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Maritime Surface Surveillance Scientometric Study

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Maritime Surface Surveillance

Scientometric Study

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1 EXECUTIVE SUMMARY

This scientometric study was commissioned by Defence Research and Development Canada (DRDC) to provide a high level overview of technological trends in the field of Maritime Surface Surveillance (MSS). The study will assist DRDC in establishing future research priorities in this domain. To answer a series of three questions, searches were conducted in multiple data sources. A total of 1,166 publication records and 436 patent families were retrieved and analyzed using text mining software and a variety of analytic and visualization tools.

All sources and analyses indicate that synthetic aperture radar (SAR) along with Automatic Identification Systems (AIS) will continue to be the principal technologies used for maritime surveillance for at least the near future. However, the limitations seen in these technologies are calling for complementary sensing modalities. These are necessary to build efficient and comprehensive surveillance systems. No single system or technology will suffice to protect against all threats and in all conditions. Therefore defence agencies interested in maritime surveillance will be required to monitor and invest in multiple technologies.

A summary of findings for each of the key questions appears in Table 1 below.

Table 1. Summary of Findings

Key Question	Key Findings
Major Topics	• The main research and commercialization focus in MSS is imagery processing with different algorithms. The goal is automation of the processes for fast, robust and reliable ship detection. • Synthetic aperture radar (SAR) is the main modality and the backbone of the maritime surface surveillance system, along with automatic identification systems (AIS). • Challenges posed by small targets detection, difficulties for detection in cluttered areas and possible manipulations in AIS signals are calling for the creation and use of surveillance systems relying on more than one modality. • Innovation in radars is a major aspect found in patents. Innovations focus systems including at least one radar and on novel radars.
Current and Emerging Sensing Modalities and Technologies	• Polarimetric SAR, which offers high-resolution images, is attracting more attention for ship detection, as is X-Band SAR, which is more sensitive and can detect smaller particles than traditional C-Band SAR. • Sensor fusion, or merging together data coming from heterogeneous sensors, is also a top topic in the literature. • Global positioning systems (GPS), acoustics sensors, optical images and infrared cameras are top topics in patents. All these modalities are used in the many surveillance systems patented. Innovations in acoustics sensors for use in sensor networks are also discussed, as well as improvements in infrared cameras, which can detect and identify surface contacts, beach-borne and land-based threats that have very low radar signatures. • Emerging technologies in the literature are wireless sensors, acoustics sensors, interferometric SAR, infrared cameras and moving target indication (MTI) mode of operation for radars. These modalities are all being researched as possible additions to the backbone system. The acceleration of research on these topics shows that they are viewed as the best possible candidates to complete the current systems.
Surveillance of specific targets	• Techniques to find non-cooperative targets are focused on better image processing. • Wireless sensor networks that are part of distributed surveillance systems are found to be an attractive choice to complement surveillance systems for non-cooperative target

Key Question	Key Findings
	detection. • Small targets can be hard to detect for more traditional sensing modalities whether they are cooperative or non-cooperative. Frequency Modulated Continuous Wave (FMCW) radar and Global System of Mobile Communication (GSM) passive radar and cameras are modalities that are well suited for small target detection. • Systems including multiple modalities are key in finding such targets.
Surveillance for specific activities	• Surveillance, intelligence and early warning activities are best accomplished when a mix of several modalities are used. The combinations that are most often seen include sensors, radars, SAR and AIS. High frequency radar, because of its over-the-horizon coverage capability and continuous-time mode of operation, is often mentioned for early warning activities. • Ship detection is mainly done with SAR. Patents and literature focuses on SAR image processing as a way to improve the detection of targets in images and to automate the detection.
Surveillance for Arctic region	• SAR and AIS are the two modalities forming the backbone of the surveillance system in the Arctic region. • Limitations of these modalities call for systems that complement them. Local sensor networks, EO/IR cameras and passive and active radars are among the technologies recommended for a better surveillance in these particularly difficult regions.
Modality Features	• Ship wake and ship signature can be detected mainly with SAR but sensors and cameras can also be used for this purpose. • Sensing modalities found in the literature are typically airborne and spaceborne. Land-based modalities are more often found in patents, which indicates an interest in coastal surveillance. • Unmanned Aerial Vehicles are also significant in both patents and literature, indicating that these platforms play a growing role in maritime surveillance.
Major Players	• China is the top player in both literature and patents. • China's collaborating and patenting profile shows a country-centric attitude rather than an international focus. • Italy, Germany and Canada, also top players, demonstrate a greater tendency to collaborate internationally. • USA, another top player, is showing a slowdown in its research production while showing accelerating its patenting activities. This seems to indicate a shift towards commercialization.
Commercial products	• 29 different products intended for MSS and covering all modalities have been identified. • USA is the country with the most products on the market. • EO/IR sensors and cameras are the most frequently mentioned products. • Airborne platforms are also among the most frequently mentioned platform, which indicates that the market tends to complement SAR and AIS with aerial modalities.
Further study	• Future analyses could target processing methods and algorithms to better understand the issues surrounding target detection. Arctic issues (sensing, communications, infrastructure, materials) should also be studied from a broad perspective to better understand the state of research for that particular region.

2 BACKGROUND

2.1 Context

In order to assist with long-term R&D planning and the prioritization of research topics, scientometric studies are commissioned by Defence Research and Development Canada (DRDC) to provide a high-level overview of worldwide research activity in scientific domains. These studies assist DRDC in uncovering and understanding the potential impact of new research on future defence and security capabilities and operations.

As part of its All Domain Situational Awareness (ADSA) Threat, Requirements and Gaps (TRG) project, the Canadian Department of National Defence (DND) has been studying air and underwater surveillance technologies. A new aspect, focusing on maritime surface surveillance, has recently been added to the project. In the context of this project, maritime surface surveillance is defined, by the client, as the detection, classification, identification and tracking of vessels and/or their cargo. The surveillance can be performed from underwater, ground, air, or space and based on a number of sensing technologies such as:

- acoustic sensors;
- magnetic sensors;
- electro-optical or infrared (EO/IR) sensors;
- seismic sensors;
- chemical/hyperspectral sensors;
- passive coherent location;
- various types of radar (over-the-horizon, high frequency surface wave radar, and beyond line of sight or BLOS radar).

The information provided within this project will be used to ascertain emerging technologies that could have a significant impact on defence and security communities. More specifically, the purpose of this study is to identify technologies that might have the potential of being integrated to Canada's maritime security and defence system.

This project is to be considered within the same context as two projects conducted in 2016 by NRC-NSL for DRDC on the topic of surveillance:

- STI-BB-2016-01: Scientometric Study on Air Surveillance
- STI-MC-0006: Scientometric Study on Underwater Surveillance

2.2 Key Issues

DND needs to know the current and emerging technologies used in maritime surface surveillance operations along with their respective strengths and limitations. In order to provide information on these topics, NRC-NSL will conduct a scientometric study to identify the main research topics on maritime surface surveillance and determine their status within the domain.

More specifically, the study will examine the technologies used to perform surveillance of different types of targets (cooperative, non-cooperative and naive) and different contexts (operational surveillance versus intelligence gathering). It will also examine products that are currently on the market. In addition, the study will explore technologies that would be relevant for maritime surveillance in an Arctic environment.

2.3 Key Questions

The project will answer the following questions:

1) What are the current and emerging sensing technologies with respect to the detection, classification, identification and tracking of maritime surface vessels as well as their cargo? Sensing modalities of all types are to be considered and well as sensing from a variety of locations (ground, underwater, air and space).

    a. What are the technologies that are more suitable to support the surveillance of cooperating targets, non-cooperating targets and naive targets?

    b. What are the technologies that are more suitable to support the surveillance done in operational context versus the surveillance done in an intelligence gathering context?

    c. What are the technologies that are more relevant to the context of surveillance in an Arctic environment?

2) What are the top countries patenting and publishing on maritime surface surveillance technologies?

3) Who are the companies with commercial products on the market? What are their products and which technology do they rely on?

3 INTRODUCTION

To address the key questions for this project, a search on sensing modalities for maritime surface surveillance (MSS) was conducted in scientific and technical bibliographic and patent databases, market reports and corporate websites. A complete description of the search sources and strategy is included in section 10.2 of this report.

Bibliographic records and patent documents[a] were used for the analyses on major and emerging topics. Once duplicates were removed, a total of 1,166 publications (2012–2017) and 436 patent records (2007–2017) were retained for analysis.

Figure 1 shows the trajectory of publications and patents for the period studied. It must be noted that publication counts are incomplete for 2017, while patent counts are incomplete for 2016 and 2017. For patents, the decline in grants and applications in the final two years may be attributed to the "silent period" of approximately 18 months which ensues between deposition and publication of an application (i.e., the patents are not publicly searchable during this time). For publications, the indexing of bibliographic records for conference proceedings typically takes some time so records from the first months of 2017 might not have been included in the databases at the time of the search. Starting in 2014, there is an increase in both patenting and publication activities in the field, indicating an increased interest in research and patenting activity for maritime surface surveillance technologies.

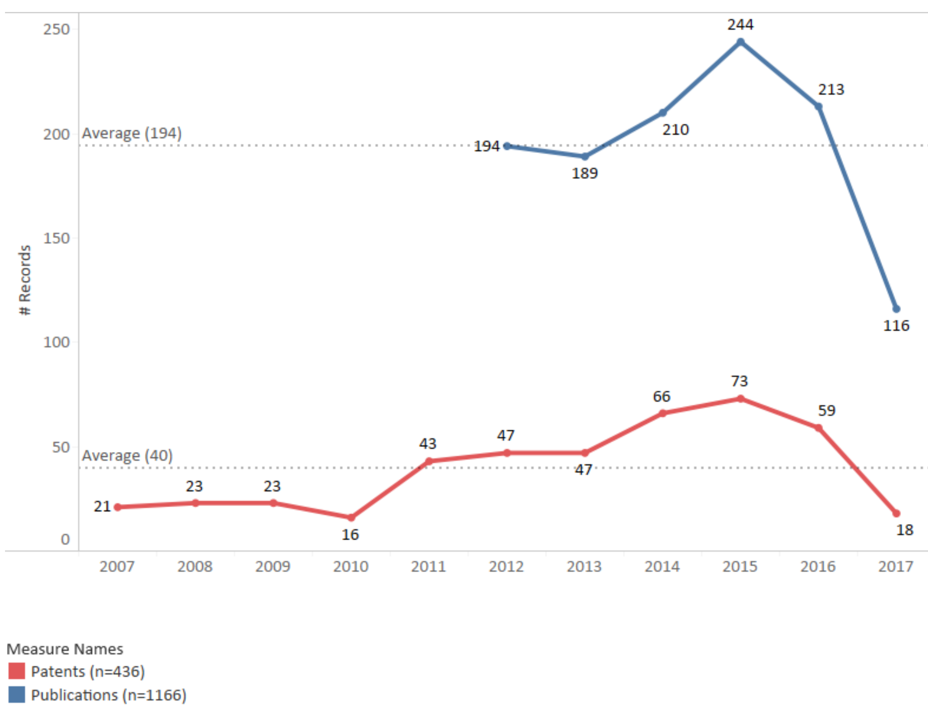

Figure 1. Publication and Patent Counts by Year, 2007–2017

[a] Patent families were used for this project. A patent family is the grouping of all the documents (patents and applications in different countries) pertaining to a single innovation into one record. A patent family is about the innovation not about the number of times and place where it's protected. In the present report, the word "innovation" will be used to describe the family and the word "patent" will be used when describing a specific innovation.

To understand the content of the literature and patent datasets, records were organized into topical groups that represent the topics discussed in the articles and the patents. These groups will be the basis of the analyses presented in this report. A total of 92 topical groups were created in the literature, while 79 were in the patent dataset. While the groups in the two datasets represent the same topics, 13 groups found in the literature had no correspondence in the patent dataset, which can be explained by its smaller size. The topical groups were created by searching subject keywords in the descriptor, title and abstract fields of the articles and by searching the subject keywords from the title, abstract, descriptor and claims fields of the patents. The groups are not exclusive, meaning that one article or one patent can be in more than one group at once.

All the groups were further classified into five non-exclusive categories that represent the subject matter addressed in the datasets. The complete list of groups for each category is included in Attachment 1—Maritime Surveillance—Subject Groups and also in section 10.3 on this report. Figure 2 below shows the five non-exclusive categories and their coverage in the two datasets.

