm waveform diversity design for mimo sar imaging. In *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pages 2090 –2093, july 2012.

Abstract: Multiple-input and multiple-output (MIMO) synthetic aperture radar (SAR) should use the waveforms that have a big product of time-width and frequency-width and a constant modulus. In this case, the Barker code-based waveforms are not suitable. In this paper, a kind of orthogonal frequency diversion multiplexing (OFDM) chirp diverse waveform is presented for MIMO SAR imaging. The waveform performance is evaluated by the radar ambiguity function. Numerical results show that the waveform has the superiorities of high range resolution, constant modulus, large time-banwidth product, implementation simplicity, and low ambiguity function sidelobes.

[751] G. Krieger, M. Younis, S. Huber, F. Bordoni, A. Patyuchenko, J. Kim, P. Laskowski, M. Villano, T. Rommel, P. Lopez-Dekker, and A. Moreira. Mimo-sar and the orthogonality confusion. In *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pages 1533 –1536, july 2012.

Abstract: This paper reviews radar architectures that employ multiple transmit and multiple receive channels to improve the performance of synthetic aperture radar (SAR) systems. These

advanced architectures have been dubbed multiple-input multiple-output SAR (MIMO-SAR) in analogy to MIMO communication systems. Considerable confusion arose, however, with regard to the selection of suitable waveforms for the simultaneous transmission via multiple antennas. In this paper, it is shown that the mere use of orthogonal waveforms is insufficient for the desired performance improvement in view of most SAR applications. As a solution to this fundamental MIMO-SAR problem we had previously suggested to exploit the special data acquisition geometry of a side-looking imaging radar equipped with multiple receiver channels in addition to appropriately designed waveforms transmitted by multiple antennas. Here, we extend this approach to a more general set of radar waveforms with special correlation properties that satisfy a short-term shift-orthogonality condition. We show that the echoes from simultaneously transmitted pulses can be separated if the short-term shift orthogonality is combined with digital beamforming on receive in elevation. This enables the implementation of a fully functional MIMO-SAR without correlation noise leakage for extended scattering scenarios.

[752] E. Malz, R. Zetik, P. Semashko, R.S. Thoma, and A.P. Garzia Ariza. Polarimetric ultrawideband radar. In *Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International*, pages 5919 –5922, july 2012.

Abstract: In this paper the principles of polarimetric Ultrawideband Radar are discussed. First an overview of the state of the art and the theory is given. The calibration principles of polarized UWB Radar data as well as possible imaging algorithms are discussed. Possible applications are listed and one example, to detect certain targets using a polarimetric MIMO UWB radar by performing an analysis of the radar cross section (RCS) of the individual targets, is shown.

[753] S. Ahmed, J.S. Thompson, and B. Mulgrew. Mimo-radar waveform design for beampattern using particle-swarm-optimisation. In *Communications (ICC), 2012 IEEE International Conference on*, pages 6381 –6385, june 2012.

Abstract: Multiple input multiple output (MIMO) radars have many advantages over their phased-array counterparts: improved spatial resolution; better parametric identifiably and greater flexibility to acheive the desired transmit beampattern. The desired transmit beampatterns using MIMO-radar requires the waveforms to have arbitrary auto- and cross-correlations. To design such waveforms, generally a waveform covariance matrix, R, is synthesised first then the actual waveforms are designed. Synthesis of the covariance matrix, R, is a constrained optimisation problem, which requires R to be positive semidefinite and all of its diagonal elements to be equal. To simplify the first constraint the covariance matrix is synthesised indirectly from its square-root matrix U, while for the second constraint the elements of the m-th column of U are parameterised using the coordinates of the m-hypersphere. This implicitly fulfils both of the constraints and enables us to write the cost-function in closed form. Then the cost-function is optimised using a simple particle-swarm-optimisation (PSO) technique, which requires only the cost-function and can optimise any choice of norm cost-function.

[754] Jingquan Zhou, Pengcheng Gong, and Zhenhai Shao. Sparse sampled mimo radar for angle-range-doppler imaging. In *Computational Problem-Solving (ICCP), 2012 International Conference on*, pages 190 –192, oct. 2012.

Abstract: MIMO radar can provide higher resolution, improve sensitivity, and increase parameter identifiability without considering sparse sampled. Sparse signal recovery algorithms can offer

improved estimation when the scene of interest contains a limited number of targets. In this paper, we present a modified approach to sparse signal recovery. The proposed approach follows an lq-norm constraint (for 0 lt;;0 lt;;1) and can provide increased sparsity via iterative minimization compared to existing approaches. Simulation results show the proposed approach provides superior performance for sparse MIMO radar imaging applications at a low computational cost.

[755] Xiaodong Li, Qian He, Boxiao Han, and Zishu He. Detection performance of mimo-oth radar: Advantages of multipath ionospheric propagation. In *Computer and Information Technology (CIT), 2012 IEEE 12th International Conference on*, pages 758 –762, oct. 2012.