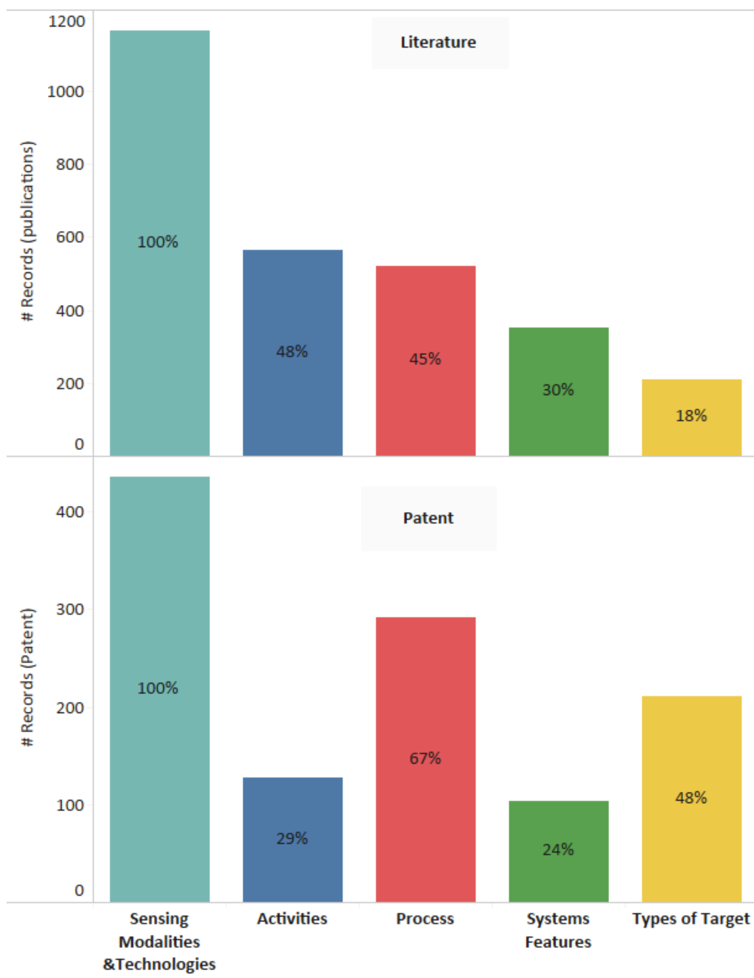

Figure 2: Literature and Patent Categories

All of the records in each dataset discuss at least one of the topics included in the *Sensing Modalities & Technologies* category, which is the project's core focus. Articles and patents that were not discussing a specific sensing modality were eliminated[b] from the datasets and not included in the analysis.

Processes is the second-largest category for both datasets, although there is more coverage for that category in patents than in the literature. This category includes all the groups that pertains to data processing techniques (e.g. methods and algorithms) and issues (e.g. clutter and false alarm). The category was created to illustrate how these topics are significant in both the literature and patents on MSS. In fact, the presence of these topics shows that research and development and innovation is greatly focused on algorithms and data processing.

The *Activities* category includes the groups on specific activities for which the sensing means and used. Coverage is similar for both dataset. The topics classified in this category will be used to answer key questions on technologies suitable for surveillance and intelligence activities as well as in Arctic regions.

The *Type of target* category includes the groups representing different types of target a sensing modality can detect. The targets in that category are precise targets, like small targets, non-cooperative targets. It was created to answer the key question on technologies suitable for cooperative and non-cooperative targets. Only 18% of all articles in the literature dataset mention a target type as opposed to 48% of patents which indicates that literature is less focused than patents on these specific targets and looking at more general targets like ships or vessels.

The last category *System features* have a similar coverage within the two datasets. This category includes topics like the location of the sensing mean or characteristics that can be detected (e.g. ship signatures). Although there is no precise question linked to these topics, they will be used to help understand better the sensing modalities discussed in the report.

4 MAJOR TOPICS

4.1 Literature

To identify major topics within the literature dataset compiled for this project, an analysis of the number of articles for each of the 92 topical groups was done. Figure 3 below lists the top 20 groups, based on its coverage rate, in the literature dataset.

[b] See 10.2.2 for a list of topics that excluded from the datasets.

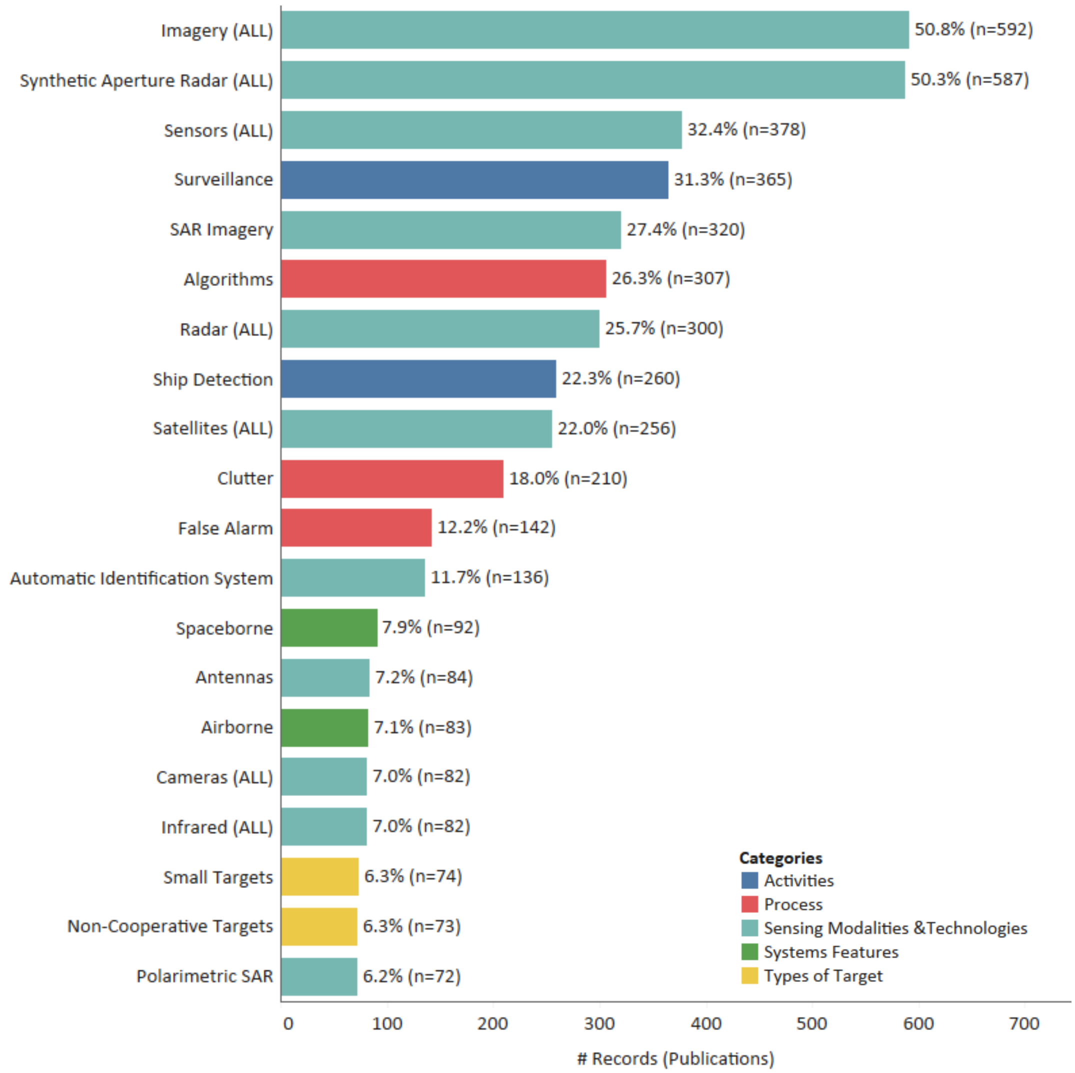

Figure 3: Top 20 Topic Groups—Literature

Imagery (ALL), which includes all types of imagery (infrared, satellites, etc.), is the top topic group with a coverage rate of 50.8%. Images are a by-product of sensing modalities and although they were not included in the search strategy, they emerge as a substantive thread in the research literature. Images are used for the detection, recognition, identification and classification of ship targets and they have become a significant research topic in the maritime domain.[1,2] Articles on this topic mainly discuss "reliable automatic ship detection",[3] "algorithmic approach in all of the steps of the ship detection"[4] and "mass processing of […] images for maritime surveillance."[5] The presence of these themes, coupled with the fact that the topic group *Algorithms* also ranks among the top groups (26.3% coverage rate), show that research is largely geared towards exploring different algorithms with the goal of automating imagery processing for fast and reliable ship detection. While algorithms and imagery processing are not the primary interest of this project and will not be explored further, it is be recommended to explore these topics further to gather a more complete portrait of the MSS field.

The second most discussed topic group is *Synthetic Aperture Radar (ALL),* which includes all occurrences of this type of radar and covers 50.3% of the dataset. This coverage rate clearly makes this *Sensing Modality and Technologies* the most often referenced in the MSS literature. Synthetic aperture radar

(SAR) surveillance is an integral part of large ocean area monitoring[6] and has proven to be a useful tool when applied to Maritime Domain Awareness (MDA) problems.[7] SAR are "able to monitor large tracts of the Earth, day or night, in any weather conditions [which] allows for the tracking of hundreds of square kilometres of sea area in a single image."[8] SAR can produce "very wide field of view imagery when searching for vessels in open ocean."[7] SAR can be deployed on satellites, aircraft and unmanned aerial vehicles[9], making them a modality of choice in MSS. The popularity of this sensing modality brings a "higher demand for the resolution and swath of SAR images, which brings a huge amount of imaging calculation."[10] This is confirmed by the presence of *SAR Imagery* among the top groups (ranking fifth with a coverage rate of 27.4%). Most publications on SAR in the dataset discuss imagery processing methods, indicating that the research is directed on the analysis of the images rather than on SAR technological improvements.

According to market research firm Frost and Sullivan, maritime surveillance is evolving from "a basic construct of radar and Automatic Identification System (AIS) to an architecture of interconnected systems."[11] F&S also mentions that near-real-time situational awareness requirements are growing, calling for "an evolved maritime surveillance solution with subsystems constantly processing data and updating across each other seamlessly."[11] Several authors, whose publications are included in the dataset, are discussing "merging data from multiple heterogeneous sensors" to develop a robust maritime surveillance system.[6,12,13]

The other major systems found in the datasets are *Sensors (ALL)*, *Radar (ALL)*[c], *Satellites (ALL),* and *Automatic Identification Systems*. The groups are the *Sensing Modalities and Technologies* groups covering more than 10% of the publications dataset. *Sensors (ALL)* includes all mentions of sensors, regardless of the type, and covers 32.4% of the dataset. In many cases, the term "sensors" is used to refer to specific sensing modalities (e.g. SAR sensors, radar sensors, etc.), which explains why this topic group has the third-highest coverage rate in the dataset. Apart from such occurrences, aspects related to sensors that are most often mentioned are *Sensor Fusion* (5% coverage rate), *Multi-Sensors* and *Sensor Networks* (4% coverage each). This supports the conclusion that research is looking at gathering and fusing data from multiple sources.

Each of the above systems and platforms has limitations. SAR have less than optimal "performance in finding small, non-metallic vessels,"[7] while radar-based systems are not suitable for vessels traffic in populated areas due to high electromagnetic radiation emission. [12] Satellites are space-borne and may not be adapted for all monitoring situations and Automatic Identification Systems can be illegally manipulated.[12] This is why current ship detection research is focusing on combining data from these diverse sensing modalities to create "broad ship detection dataset[s]"[6] that will offer a more robust surveillance system.

4.2 Patents

As for the literature dataset, an analysis of the number of patents for each of the 79 topical groups was done to identify major topics within the patent dataset. Figure 4 shows the top 20 groups in terms of coverage rate in the patent dataset.

[c] Note that this topic group excludes records mentioning Synthetic Aperture Radars.

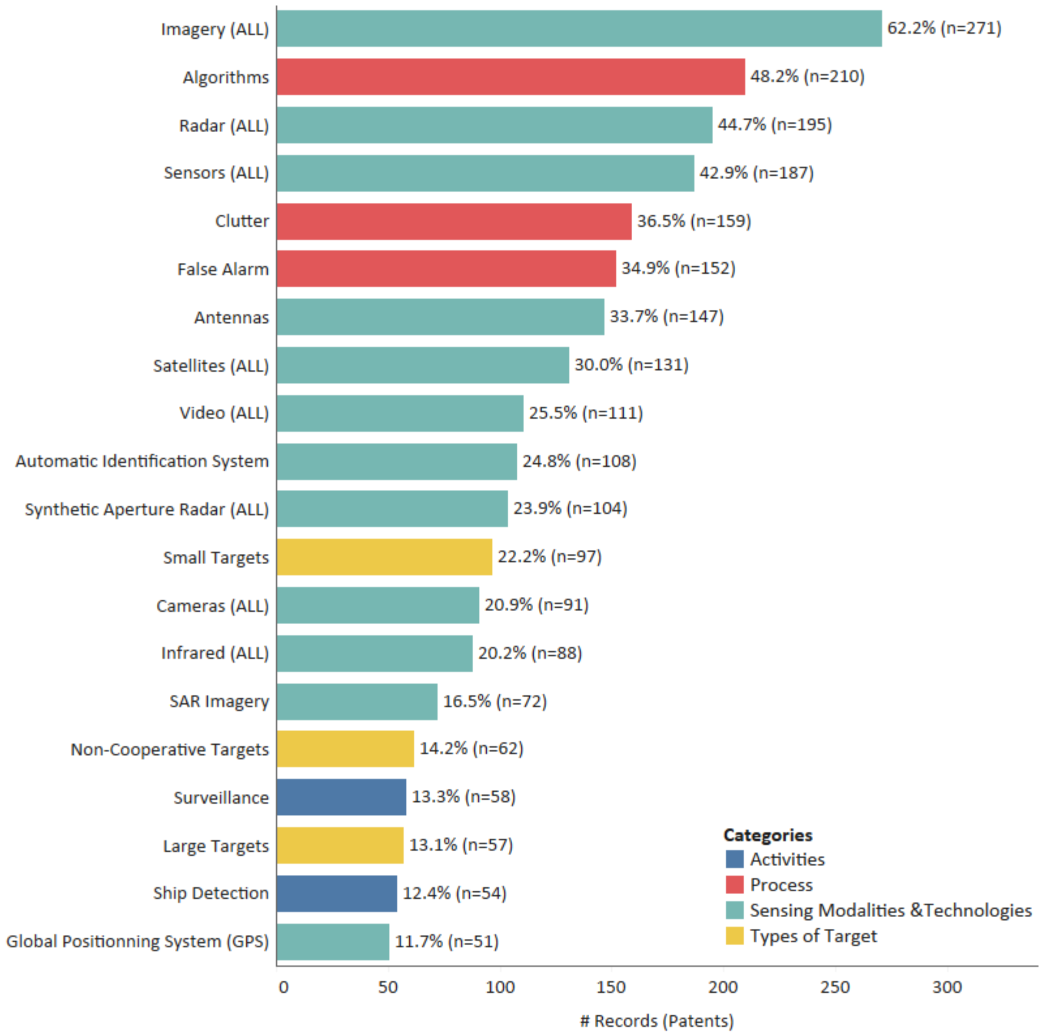

Figure 4: Top 20 Topic Groups—Patents

Just like in the literature dataset, *Imagery (ALL)* is the top topic group in patents. The focus of the majority of the patents in that group is on imagery processing, indicating that this topic, is one of the main focuses in the MSS field for both research and patents. As seen previously, processes are a significant topic in patents: More than half of the patents discuss either an *Algorithms* or techniques for dealing with *Clutter* and *False Alarm.* This, along with the emphasis in imagery processing in patents further highlights the how processes are a main preoccupation in patents in the MSS field.

The third top topic group in patents is *Radar (ALL*), which covers 44.7% of the dataset. Close to 70% of the patents in this group discuss methods for processing radar signal for clutter removal or for false alarm detection. The others discuss systems for ship detection that include a radar[14,15] or novel radars.[16,17] *Radar (ALL)* is the top sensing modality in patents, with a higher coverage rate than what was observed in the literature.

Sensors (ALL) is the second top sensing modality in patents and the fourth top topic overall, with a 42.9% coverage rate in the dataset. Much like what was observed in the literature, “sensors” is used to name the different sensing modalities (e.g. SAR sensors, radar sensors, etc.), which causes overlap between the groups covering sensing modalities and those focusing solely on sensors. After removing occurrences of sensing modalities and image processing methods, the analysis shows that the top sensors mentioned in the patent dataset are *Acoustic Sensors* (5% coverage rate), *Infrared Sensors* and *Sensor Network* (4.5% coverage rate each).

Antennas are the third top sensing modality, accounting for 33.7% of the dataset. A significant portion (61%) of the patents mentioning *Antennas* are also mentioning *Radar (ALL)*. When looking closely at these co-occurrences, we find that most of them discuss antennas as parts of the radar and that no innovation is brought to the antennas themselves. When examining the patents that do not mention radar, we also find that very few patents discuss innovations made to antennas; most of the time, patents mention antennas in the claims while describing a system. For example, patent EP2778712 by Thales states that “the present invention regards a method of operation of a real aperture radar system for surveillance of the Earth’s surface, said real aperture radar system being installed on a space vehicle/platform that moves in a direction of flight and comprising a transceiving antenna, or a transmitting antenna and a receiving antenna, which is/are electronically steerable.”[18] Since patents need to be very detailed in their definition of the technology described, the presence of antennas among the top-sensing technologies is not an indication that innovation in that technology is taking place but merely that antennas are an essential part of the sensing modalities.

The case of *Satellites (ALL)* is similar to *Antennas*. Almost all the occurrences of the keywords used to create this group are found in the claims and are used to describe the innovation. For example, patent EP2610636 describes a way to “[provide] near real-time maritime insight from satellite imagery and extrinsic data”[19] and patent US8958602 describes a “method and system (…) [where] video data input may be received from satellites, aircraft, UAVs and other aerial vehicles.”[20] This indicates that there does not seem to be a many innovations in satellite technology that mentioned a possible application in the MSS field. However satellites are an essential part of systems used in the field.

Video (ALL) is the fifth top sensing modality in patents (25.5% coverage rate), which is much higher than what was observed in the literature. A proportion of 58% of the patents in the *Video (ALL)* group mention *Cameras (ALL)*, making these two groups closely related. For example, patent US9031285 discusses the “detection of floating objects in maritime video using a mobile camera.”[21] Many patents in these two groups discuss innovations in infrared cameras and video images. According to a 2015 US Navy solicitation “an EO/IR system [can] greatly increase operator situational awareness by providing the ability to discern land terrain, sea and waterway features and contacts, such as small boats and patrol craft in the near-shore environment where surface radar performance is limited. A hyper-spectral imagery system with thermal contrast, such as an EO/IR sensor, [can] provide capability to detect and identify surface contacts and beach-borne and land-based threats that have very low radar signatures.”[22] These characteristics make EO/IR systems, cameras in this case, an interesting choice to complement the other sensing modalities for MSS.

The topic *Automatic Identification Systems* is also found among the top sensing modality in patents. *Automatic Identification Systems,* the automatic tracking system used by ships, is not necessarily the object of innovation in the patents included in this group, but it is part of the system described in the patents. For example, in patent KR101334804, the inventor discusses a method for the integration of satellite information and ship information, AIS in this case, for “integrally monitoring ship.”[23] This further reinforce the assessment made earlier in the report, that maritime surveillance systems are moving towards the integration of heterogeneous sensors.

Synthetic Aperture Radar (ALL) ranks in the tenth position in patents while it was the top-sensing modality in the literature. Most of the patents mentioning SAR in the dataset are focused on processing methods for imagery treatment and not on ways to improve data collection or the technology. However, it is possible that patents describing innovations on SAR technologies do not mention applications in MSS. Further investigations would be needed to verify if there are innovations on SAR, regardless of the field of application.

Three types of targets also appear among the top topic groups: *Small Targets, Non-Cooperative Targets* and *Large Targets*. These targets will be discussed further in section 5.3 of this report.

5 SENSING MODALITIES

The topic groups presented above mostly highlight the general *Sensing Modalities and Technologies* (the "(ALL)" groups) discussed in the two datasets. To investigate these modalities and technologies in more detail, each of the general modalities (e.g. *Synthetic Aperture Radar (ALL)*) was mined to create topic groups representing specific modalities (e.g. *Polarimetric SAR*). In the sections below, the top and emerging specific *Sensing Modalities and Technologies* are presented.

5.1 Top Sensing Modalities and Technologies

5.1.1 Literature

Figure 5 below presents the top *Sensing Modalities and Technologies* groups accounting for 5% or more of the literature dataset.

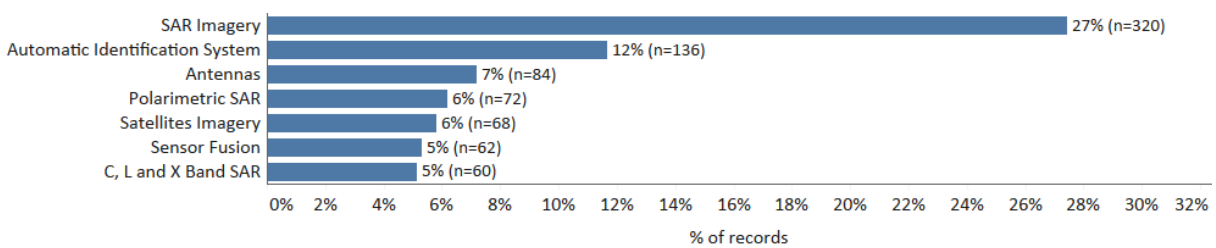

Figure 5: Top Sensing Modalities and Technologies—Literature

SAR Imagery was already discussed in section 4.1. Its presence at the top of this list reassesses of its importance in the research literature, which focuses on ways to process imagery obtained by sensing means, in this case synthetic aperture radars.

Automatic Identification Systems is the second top *Sensing Modalities and Technologies.* While the coverage for that group in the literature (12%) is smaller than what is observed in the patents (25%), its presence among the top topic groups indicates that it is a subject of interest in research and not only in commercialization. In fact, the focus of the publications is similar to what is seen in patents: AIS is used as a source of information and coupled with other sources to improve detection of ships. Examples of this can be seen in two articles published in 2017. In the first one, authors describe an experimental validation of a photonics-based dual-band radar system in which results obtained by the radar system are "compared with reference data from automatic identification system and global positioning system recorders."[24] In the second article, authors describe how to improve synthetic aperture radar detection using the automatic identification system with a method based on the "fusion of data obtained from two different sensors, namely a synthetic aperture radar (SAR) and an automatic identification system (AIS) embedded in a satellite."[25]

Antennas account for 7% of the literature dataset, which is again lower than what was observed in patents. There are only a few articles where the main topic is antennas. Of these, some discuss new miniature antennas[26,27], some antenna mode[28] and others antenna design.[29] In general, however, antennas are mentioned as being part of a sensing system or their patterns and directions are modified to enhance reception and resolution, with controllable steering of the radar antenna, for example.[30] Overall, research on antennas in the literature is focused on improving design and operation modes as well as on modifications of patterns and directions.

Polarimetric SAR is the fourth group in the *Sensing Modalities and Technologies* category in the literature with a coverage rate of 6%. Polarimetric SAR is an advanced imaging radar system used in several existing airborne and spaceborne systems such as Radarsat-2 and TerraSAR-X.[31] This technology can obtain "abundant scattering information of a target to improve the ability of target detection [and] classification."[32] Most of the articles in the literature dataset are discussing analysis methods of POLSAR imagery as polarimetric SAR images have "high resolution and multi polarization channels", which is why they "attract more attention for ship detection utilization these years."[33]

Satellite imagery, the fifth top sensing modality in literature, mostly covers the analysis of images taken from satellites. A significant proportion (60%) of the articles included in this topic group also discusses synthetic aperture radars, indicating that the satellites are equipped with this technology.

Sensors Fusion, the sixth topic on the list, was already discussed in section 4.1. and refers to the combination of data derived from disparate sources reduce uncertainty. The importance of using more than one source of information is again illustrated by the presence of that topic among the top sensing modalities.

The topic group *C, L and X Band SAR* is the seventh top *Sensing Modalities and Technologies* in the literature, with a 5% coverage rate. While these bands were grouped because none had enough coverage individually to be analyzed on its own, the X Band is the most often mentioned band in this group. The X band operates on a wavelength of 2.5-4 cm and a frequency of 8–12 GHz. Because of its smaller wavelength, it is more sensitive and can detect smaller particles.[34] As a result, X-Band imagery has "a higher resolution when compared to conventional C-band SAR data."[35]

Overall, the top groups in the *Sensing Modalities and Technologies* category confirms that imagery is a very significant aspect in the literature dataset. While merging different sensing modalities is definitely a trend in the literature, synthetic aperture radars, once again, emerge as the top sensing modality type studied in the literature.

5.1.2 Patents

Figure 6 presents the top groups in the *Sensing Modalities and Technologies* category that cover 5% or more of the patent dataset.

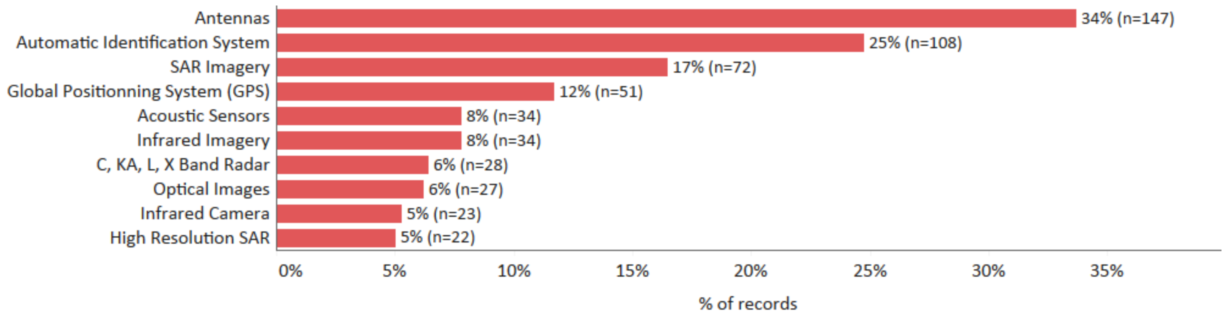

Figure 6: Top Sensing Modalities and Technologies—Patents

Among the top sensing modalities shown above, *Antennas, Automatic Identification Systems, SAR Imagery* and *Infrared Camera* have already been discussed in the section 4.2.

Infrared Imagery and *Optical Images*, ranking at the sixth and eighth positions respectively in Figure 6, demonstrate the significance of the topic of imagery in the patent dataset. *SAR Imagery*, ranking even higher at the third position, reinforces this importance. Methods to process these images are the focus of the patents mentioning these topics.

Global Positioning System (GPS) is the fourth group in the *Sensing Modalities and Technologies* category. It is quite strong in patents, with a 12% coverage rate, while it is almost absent in the literature dataset, where it accounts for 3% of the dataset. Most patents mentioning GPS describe systems with a plurality of sensors, among which a GPS is found. For example, patent EP2355451 describes a "distributed surveillance system comprising a group of […] nodes each comprising at least two sensors […] selected from a group comprising a radar, an AIS, an EO sensor, a passive sonar, a Sound Direction Finder, a Radio Direction Finder and an Electronic Support Measures (ESM). Furthermore, a GPS and Attitude Heading Reference System (AHRS) will provide the time and spatial references."[36] Along with AIS, GPS is another modality considered in systems where more than one information source is used.