Abstract: Multipath ionospheric propagation (MIP), a typical phenomenon the sky wave over-the-horizon (OTH) radar may encounter, is often viewed as an annoying factor to be eliminated in the traditional OTH radars. In this paper, we consider multiple-input multiple-output sky wave over-the-horizon (MIMO-OTH) radar with closely spaced antennas. We develop a signal model using the multi-quasi-parabolic (MQP) ionospheric model, based on which we derive an optimum detector according to the Neyman-Pearson criterion. We show that MIMO-OTH radar has superior detection performance over the conventional OTH radar and that the existence of MIP can improve the detection performance of the MIMO-OTH radar system.

[756] T. Hayashi, N. Kikuma, H. Hirayama, and K. Sakakibara. A consideration of performance improvement of location estimation of scatterers in mimo radar. In *Antennas and Propagation (ISAP), 2012 International Symposium on*, pages 1144 –1147, 29 2012-nov. 2 2012.

Abstract: In this paper, we perform a location estimation of scatterers using the MIMO radar. Specifically, we introduce into the MIMO radar the MUSIC algorithm which is the representative of nulling methods. In addition, we compare the performances between the MUSIC-based method and the conventional beamforming methods in the location estimation of scatterers, and clarify the performance difference between them.

[757] Li Fanghua and Zeng Fanzi. Radar target location based on compressive sensing technique. In *Computer Science Service System (CSSS), 2012 International Conference on*, pages 1018 –1021, aug. 2012.

Abstract: In order to reduce the sampling rate and efficiently make use of samplings in radar target estimation, the paper proposed a novel MIMO radar target localization algorithm based on compressive sensing. It firstly divides the target area into grids which is assumed contained the target. A grid is denoted 1 if it includes the target, otherwise, it is denoted 0. The entire region thus is surrogated by a sparse vector comprising number 0 and 1, turning the problem of target location into a sparse vector-reconstruction problem. This paper then establishes a target echo signal model of MIMO radar in the grid. Few samples is obtained by use of compressive sensing, they can reconstruct the radar target location sparse vector by use of adaptive matching pursuit algorithm (SAMP). Solving the reconstructed matrix yields the problem of radar target location. The effectiveness of the proposed algorithm is verified by use of simulation experiments.

[758] Chee Wee Kim, Bin Luo, Ying-Chang Liang, M.Y.W. Chia, and null. Mimo-ofdm radar array configuration for resolving doa ambiguity. In *Communication Systems (ICCS), 2012 IEEE International Conference on*, pages 85 –89, nov. 2012.

Abstract: In direction-of-arrival (DOA) estimation using millimeter waves or ultrasonic, the physical size of the sensors can require inter-element spacing of greater than half wavelength. The accompanied benefits of such spacing are larger array aperture and reduced mutual coupling, but the serious problem of DOA ambiguity arises. This paper proposes a method to suppress grating lobes by employing a MIMO radar array configuration. The resultant virtual array has sufficient half wavelength spacings to significantly suppress grating lobes while the transmit and receive array elements have greater than half wavelength spacing. The grating lobe suppression performance is evaluated by simulation of MIMO-OFDM radar system that also has frequency diversity properties against DOA ambiguity. The simulation results show that the grating lobe suppression performance increases with signal-to-noise ratio (SNR). The effectiveness of the proposed array configuration and frequency diversity for resolving DOA estimation is also demonstrated.

[759] Jian Dong, Ronghua Shi, Ying Guo, and Wentai Lei. Antenna array design in mimo radar using cyclic difference sets and genetic algorithm. In *Antennas, Propagation EM Theory (ISAPE), 2012 10th International Symposium on*, pages 26 –29, oct. 2012.

Abstract: This paper addresses the issue of how to properly arrange the transmitting and receiving (Tx/Rx) antenna elements of MIMO radar in order to achieve the best spatial resolution. By combining the positive features of cyclic difference sets (CDSs) and genetic algorithm (GA), a hybrid optimization method is proposed for the optimal design of MIMO radar arrays. Numerical results are also presented, showing the variety in array configurations and notable improvement in the spatial resolution.

[760] Zhiguo Zhao, Jianwen Chen, and Zheng Bao. Slow time random phase-coded waveforms in mimo othr. In *Antennas, Propagation EM Theory (ISAPE), 2012 10th International Symposium on*, pages 1195 –1198, oct. 2012.

Abstract: With multiple-input multiple-output (MIMO) technique, skywave over-the-horizon radar (OTHR) is able to implement transmit adaptive digital beamforming (TADBF) to suppress multipath clutter or interference, which is a key technique in next generation OTHR. Time-staggered linear frequency modulated continuous wave and Doppler offset waveforms have been proposed in MIMO OTHR. However, both of the waveforms are constrained by Doppler ambiguity. To solve the problem, a slow time random phase-coded (STRPC) waveforms set fit for both maritime and aircraft surveillance in MIMO OTHR is proposed. And to detect weak targets submerged by cross- correlation peaks caused by strong clutters or large targets, a hierarchical waveform separation (HWS) is proposed. Simulation results are presented to verify the effectiveness of STRPC waveforms and HWS.