Acoustic Sensors, ranking fifth in Figure 6, accounts for 8% of the patent dataset. Reading through the patents included in the group shows no clear innovative trend for these sensors. In several patents, acoustics sensors are only mentioned as one of the many devices that can be used in maritime surveillance. In the patents where acoustic sensors are the object of the innovation, several different uses are seen. In some, passive sonars are used, like in patent EP3094988 where the inventor extends the function of a passive sonar to detect objects with no active signature and states that improved accuracy can be achieved by using a plurality of sonar emitters.[37] In others, port or coastal surveillance is achieved by a plurality of detection systems among which can be "a sonar, an underwater robot and underwater sound interception equipment"[38] or a "sensor device for recording acoustic signals."[39]

The *C, KA, L and X Band Radar* topic group is the specific type of radar most often referenced in the patent dataset with a 6% coverage rate. As seen previously, close to 70% of the patents in the general group *Radar (ALL)* discuss methods for processing radar signal for clutter removal or for false alarm detection and not specific types of radar. It is not different for the patents in the *C, KA, L and X Band Radar* topic group: they discuss improvement of radar information processing rather than improvements on the radar itself. In fact, none of the patents in this group specifically describes an innovation about these types of radars; they are only mentioning the radar band type as a way to specify their description. For example, patents US9766623 and US9268008 focus on the detection and tracking of one or more objects are using an "X-band, maritime, non-coherent radar and the Doppler spectra computed from the high-frequency amplitude modulations produced by the object interacting with the land-based clutter to determine the presence, velocity, and track of the object."[40,41]

High resolution SAR ranks last among the top sensing modalities, with a 5% coverage rate. All the patents in this group discuss imagery types and methods for processing high-resolution SAR imagery. For example, patent CN104036239 presents a "fast high-resolution SAR (Synthetic aperture radar) image ship detection method based on feature fusion and clustering."[42] No patent in this group describes an innovation for this type of radar.

Overall, the top groups in the *Sensing Modalities and Technologies* category show that imagery is also very significant in the patent dataset, as is the merging of different sensing modalities in systems to offer a better coverage of the area under surveillance.

5.2 Emerging Sensing Modalities and Technologies

The analysis of emerging research topics is based on the research momentum indicator, which plots the relative growth and volume of publications for each topic groups for period studied. The indicator, which was developed by NRC National Science Library, enables the comparison of large and small research topics with respect to their rates of growth or decline. To do so, the indicator computes standardized publication volumes and growth for topic groups, plotting them into one of four quadrants (*Established*, *Hot*, *Emerging*, and *Brand New or Disappearing*) based on their performance relative to other topics in the dataset. The two axes in the visualization correspond to standardized growth rates (*x* or horizontal axis) and standardized publication counts (*y* or vertical axis). A more detailed description of the methodology appears in section 10.2.4 of this report.

The techniques involved in producing this indicator can be applied to both literature and patent data. However, emergence is a concept more relevant to publications than to patents, because the latter are closer to the application stage, when the technology has matured. The literature covers a broader range of topics, is more diverse, and explores pre-commercial problems by attempting different strategies. This type of exploration usually precedes what eventually appears in patents, whereas patents represent a relatively small subset of what is seen in the literature (i.e., the part of research that can be exploited commercially). Therefore, we can assume that emerging subjects are much more likely to appear in the literature. Once reaching the patenting stage, they have generally passed the exploration phase and have already demonstrated real or anticipated commercial attractiveness. This is why, for this study, we have opted to apply the momentum indicator to the literature dataset only.

All the sensing modalities and technologies groups in the literature dataset were analyzed, categorized in nine modality groups and coloured accordingly. The group *Other* includes modalities and technologies that do not fit in the rest of the categories, such as *Automatic Identification Systems* and *Global Positioning Systems*. The size of the bubble reflects the number of documents for each topic group.

The complete results of the calculation are shown in Figure 7 below. The top quadrants show the *Established* and *Hot* topics. Since these have above-average publication counts, most of them have already been discussed in section 5.

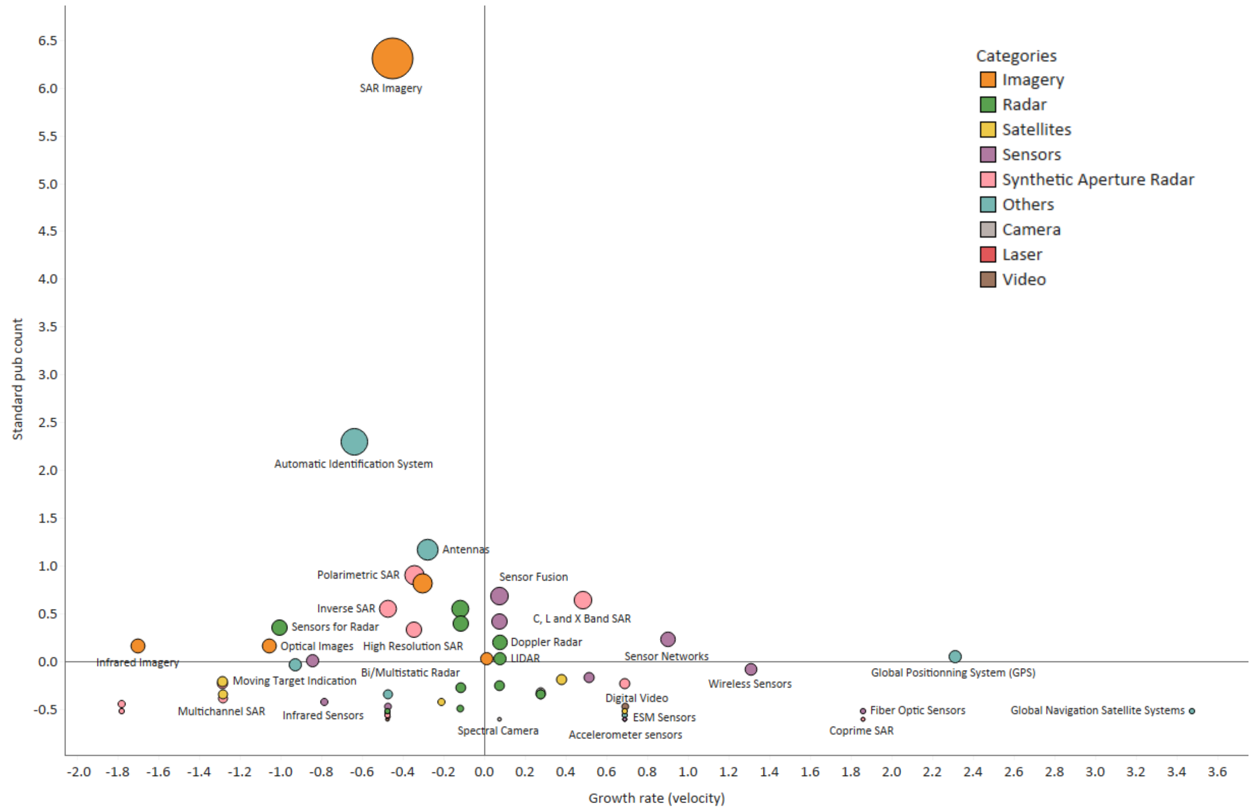

Figure 7: Sensing Modalities & Technologies, Research Momentum, 2012–2017

Emerging and *Brand new topics* are found in the lower quadrants and can be better seen in Figure 8 below. The very small technology groups were excluded from this view, since they had fewer than ten publications for the last five years. Overall, twenty modalities and technologies[d] were excluded from this view and a total of 18 *Sensing Modalities and Technologies* are shown.

[d] The excluded modalities and technologies are *Digital Video (9); Hyper/Multispectral Sensors (9); Laser Radar (8); Advanced Satellites (7); Fiber Optic Sensors (7); Global Navigation Satellite Systems (7); Nautical Radar (7); Velocity SAR (7); Multiple Camera (6); Bistatic SAR (5); Radio Frequency Identification (RFID) (5); Laser Scanner (4); Accelerometer sensors (3); Coprime SAR (3); ESM Sensors (3); Full Motion Video (3); GeoSynchronous SAR (3); Infrared Video (3); Multimode SAR (3); Spectral Camera (3).*

Figure 8: Emerging and Disappearing/Brand New Sensing Modalities & Technologies, 2012–2017

Seven sensing modalities are identified as being emerging: these have a higher than average growth rate but a lower than average publication count. Topics showing the highest growth rates are *Wireless Sensors*, *Acoustic Sensors* and *Interferometric SAR*.

In the articles included in the dataset, *Wireless Sensors* are always arranged in networks and these wireless sensor networks are defined as an "organization of a network with a collection of sensor nodes [who each] has some processing capabilities, such as multiple types of memory, and has a some power source, and can accommodate various sensors and actuators."[43] In most of the articles in the dataset, *Wireless Sensors* are associated with harbour and port surveillance.[44-46] A 2015 Chinese article states that "wireless sensor network (WSN) plays an important role in monitoring the environment near the harbour in order to make the ships nearby out of dangers and to optimize the utilization of limited sea routes."[47] A quarter of all the articles on *Wireless Sensors* are also discussing *Algorithms*, indicating that the management of the information they generate is one of the main topics of interest when it comes to these types of sensors.

Acoustics Sensors are a top topic in the patents dataset and an emerging topic in the literature which is not a typical situation: emerging topics in the literature usually do not have high occurrences in patents. This situation may illustrate that MSS is not a new field: research and commercialization are happening concurrently instead of one after the other. Articles on *Acoustics Sensors* have a similar angle as the patents dealing with that topic. They either discuss using acoustic sensors in systems where a plurality of sensors are used[48] or using them for harbour and coastal surveillance.[49] Most of the acoustic sensors mentioned are of the passive type and located underwater.

Interferometric SAR is a topic exhibiting a low growth rate. This type of SAR can be used for detecting small boats[50]; a 2017 article states that "current ship detection research is focused on using high-resolution interferometric wide (IW) swath imagery"[6], which explains the emergence of interferometric SAR. More than 40% of the articles on the topic are also discussing imagery and clutter, indicating that the focus is, again, on image processing. The other articles discuss using interferometric SAR for target detection. The presence of these two aspects in the dataset tends to show that research is not so much focused on improving the technology but on exploring its use as a tool for MSS.

Infrared Cameras are found in the emerging quadrant, while they are a top topic in patents. Although this group exhibits a very faint growth rate and covers only 1.3% of the literature dataset, its presence in the top list in patent and in the emerging list in literature is interesting. It mirrors what was observed for acoustics sensors and could further illustrate how research and commercialization are happening concurrently in the MSS field. Articles on this topic discuss how these cameras are used for short-range surveillance[51], for tracking multiple ships despite occlusions, and for deployment in populated areas.[12] Infrared cameras are also used in systems where information from multiple different sensors is fused to enhance target detection.[51]

In the bottom left quadrant of Figure 8 are topics that are either disappearing or brand new. To determine which is what, a close look at the publications counts by year for each topic was done. While most topics in the quadrant show a disappearing trend, one exhibits a publication count that deserves some interest: *Moving Target Indication*.

Moving Target Indication accounts for 2.5% of the dataset. This topic includes mentions of "established modes like ground moving target indication (GMTI) [and] "newly developed maritime modes, e.g. maritime moving target indication (MMTI) and Open Sea modes".[52] The MMTI mode is seen as equivalent to the GMTI mode in terms of mode design and processing techniques but is designed to work with the specific characteristics found in maritime environments. In the two modes, bursts are processed coherently.[53] In addition, both are target imaging modes that, "in contrast to the ultra-high-resolution imaging modes where the bandwidth is applied in total […] do not need such a high range resolution but rather a resolution in the range of the expected target dimensions."[53] These modes benefit from frequency agility and as a result an "enhanced target visibility is obtained."[53] Several articles in that group discuss the SmartRadar, an acronym for Scalable Multipurpose Aerospace Radar Technology, engineered by Airbus Defence and Space.[52-54] This radar does allow the new MMTI mode.

5.3 Sensing Modalities for Specific Targets

One of the objectives of this report is to identify the technologies that are more suitable for the surveillance of cooperating targets, non-cooperating targets and naive targets. In order to do this, topic groups for each target type were created in the literature and the patent datasets, and crossed with the sensing modalities and technologies in order to see the co-occurrences between each of them.

Seven types of target were identified in the two datasets. The coverage for each target type in each dataset is detailed in Table 2 below.

Table 2: Types of Target, Literature and Patents

Types of Target	Literature	Patents
Cargo	0.4% (n=5)	0.7% (n=3)
Cooperative Targets	0.9% (n=10)	0.0% (n=0)
Fast Targets	1.0% (n=12)	4.6% (n=20)
Large Targets	2.1% (n=24)	13.1% (n=57)
Multi Targets	3.3% (n=38)	9.4% (n=41)
Non-Cooperative Targets	6.3% (n=73)	14.2% (n=62)
Small Targets	6.3% (n=74)	22.2% (n=97)

Overall, only 18% of the articles in the literature dataset discuss a specific target type, whereas 48% of the patents do so. Frost & Sullivan, in their 2016 maritime surveillance market report, viewed the need to be able to detect and control non-cooperative and small targets as a key market driver.[11] The larger proportion of patents indicating an application for these specific targets could be explained by this market need.

Very few occurrences of *Cargo* and *Cooperative Targets* were found in each dataset. More often than not, the term "cargo" is used in the datasets to reference to cargo ships, which was not a focus of interest in this project. A manual cleaning was done to remove these occurrences and focus on articles and patents where "cargo" was used to describe containers or cargo, hence the very low coverage for this group in both datasets. As for the term "cooperative targets", it was not often seen in the literature and does not even appear in patents. One might assume that when authors are not discussing a non-cooperative target, they are, by default, discussing cooperative ones, which would explain why there are so few occurrences for this term. Based on this hypothesis, it could mean that most of the observations made so far are applicable to cooperative targets.

The term "naive target", which refers to a target that is not aware of doing something illegal, was not found in either of the datasets. A search was conducted separately to find additional information but did not yield any interesting results. Therefore, this portion of the question cannot be answered.

5.3.1 Small Targets

Figure 9 below shows the top topics in *Sensing Modalities and Technologies* associated with the topic group *Small Targets*. The percentages shown represent the number of articles dealing with small targets for each sensing modality. For example, out of the 74 articles on small targets, 39 also discuss *Imagery (ALL)* which equals to 53%. This is applicable to all the percentages shown in the sections discussing a target, an activity, a region and a feature. Only co-occurrences with coverage rates exceeding 10% are shown.

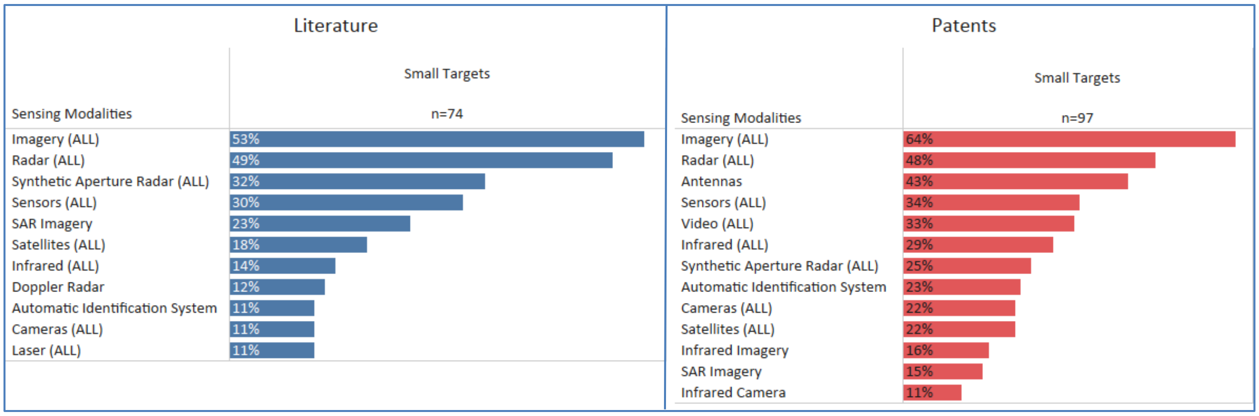

Figure 9: Top Sensing Modalities for Small Targets—Literature and Patents

Small Targets are difficult to detect with traditional sensing modalities due to limitations in sensitivity and resolution.[55] As a result, persistent detection, positioning, tracking, and possibly identification of small surface targets, such as small boats at sea and in littoral waters, have become important research topics in recent years because of their use in "countering illegal immigration, piracy, drug trafficking and asymmetric threats", among other things.[55] One key aspect on which research and commercialization are both focusing is image processing to detect small targets in sea clutter, which is demonstrated by the strong presence of *Imagery (ALL)* as the top co-occurring topic group in the *Sensing Modalities and Technologies* category.

In addition to image processing, publications and patents also cover different modalities, among which radars are the most frequently mentioned. Several articles discuss specific radars that could be well suited to detect small targets. For example, Frequency Modulated Continuous Wave (FMCW) radar[56] and Global System of Mobile communication (GSM) passive radar[57] can detect and track small agile targets. In the patents, the focus is on processing radar images to remove clutter in order to better detect the small targets. Patent CN102540159, for instance, describes an innovation that "relates to a radar target detection method of signal processing" for small object detection.[58]

Sensors of various types are also seen as possible modalities to better detect small targets. One example is anisotropic magnetoresistance (AMR) sensors, which have been tested for small boat detection in harbour.[59] Other strategies involve the fusion of data from multiple sensors (e.g. AIS, radars, cameras, acoustic sensors)[48,60] to improve detection. Some patents use infrared and video data to detect small targets. For example, patent CN105374026 describes a "maritime infrared small target detection method suitable for coastal defenses monitoring" [61] in which images are obtained from a coastal defense monitoring video camera.

Overall, the wide variety of proposed solutions and innovation shows that, to date, there is not one established solution for detecting small targets.

5.3.2 Non-Cooperative Targets

Figure 10 shows the top sensing modalities and technologies associated with non-cooperative targets. Only occurrences of 10% or more for each modality and target type are shown.

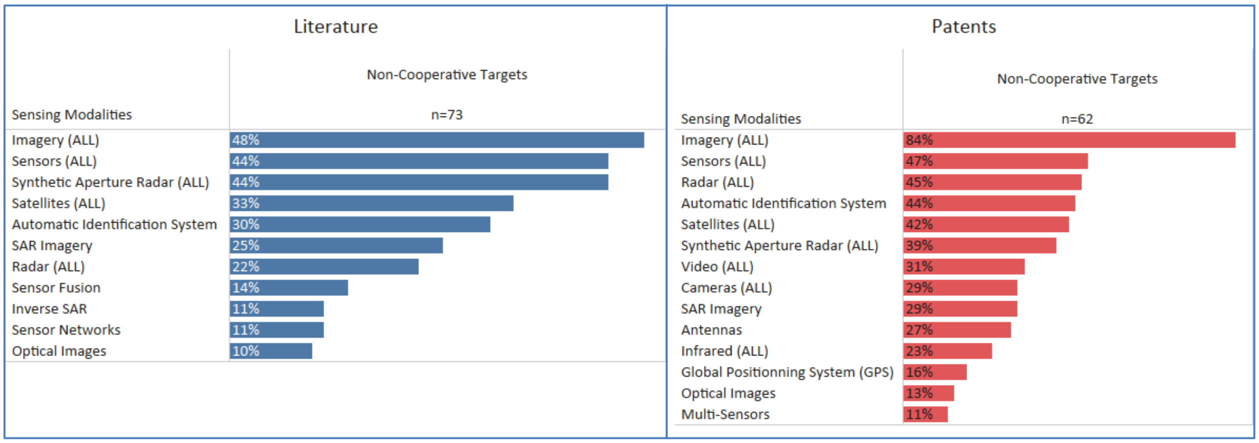

Figure 10: Top Sensing Modalities for Non-Cooperative Targets—Literature and Patents

The detection of non-cooperative targets is increasingly generating interest because of the need to combat terrorism, smuggling activities, and illegal immigration.[62] However, these targets can be difficult to detect because they typically operate in a covered manner, trying to hide their illegal activities in various ways.[63] Much like what was seen in section 5.3.1, research and commercialization activity on the detection of such targets is focused on image processing as a way to find targets in the images collected.

Studies and innovations that do not focus on image processing are often found in the *Sensors (ALL)* topic group. Several articles discuss tempered AIS signals by non-cooperative targets. In these cases, wireless sensor networks can be used for ship location detection in harbours.[64,65] In other cases, “range-gated laser imaging sensors [that are] suitable for high accuracy range especially in night and no moonlight” are used for coastal surveillance of illegal activities.[66] In patents, systems are described where sensors can be used in association with other technologies (radar, AIS, EO sensors, passive sonar) to build a distributed surveillance system that is capable of detecting non-cooperative targets. For example, in an “offshore suspicious ship and ship oil contamination discovering system”, a “VTS (vessel traffic service) radar tracking data acquisition unit and a shore-based AIS (…) tracking data acquisition unit are connected with a ground base station data acquisition processing unit” to create a system that will detect suspicious ships.[67]

In summary, there is a variety of modalities and solutions being investigated for detecting non-cooperative targets. This indicates that, to date, there is no one established solution for detecting these types of targets.

5.3.3 Other Targets

Topic groups created for the other types of targets are *Cargo, Cooperative Targets, Fast Targets, Large Targets* and *Multi-Targets. Cargo* and *Cooperative Targets* do not have enough occurrences in the datasets to be analyzed in detail. In general, in both the literature and the patents, cargos are tracked by sensors (wireless and networked) and GPS. All the articles and patents on *Cargo* discuss legal cargos and ways to track them for logistic purposes. No mention of cooperative targets was found in the patents. In the literature, these targets are associated with *Radar* (ALL), *Sensors* (ALL) and *AIS* and combinations of these sensing modalities, which is in line with what was observed in the previous sections of this report.

Problems surrounding fast targets are linked to imagery: tracking these targets in images can be difficult because images may exhibit defocusing and/or smearing.[68] Therefore, robust detection methods are needed for these types of targets. Patents and articles on fast targets mostly discuss improved methods of detection in imagery.

Large targets tend to have a rich set of discernible features making classification straight forward.[69] The most relevant articles on this type of target discuss how to detect small boats that are hidden by larger ones[70,71] and how different resolutions can be used to detect all vessels sizes.[72] Relevant patents on large targets discuss similar issues. For example, patent EP3026458 describes a "short- to mid-range radio detection and ranging devices operating in a high millimetre or centimetre wavelength range to provide anti-collision surveillance and detection of small to large objects."[73]

Finally, multi-targets, which are defined as more than one target in the same area, are part of the "nonhomogeneous sea clutter environments [along with] meteorological and oceanographic phenomena" that make detection a "complex and challenging task due to the capture effect from interfering outliers and the clutter edge effect from background intensity transitions."[74]. Articles discussing these targets investigate algorithms (e.g. Track-Before-Detect[75,76]) that are capable of mitigating these challenges as well as the use of multiple sensors (e.g. HFSW radars[77] or photonics-based dual-band radar[24]) to improve the tracking of multiple targets. Patents mainly discuss imaging methods and algorithms that are applicable to multi-target tracking.

5.4 Sensing Modalities for Specific Activities

One objective of this report is to identify technologies that are more suitable for surveillance activities conducted in an operational context versus an intelligence-gathering context. An operational context is defined, in agreement with the client, as real-time or near-real-time detection of targets for immediate use. An example of this would be detecting a ship as soon as it enters a specific zone and verifying if it is entitled to be in that zone. The intelligence context, on the other hand, is defined as the gathering of information on various targets to determine if any of them exhibit an abnormal behaviour that should eventually lead to an action. An example of this would be gathering information on a ship that just left a port, tracking it to assess if its behaviour changes along its course and determine if this change should be considered as an abnormality. The intelligence context implies the detection and tracking of multiple targets, not necessarily in the same location, the gathering of a great amount of data and the analysis of the data to detect anomalies.

Determining which sensing modalities and technologies are suitable for these two activities is not easy because they are not specifically mentioned in either the literature or the patents. The activities mentioned in the datasets are *Early Warning, Intelligence, Ship Detection* and *Surveillance*. In a general manner, ship detection and surveillance can be associated to a use in an operational context while early warning and intelligence can be associated to a use in an intelligence gathering context. Four groups were created for each of these four activities and then crossed with those on sensing modalities and technologies in order to see which were referenced with which most frequently. The coverage rates for each of them are detailed in Table 3 below.

Table 3: Activities, Literature and Patents

Activities	Literature	Patents
Early Warning	1.2% (n=14)	3.2% (n=14)

Activities	Literature	Patents
Intelligence	1.9% (n=22)	3.7% (n=16)
Ship Detection	22.3% (n=260)	12.4% (n=54)
Surveillance	31.3% (n=365)	13.3% (n=58)

Overall, 48% of the articles mention one of the four activities, compared to 29% for the patents. The most frequently mentioned activities in both the literature and the patents are surveillance and ship detection. This is most probably due to the use of keywords related to these activities in the search strategy used to build the datasets. The coverage rates for these four activities indicate that the literature is more focused on these topics than the patents. This could be due to the way patents describe the activities, since referring to specific applications in a patent can potentially limit its scope.

5.4.1 Surveillance and Ship Detection

Figure 11 below shows the top sensing modalities and technologies associated with the *Surveillance* topic group. Only modalities and technologies accounting for more than 10% of the publications for the activity are shown.

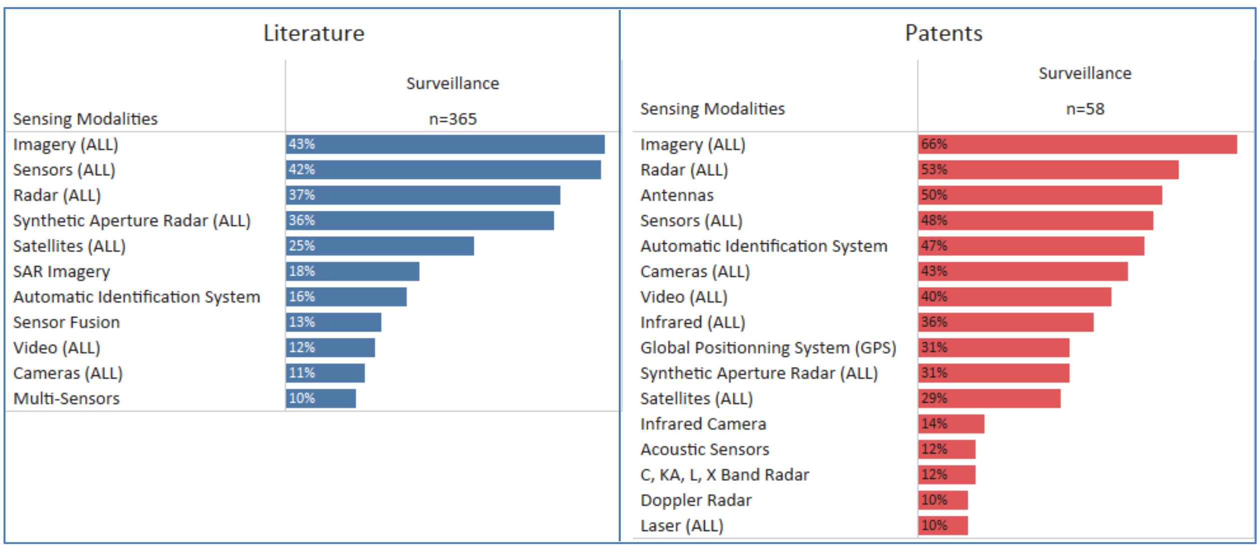

Figure 11: Top Sensing Modalities for Surveillance Activities—Literature and Patents

The European Defence Agency defines surveillance as the "ability to achieve continuity of knowledge on activities in the maritime domain in order to support a timely decision process."[78] This definition implies that surveillance includes tasks like detection, intelligence and decision-making. In the literature and in patents, the *Sensing Modalities and Technologies* topic groups associated with *Surveillance* show very high co-occurrence rates for the top sensing modalities. This indicates that surveillance can be done using many modalities, either concurrently or alone. An example of the use of one modality is found in a 2012 article which describes 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 […]."[79] An example of concurrent use is found in patent US9766623 which describes a method and apparatus for detection, tracking, and classification of land, maritime, or airborne objects using a "real-aperture radar mounted on a parasail airborne platform. […]The parasail can circle or move to a specified location for surveillance […] and automatically cue or manually steer an EO/IR camera to a target of interest for classification and identification."[40]

Ship detection, on the other hand, is a specific activity that is part of *Surveillance.* As shown in Figure 12, the distribution of the *Sensing Modalities and Technologies* topic groups is very different than what was observed for the topic of *Surveillance*. Again, only modalities and technologies with a coverage rate exceeding 10% for surveillance activities are shown.