[761] A. Roshanzamir, M.H. Bastani, and M. Roshanzamir. Analysing of 3d beamforming in mimo radars. In *Information and Communication Technologies (WICT), 2012 World Congress on*, pages 745 –749, 30 2012-nov. 2 2012.

Abstract: A multiple input multiple output (MIMO) radar system is an emerging research field which has attracted many studies in recent years. This type of radar, unlike conventional phased array radar, can transmit different probing signals via its antennas, that may be correlated or uncorrelated with each other. This waveform diversity offered by MIMO radar systems enable superior capabilities compared to conventional phased array radar. Many papers have introduced different ways for beamforming of MIMO radar. In this paper it is desirable to analysis some methods for beamforming of MIMO radars with planar arrays constellation and examine their 3D result beam-pattern of such constellations for covariance based MIMO radar waveforming method. MATLAB software is being employed for simulations.

[762] Oscar Gomez, Benoit Poussot, Florence Nadal, Pascale Jardin, and Genevieve Baudoin. An experimental platform for mimo radar with colocated antennas. In *Microwave Conference Proceedings (APMC), 2012 Asia-Pacific*, pages 1085 –1087, dec. 2012.

Abstract: This paper presents an experimental platform for Multiple-Input Multiple-Output (MIMO) radar. Some detection techniques which have been recently proposed, such as Capon and the Generalized Likelihood Ratio Test (GLRT), will be tested in order to analyze their performance in real conditions.

[763] Zhu Yupeng. Waveform design based on modified genetic algorithm for mimo radar imaging. In *Instrumentation, Measurement, Computer, Communication and Control (IMCCC), 2012 Second International Conference on*, pages 909 –913, dec. 2012.

Abstract: MIMO radar imaging which integrates wideband signal processing with MIMO radar system is a potential technology for remote sensing. Waveform design is a principal important issue before radar imaging successfully in MIMO. There are two main requirements for the waveform used in MIMO radar imaging: the signals should be orthogonal and its auto-correlation function should have low side lobe noise and narrow main lobe. This paper analyses statistical characteristics of random stepped frequency (RSF) signal's auto-correlation deeply and proves that large stepped frequency number is suitable for MIMO imaging radar. Then a method for designing random stepped frequency-coding waveforms by modified genetic algorithm is presented here. A random matrix is used for initializing the genetic algorithm, and annealing algorithm is applied here for avoiding GA's disadvantages such as prematurity. In the end we compare the waveforms designed by GA and MGA and apply the waveforms in MIMO radar imaging simulation, the result proves that it is suitable for overcoming interfere among MIMO radar channels and imaging target.

[764] Zhenghuan Xia, Shiyou Wu, Shengwei Meng, Jie Chen, Guangyou Fang, and Hejun Yin. Implementation of the uwb radar with two transmitting and four receiving channels based on fpga. In *Instrumentation, Measurement, Computer, Communication and Control (IMCCC), 2012 Second International Conference on*, pages 1033 –1036, dec. 2012.

Abstract: Hardware design methods for MIMO (Multiple-input multiple output) UWB (Ultra wideband) radar are presented. The MIMO-UWB radar system mainly consists of two

transmitting antennas, four receiving antennas, two impulse generator, sample-and-hold, AD converter, and data acquisition subsystem base on FPGA. All these modules are designed and realized. Additionally, the designed system supports four equivalent time sampling channels with 50GS/s sample rate. Finally, we proved the feasibility of the designed system through closed-loop testing.

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MIMO Radar: Literature survey of papers published between September 2008 and December 2012

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5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
June 2013	262	764

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Ottawa
3701 Carling Avenue
Ottawa, Ontario K1A 0Z4

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
11as03	W7714-125466

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
	DRDC Ottawa CR 2013-018

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

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Multiple-Input Multiple Output (MIMO) radars are present more than 10 years within the research community. There is significant number of papers in the open literature where MIMO radar is primary topic.
Basic principle of MIMO radar is that radar simultaneously transmit a set of waveforms, one waveform per transmit antenna. Reflected waveforms are collected by using set of receivers. This introduces a whole new concept for radar resource management, and different detection, localization, identification and tracking algorithms are required.
This Technical Memorandum reports on the literature survey of journal and conference papers on the topic of MIMO radars published between September 2008 and December 2012. Total number of papers given in the literature survey is 764.
Presented papers are analyzed and categorized according to their topic. The literature survey gives research trends in MIMO radar area.

This Technical Memorandum should be used along with previous work on this topic that cover MIMO radar literature form 2003 to September 2008.

P. Sevigny: Multiple-input multiple-output (MIMO) radar: Literature survey of papers published between 2003 and September 2008, DRDC Ottawa Technical Memorandum, 2008-33, March 2009.

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MIMO radar; literature survey

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