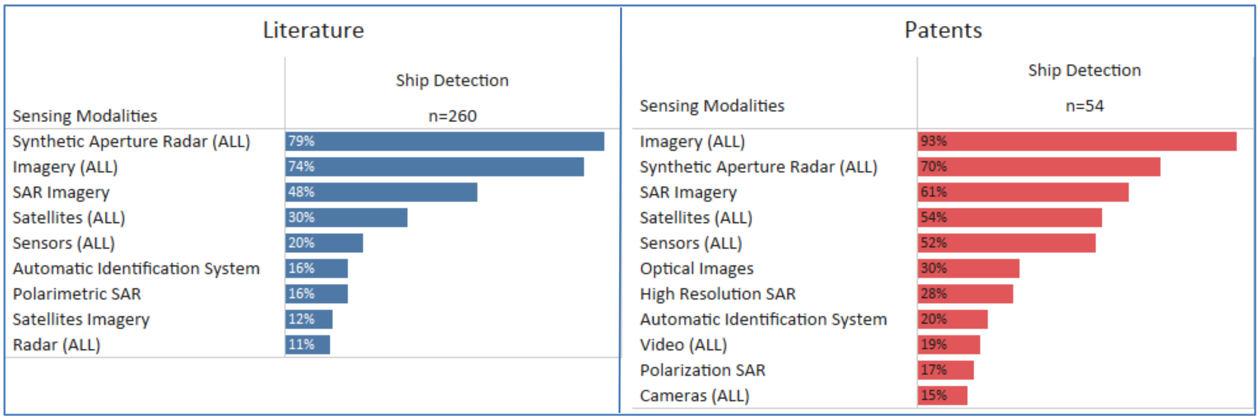

Figure 12: Top Sensing Modalities for Ship Detection Activities—Literature and Patents

As can be seen in Figure 12, 24% of the articles in the publications dataset discuss *Ship Detection*, while only 12% of the patents do so. This could be explained by the nature of the patents; referring to specific applications might be too limitative in terms of scope.

However, despite this difference in coverage, similarities can be observed. The three top-sensing modalities in the literature and the patents are the same: *Imagery (ALL)*, *Synthetic Aperture Radar (ALL)* and *SAR Imagery.* Furthermore, 66% of all the articles and 93% of the patents focusing on ship detection discuss algorithms, clutter and/or false alarms, which confirms that the focus for ship detection is on SAR imagery processing.

5.4.2 Early Warning and Intelligence

Figure 13 below shows the top sensing modalities and technologies associated with *Early Warning.* Only modalities and technologies with a co-occurrence rate of 10% or more for the activity are shown.

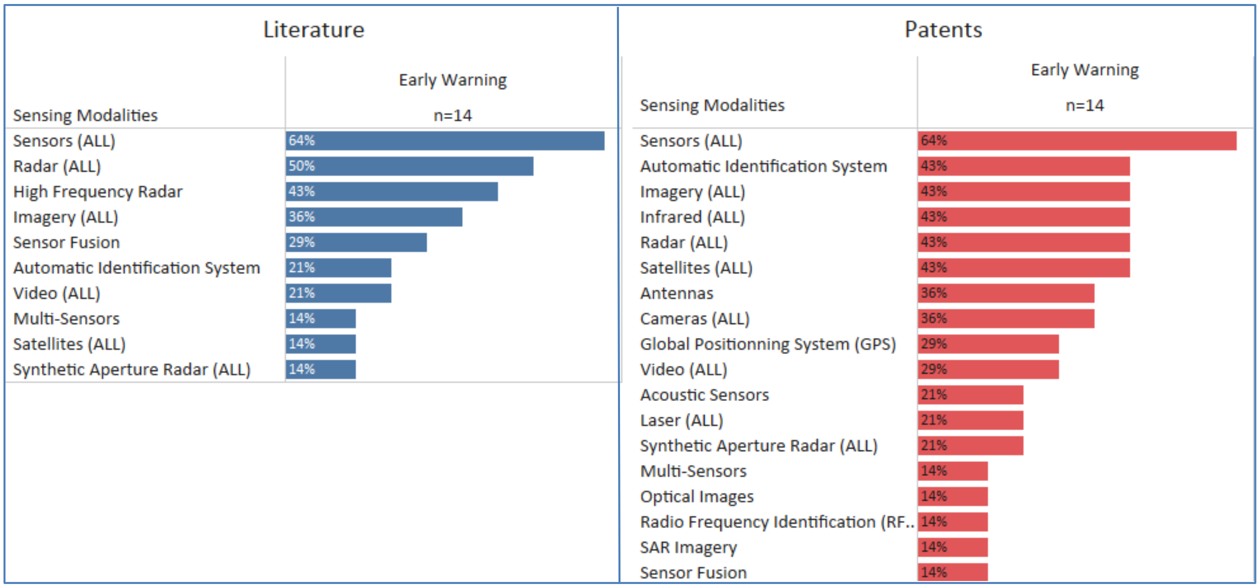

Figure 13: Top Sensing Modalities for Early Warning Activities—Literature and Patents

Early warning involves systems comprising sensors, event detection and decision subsystems working together to forecast and signal disturbances.[80] Much like what was observed in the case of *Surveillance*, the literature and in patents associated with *Early Warning* show very high co-occurrence rates with the top sensing modalities. Even if there are very few mentions of early warning systems in the two datasets, all the articles on the topic are discussing integrating “data from a combination of systems and sensors.”[81] High-frequency radars are mentioned in 43% of the articles and are described as “effective long-range early warning tools [and] additional source of information for target detection and tracking [because] of their over-the-horizon coverage capability and continuous-time mode of operation.”[82] In patents, Automatic Identification Systems and radars are the most often mentioned modalities in early warning systems. For example, patent EP2355451 describes a distributed maritime surveillance system which is capable of early warning and comprises “a radar, possibly an AIS (Automatic Identification System) and optionally an EO camera and/or a Passive Sonar, and/or Sound Direction Finder (SDF), a Radio Direction Finder (RDF), an Electronic Support Measures (ESM).”[36]

Intelligence is the collection of information acquired from multiple sensors located on satellites and sensors located terrestrially. It also covers the verification of the information and the fusion of information to produce near-real-time data on maritime vessels, as well as deduct insights and analysis that will be actionable.[19] Shown in Figure 14 is the distribution of groups in the *Sensing Modalities and Technologies* category that are associated with *Intelligence* in the two datasets. Only modalities and technologies co-occurring with at least 10% of the articles on *Intelligence* are shown.

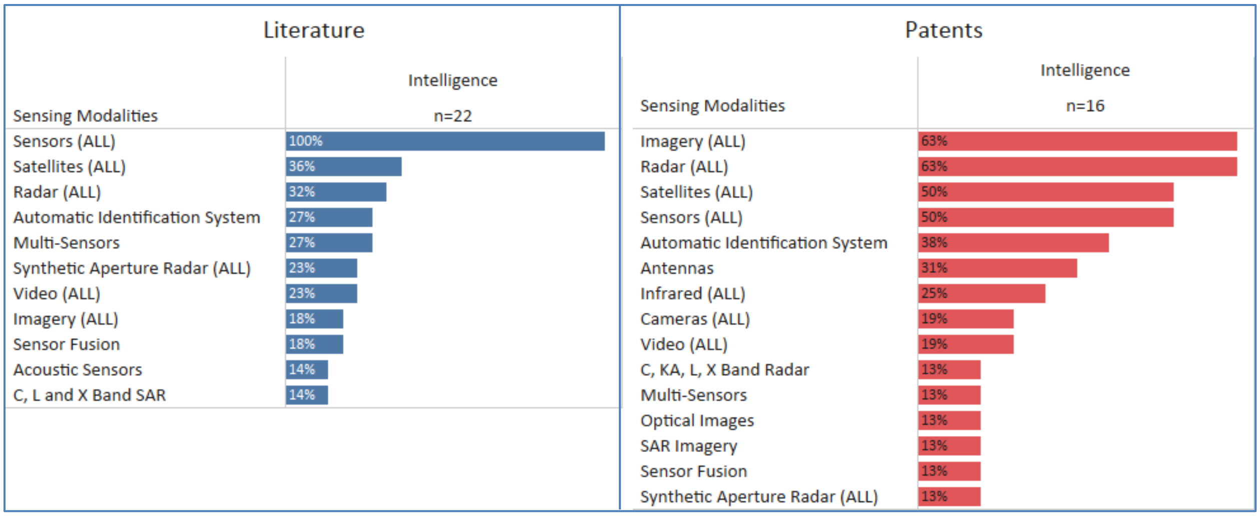

Figure 14: Top Sensing Modalities for Intelligence Activities—Literature and Patents

Intelligence, like surveillance and early warning, often involves the use of more than one modality. While this use of more than one modality seems to be reflected in the coverage distribution of the sensing modalities in patents, the literature exhibits a different coverage for the modalities, with *Sensors (ALL)* being in 100% of the articles on *Intelligence*. A search in the articles in the *Intelligence* group revealed that the term "sensors" was used as a generic term to designate different sensing modalities (radar, AIS, SAR) and often referred to the use of more than one type of sensors. For example, authors of a 2012 article discuss the "ever-growing challenge of effectively processing, exploiting, and disseminating Intelligence, Surveillance and Reconnaissance (ISR) data from multiple, diverse sensor platforms for end-users who collaborate and share information within a net-centric enterprise environment."[83] Of interest is the very low coverage of *Imagery (ALL)* in *Intelligence* articles that indicate that research on the topic of intelligence is focused on gathering information coming from multiple sensing modalities rather than on image processing.

5.5 Sensing Modalities for Arctic Region

Recent articles and reports on Arctic security and surveillance note that the effects of climate change will potentially open up the Northwest Passage as a viable transportation route. There is also rising concerns over increased Russian military activity in the region—for example, the establishment of an Arctic drone base—even if Russian capabilities do not yet match combined U.S. and Canadian assets.[84-87] The potential for increased maritime traffic, economic activity (e.g. oil and gas exploration), military ambitions, and environmental damage is focusing new attention on monitoring technologies in the region.[88]

Despite this new attention, very few articles and patents are published for the topics included in the *Sensing Modalities and Technologies* category on operations in Arctic region. Only 2% of the articles in the literature dataset discuss this aspect and only 1% of the patents in the patent dataset do so. Figure 15 below show the top groups in *Sensing Modalities and Technologies* associated with Arctic region in the two datasets. Only modalities and technologies with covering 10% or more of articles and patents on Arctic are shown.

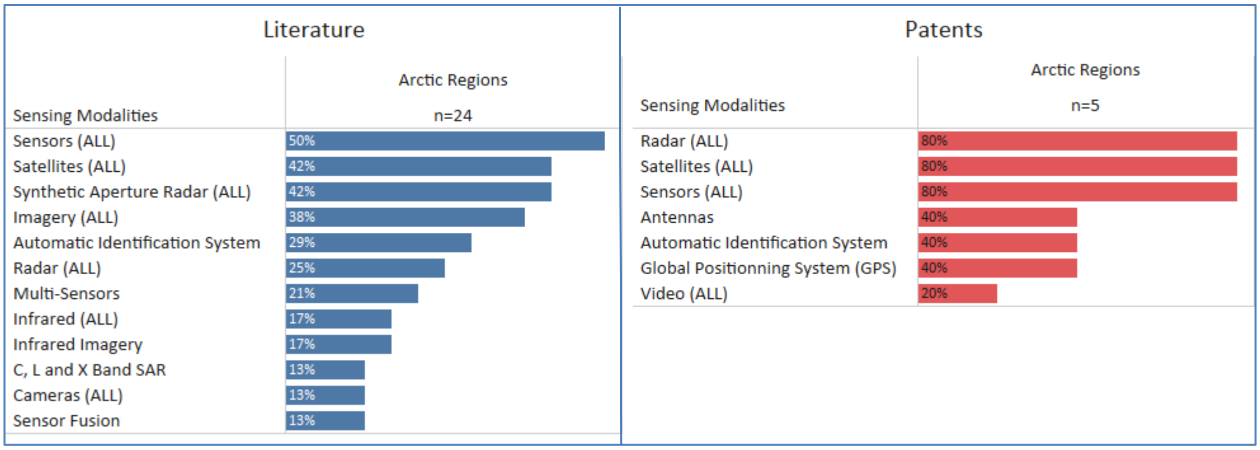

Figure 15: Top Sensing Modalities for Arctic Region—Literature and Patents

The literature shows very high co-occurrence rates between the top groups in the *Sensing Modalities and Technologies* category and topics associated with Arctic region. This indicates that all these sensing modalities are viewed as having a role in Arctic maritime surveillance. An example of this is found in a 2016 article on the Canadian-German research project PASSAGES. The objective of the project is to define the requirements and the modular architecture of a persistent maritime surveillance and risk management system adapted to Arctic conditions and focused on the Northwest Passage (NWP). The architecture of the system that provides the continuous vessel traffic picture in remote and local areas includes "real and simulated sensors from space borne and ground based platforms [and] S-AIS […]. The capabilities of such multi-sensor surveillance solutions in enhancing the Maritime Domain Awareness (MDA) [have been] demonstrated over two selected operationally relevant scenarios."[89]

There are so few patents mentioning the Arctic region that results from the analysis are not statistically significant. The five patents mainly discuss radar, sensors and satellite systems which can have applications in the Arctic. However, none of the patents has this particular region as a main focus; it is only mentioned as a possible environment of application.

To complete the outlook on the Arctic region, further readings were done to better understand the challenges posed by surveillance these regions. Besides a general lack of operational experience and deficient infrastructure in the Arctic, several recent reports note the following technical challenges for surveillance in the region:[90-92]

1) Limited communications, such as degraded high-frequency radio signals in latitudes above 70° N because of magnetic and solar phenomena;
2) Degraded Global positioning system (GPS) performance that could affect missions requiring precision navigation, such as search and rescue operations;
3) Limited awareness across all domains in the Arctic because of distances, limited presence, and the harsh environment.

Other key challenges identified include shortfalls in ice and weather reporting and forecasting; limitations in command, control, communications, computers, intelligence, surveillance, and reconnaissance because of a lack of assets and harsh environmental conditions; limited inventory of ice-capable vessels; and limited shore-based infrastructure.

According to a 2017 conference paper about persistent maritime traffic monitoring for the Canadian Arctic and the PASSAGE project discussed above[13], a variety of proprietary systems already exist and are currently used for monitoring the area. The backbone of the surveillance systems is the Satellite-based Automatic Identification System (S-AIS). However, it is not sufficient for continuous vessels monitoring for many reasons:

- There are temporal gaps due to limited satellite coverage and low reporting frequency;
- AIS transponders are not mandatory for small vessels;
- False AIS due to technical failure or even spoofing were reported.

These limitations were reduced, in the PASSAGE project, by adding additional sensors data to complement the S-AIS data. Space borne sensors such as SAR and optical imagery played a key role in the project, even if they were subjected to observation gaps due to limited satellite coverage, and so did local sensors such as active and passive radar systems. All these modalities were used to build a global system in which multi-sensor data fusion algorithms were used to compile common operational pictures.

This summary of the PASSAGE project confirms what was observed in the literature: the use and fusion of data from multiple sensors is viewed as a key solution for maritime surveillance. This is also true for operations in the Arctic region.

5.6 Sensing Modalities and Features

Although not covered by the key questions for this project, specific features characterizing the sensing modalities and technologies were found in both datasets. The features identified relate to the characteristics that can be detected by the sensing modalities to assist in target detection as well as the location of the modalities. Each of the features found were crossed with the sensing modalities and technologies to see which were referenced with which most often.

5.6.1 Characteristics Detected

Two characteristics were found to assist in target detection: *Ship Signature* and *Ship Wake*. Both can be detected by a sensing modality and used as a proxy for target identification. Ship signature includes a combination of ship emissions (acoustic, electric, thermal, doppler and spectral/hyperspectral) Ship wake is the wave pattern on the water surface produced by a moving object caused by pressure differences between the fluids above and below the free surface and the gravity (or surface tension).

Ship signature is covered by 3.4% of the literature dataset has and 2.5% of the patents dataset. *Ship Wake* has a slightly larger coverage, with 4% of the publications and 3.9% of the patents. Shown in Figure 15 below are the general sensing modalities associated with each characteristic.

Literature

Sensing Modalities	Ship Signature n=40	Ship Wake n=48
Cameras (ALL)	15%	4%
Imagery (ALL)	60%	56%
Radar (ALL)	30%	25%
Satellites (ALL)	28%	17%
Sensors (ALL)	35%	19%
Synthetic Aperture Radar (ALL)	35%	38%
Laser (ALL)	5%	4%
Video (ALL)		4%

Patent

Sensing Modalities	Ship Signature n=11	Ship Wake n=17
Cameras (ALL)	27%	18%
Imagery (ALL)	45%	88%
Radar (ALL)	36%	18%
Satellites (ALL)	64%	65%
Sensors (ALL)	64%	47%
Synthetic Aperture Radar (ALL)	45%	71%
Video (ALL)	9%	12%
Laser (ALL)	9%	

Figure 16: General Sensing Modalities by Characteristic—Literature and Patents

The focus of literature is on *Imagery (ALL)* is obvious: over half of the articles on ship signature and ship wake discuss this topic. The other sensing modality co-occurring most often with the two characteristics is *Synthetic Aperture Radar (ALL).* Interpretation of signatures from synthetic aperture radar (SAR) data poses some challenges because of "radar specific imaging effects like layovers, multi-path propagation or speckle noise."[93] Other challenges are specific to maritime security such as "additional defocusing effects due to the ship's movement even when they are anchored."[93] For ship wakes, "ocean waves reduce the detectability of Kelvin wakes in SAR images."[94] As a result, most of the articles in the literature dataset discuss models and simulations to improve the classification and characterization of ship signatures and wakes from Synthetic Aperture Radar imagery. Opto-electric and infrared sensors are also used in detection of ship signatures.

In patents, *Ship Wake* is associated with the same sensing modalities than those seen in the literature. Patents discussing ship wake focuses on methods to improve the detection of wakes in imagery. Ship signature, however, are covered differently in patents than in the literature. Patents on this topic describe systems and sensors that are capable of detecting the signature. These systems are often mounted on satellites or use data obtained by satellite transmission. For example, patent DE102015103325 describes an underwater sensor for recording acoustic ship signatures in which the pre-processed data is conveyed by satellite communication to a central monitoring station.[39]

5.6.2 Locations

A total of six locations from which sensing modality can be operated were identified in the datasets. One of the locations, Unmanned Aerial Vehicles (UAVs), could be arguably be included in the *Airborne* topic group. However, since there is a relatively recent interest in UAVs, it was deemed preferable to keep both separated.

Only 24% of the articles mention at least one location, while 19% of the patents do. As shown in Figure 17 below, spaceborne and airborne are the two top locations mentioned in the literature dataset, while in patents, sensing modalities tend to be described as being land borne and airborne. Research is focus on sensing modalities that are located in space and on aerial platforms, especially synthetic aperture radars, while patents mainly describe radar located on land and on aerial platforms.

Literature

Sensing Modalities	Airborne n=83	Land Borne n=44	Shipborne n=38	Spaceborne n=92	Underwater n=25	Unmanned Aerial Vehicles n=36
Cameras (ALL)	2%	5%	11%		8%	25%
Imagery (ALL)	59%	27%	26%	63%	8%	50%
Laser (ALL)	5%	5%	11%	1%	4%	17%
Radar (ALL)	17%	50%	79%	11%	36%	25%
Satellites (ALL)	18%	30%	3%	53%	12%	11%
Sensors (ALL)	40%	30%	24%	27%	76%	56%
Synthetic Aperture Radar (ALL)	64%	36%	5%	78%		28%
Video (ALL)	7%	2%	5%	1%		11%

Patent

Sensing Modalities	Airborne n=19	Land Borne n=32	Shipborne n=11	Spaceborne n=12	Underwater n=10	Unmanned Aerial Vehicles n=18
Cameras (ALL)	16%	13%	45%		10%	39%
Imagery (ALL)	68%	50%	91%	33%	30%	72%
Laser (ALL)	5%	6%	9%		10%	22%
Radar (ALL)	37%	78%	9%	58%	0%	28%
Satellites (ALL)	32%	44%	55%	92%	40%	50%
Sensors (ALL)	26%	53%	45%	50%	80%	61%
Synthetic Aperture Radar (ALL)	53%	16%	18%	33%		39%
Video (ALL)	21%	28%	55%	33%	10%	44%

Figure 17: General Sensing Modalities by Location—Literature and Patents

The *Airborne* topic group is mainly associated with *Synthetic Aperture Radar* and *Imagery* in both the literature and the patent datasets. According to a 2013 article, airborne SAR "can obtain high-resolution data, can work all-day and all-weather, is more mobile than other sensors and can still provide data under the conditions of intense airspace and atrocious weather."[95] In patents, the innovations found focus mostly on methods for processing airborne SAR images. This indicates that if innovations for improving airborne SAR are patented, they do not mention maritime surveillance applications. Further investigations would be needed to determine if such innovations are being patented in airborne SAR, regardless of the application.

The *Land borne* topic group is mainly associated with *Radar (ALL)* and *Synthetic Aperture Radar (ALL)* in the literature. In patents, the topic is associated with groups like *Radar* and *Sensors*. No specific type of radar stands out in either the literature or the patents and the main focus, in both datasets, is on systems for harbour safety or coastal surveillance that include at least one radar and use either sensor and/or Automatic Identification System data. For example, patent CN104574722, describes a "Harbor safety control system based on multiple sensors" which includes a surface photo-monitoring system, a radar detection system and a ship automatic identification system.[96] Another example is found in a 2013 article describing an integrated ship monitoring system using SAR, land-based radars and AIS data.[97]

The *Shipborne* topic group is mainly associated with *Radar (ALL)* in the literature, with the most frequent type of radar found on shipborne locations being high-frequency radars. These have the advantage of extending the area monitored (when coupled with land-based high-frequency radar). However, "additional modulation on the echo signal introduced by the forward movement and six-degree-of-freedom ship motion increases the surface current measurement error". Research is investigating processing methods to overcome these errors.[98] In patents, *Shipborne* is not frequent and is only found in 2.5% of patent dataset. It is most often found in prior-art descriptions. In essence, patents in that group are describing various sensing systems and methods and are only mentioning shipborne sensing modalities as part of the background information. This can indicate that sensing modalities which could be mounted on ships for target detection are either not being developed or if they are, their intended location is not mentioned.

The *Spaceborne* topic group is mainly associated with *Synthetic Aperture Radar (ALL)* in the literature and with *Satellites (ALL)* in patents. While only 2.8% of patents discuss this location, 7.9% of articles do and it is the most often referenced location in the publications dataset, further reinforcing the predominance of spaceborne SAR in the MSS field.

Underwater locations are mainly mentioned in articles from the *Sensors (ALL)* topic group in the both the literature and the patents. The most often referenced type of sensors are acoustics sensors, which are mentioned in 40% of articles and 80% of patents. Most of time, in the literature, these sensors are part of a larger system that includes multiple sensing modalities. For example, a 2016 article discusses an experimental multi-sensor security surveillance system that "includes broadband radars, cameras, an Automatic Identification System receiver, geophones and underwater passive acoustic sensors."[48] In patents, underwater sensors are either part of a target detection system or they are the main aspect of the innovation. However, there are so few patents on the topic that no trend can be detected regarding innovations in acoustic sensors.

Finally, *Unmanned Aerial Vehicles* are the third top location in patents while it is second to last in the literature, indicating that there seems to be a greater interest for the commercial potential for this type of platform than there is for ways to improve them further. In the literature, *Sensors (ALL)* and *Imagery (ALL)* are the topic groups that are most often associated with this platform. *Cameras (ALL)*, *Radar (ALL)* and *Synthetic Aperture Radar (ALL)* are also associated with the platform. The focus of the articles is on imagery processing and on the integration of UAVs in maritime surveillance. UAVs are becoming more resourceful[65] and as a result, they are said to be "critical to augmenting capabilities of patrol boats" in intelligence, surveillance and reconnaissance tasks.[99] UAVs can carry diversified payloads such as cameras, radar and sensors. When it comes to patents, they tend to describe systems including a payload mounted on a UAV. An example of such a system is found in patent CN107132530, which covers a maritime monitoring system using satellite SAR imagery, a UAV equipped with a "radar/image/sensor dedicated monitoring pod", an unmanned boat using a "search radar/laser/ultrasonic/integrated monitoring system images" and a ground-based "ADS-B/AIS/radar/laser/ultrasonic/tracking/image integrated panoramic image monitoring system."[100]

6 MAJOR COUNTRIES

The major countries involved in research and patenting in MSS were identified by looking at the number of publications for each country in the dataset and by ranking them in descending order.

6.1 Literature

In the literature dataset, five countries have a publication count above the average of the entire dataset. China, Italy, USA, Germany and Canada all have a coverage rate of at least 6%, as shown in Figure 15 below.

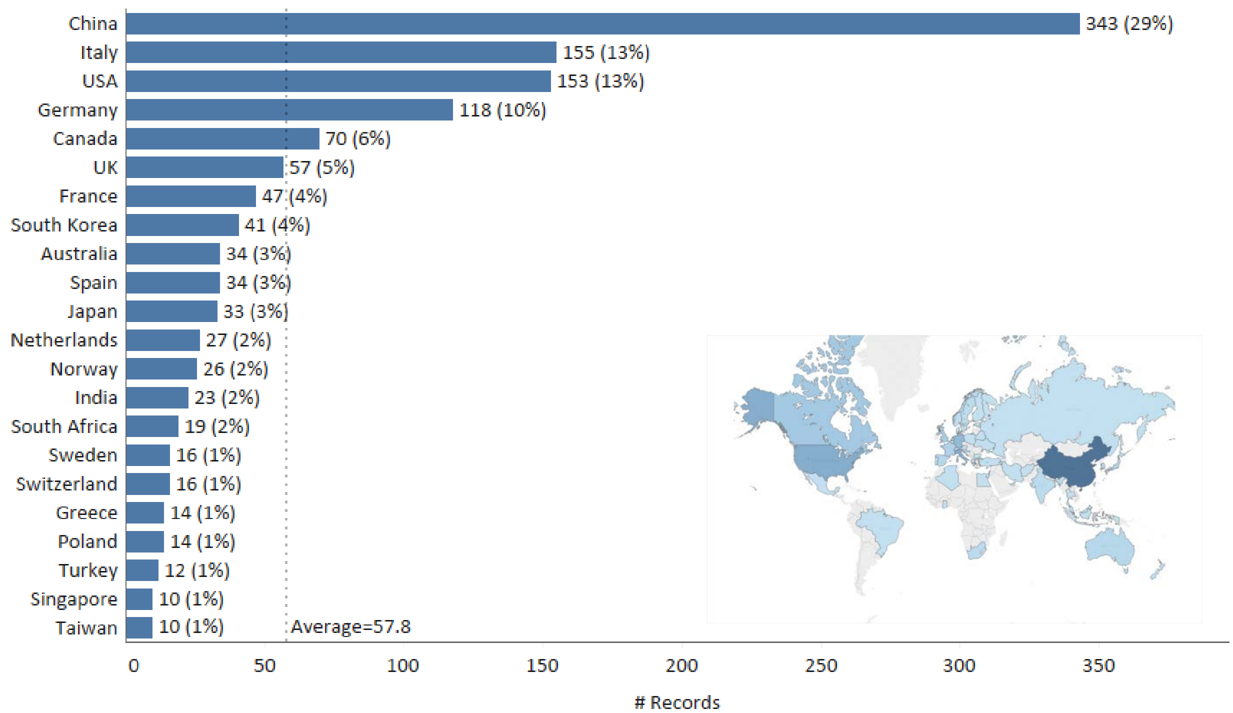

Figure 18: Top Publishing Countries, Ten Publications or more

China is a major research player in MSS, with 29% of all publications counting at least one Chinese author. China is not collaborating much with other international partners, as only 9% of their publications also have an author from another country than China. This might indicate that the Chinese contribution to the MSS field is centred around issues that are mostly relevant to the country rather than international issues.

Italy is the second major research player in the MSS field and is followed closely by the USA, each with 13% of the publications in the dataset. Italy is home to NATO's Centre for Maritime Research and Experimentation (CMRE), an established, world-class scientific research and experimentation facility centred on the maritime domain. This centre alone is in large part responsible for Italian presence among the top players in the MSS field. Both these countries collaborate internationally, with approximately a third of their articles being published with an international partner. This could indicate a greater participation in solving issues that are of international relevance than what is seen for China.

Germany and Canada occupy the fourth and fifth positions, with coverage rates of 10% and 6% respectively. These two countries are even more dynamic international collaborators than Italy and the USA. Germany collaborated with a partner from outside the country for 49% of its articles while Canada did so for 44% of them. The majority of Canada's international collaborations are found in the *Synthetic Aperture Radar* (ALL) and *Imagery (ALL)* topic groups.

Overall, a total of 54 countries have published at least one article in the MSS field between 2012 and 2017. These countries are shown on the small inlet map in Figure 15 above. The shades of blue indicate the count of publications for each country.

The evolution of the number of publications for the top countries is shown in Figure 16 below. Note that 2017 is not shown because it is incomplete.

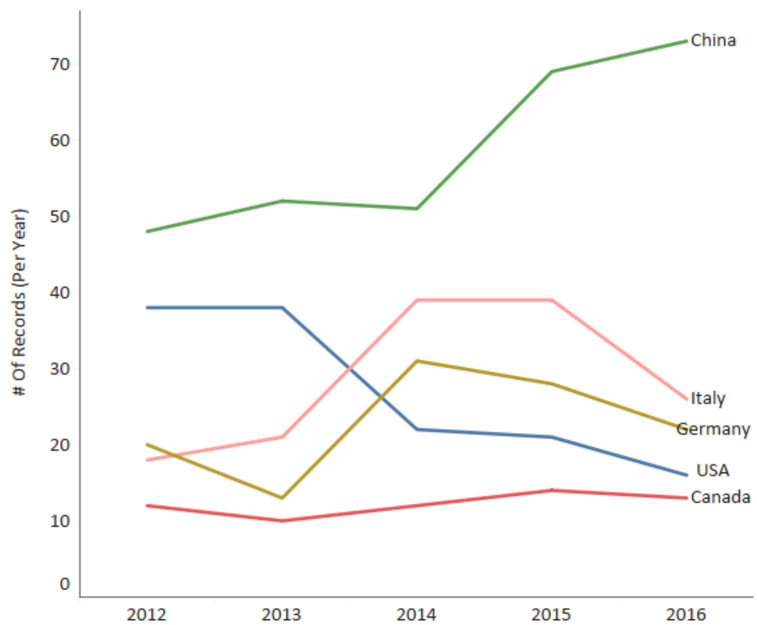

Figure 19: Acceleration of Publication Rates, Top 5 Countries—Literature

China has started to accelerate its publication rate in 2014 but the focus of its publication remains centred on synthetic aperture radar and on imagery throughout the entire period. Italy and Germany each had a boost in publications for years 2014–2015. Interestingly, this boost coincides with the beginning of the migrant crisis in Europe.[101] USA shows a clear decline starting in 2013. This indicates that USA is withdrawing from research in the MSS field, perhaps moving to a more commercial stage. Canada, on the other hand, is quite stable throughout the period.

6.2 Patents

Major countries in patents can be divided in two types: countries from which the innovation originates and countries in which the innovation is protected. Looking at the first category speaks about the innovation potential of a country while the second indicates which countries are viewed as preferred markets. Unfortunately, inventor countries are not available for all patents as only 30% of the dataset has this information, making it impossible to use. Therefore, the second indicator was used in the analysis. Results are shown in Figure 17 below.

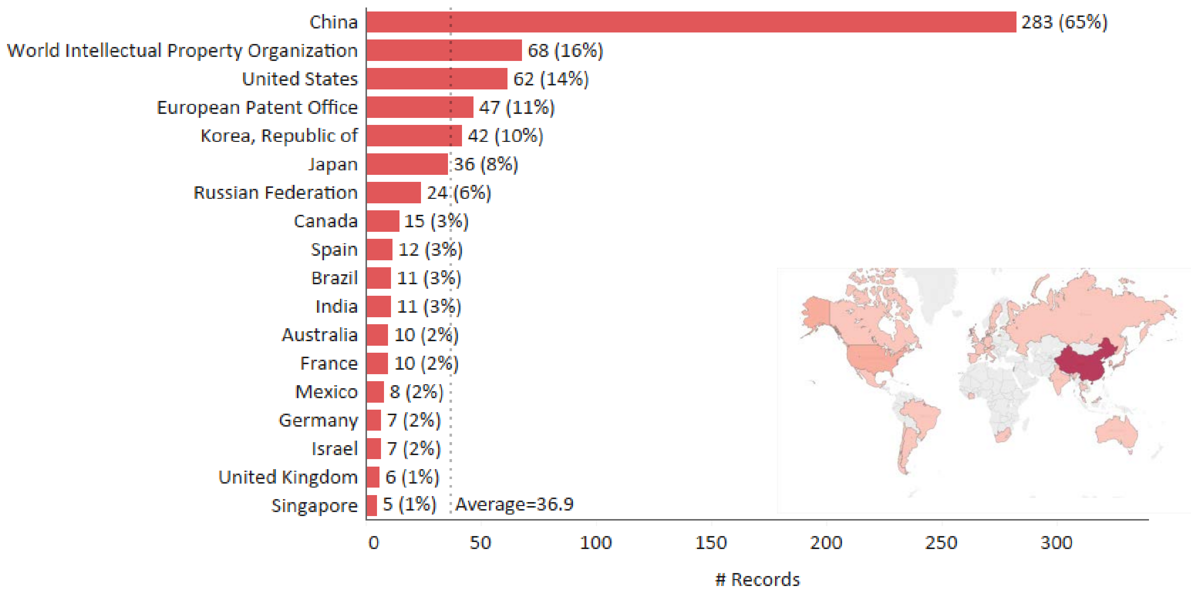

Figure 20: Top Patent Application Countries, 5 patents or more

Patents can be in force in more than one country at once, which explains why the sum of patents for all countries exceeds the 436 patent families included in the dataset. Similar to what was observed in the literature, China is the top country where innovations in MSS are protected. Most of the patents filed in China are only protected in that country: protection is sought in another country than China for 7% of them only. This further reinforces the indication that China is working in isolation from others in the MSS field.

16% of patents take the international route (WIPO) which allows an inventor to take up to 30 months to decide where to file for protection. This can indicate that many inventors think their innovation as potential in a plurality of markets. This is also the case for the 11% of patents taking the EPO route, which is a similar route than WIPO, only limited to Europe.

The third most often sought territory for protection is the USA, with 14% of the patents families included in the dataset. 71% of the innovations protected in the USA are also protected in other countries, which could indicate that USA is either seen as an interesting market for other countries or that USA inventors view their innovations as having a great international potential. However, without complete information on inventor countries, it is not possible to establish if both hypotheses are applicable or not.

Korea is the last country with an above-average patent count in the dataset, with 10% of the innovations in the patent dataset seeking protection in this country. A third of the patents filed in Korea are also protected elsewhere, indicating that the majority of Korea's innovations are destined for the country only. This indicates some isolation, although not as significant as China's.

Overall, 33 countries have at least one innovation in the MSS area seeking protection on their territory in the period of interest. These countries are shown on the small inlet map in Figure 17 above. The shades of red indicate the count of patent protection filed in each country.

To characterize further the countries with the highest number of patent families filed, a look at the rate at which each of them files for patent protection was done. Results are shown in Figure 18 below. Again, the 2017 year is not shown because it is incomplete.

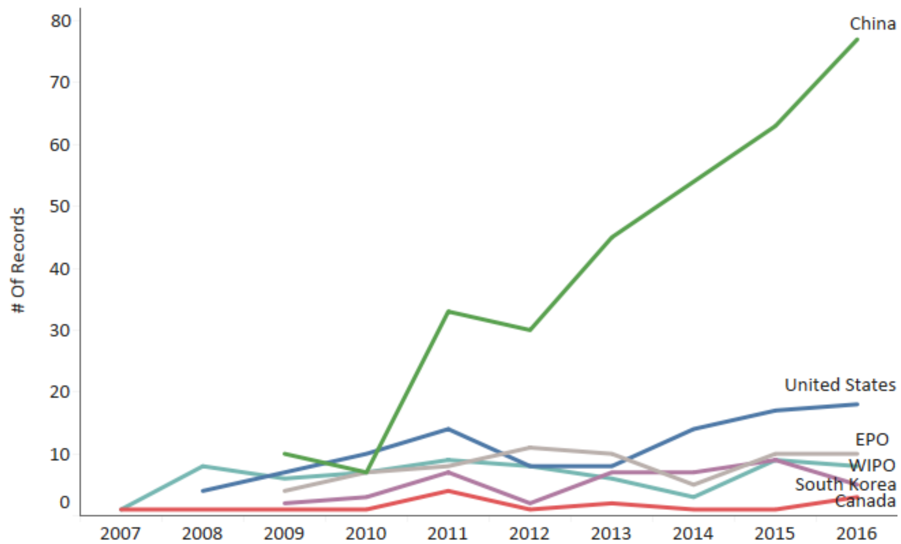

Figure 21: Acceleration of Patenting Rates, Top 5 Countries—Patents

China, EPO and Korea have no patent filings prior to 2009 while the USA has no patents before 2008. Only Canada and WIPO have patents throughout the entire period studied. This might be attributed to the small size of the dataset, which only holds an average of 43.6 innovations per year. China's amazing growth rate could be explained by the overall surge in patent applications starting in 2009–2010 for this country.[102] It is quite clear that China is increasing its number of patents every year covered by the dataset. This is a trend that can be seen in many research areas in China, and not only in MSS.[102]

Besides China, the USA is the only country for which an increase in innovations protected on its territory can be observed. The increase is observable from 2013 onwards. This could be a confirmation that USA is indeed moving from research (as shown by decreasing publications counts seen in Figure 16) into practical and marketable solutions.

7 AVAILABLE PRODUCTS

A total of 29 products were identified, covering all the sensing modalities reviewed in the literature and patent datasets. This list is not exhaustive and is the result of a web search conducted with keywords similar to those used to build the datasets. Only products and companies advertising their product as being able to perform maritime surveillance were included in the list. It is possible that other products exist but are not marketed as specifically applicable to MSS.

Overall, the list shows products for all the modality types but EO/IR sensors and cameras are more often mentioned than any other modality. Many products are designed for airborne platform deployment, as opposed to other platform types.

The list is available in the Excel file named “*Attachment 2—Maritime Surveillance—Products on Market.*”

8 SUMMARY AND CONCLUSIONS

DRDC commissioned this scientometric study to better understand the state-of-the-art in the field of maritime surface surveillance (MSS) before committing to specific research areas and applications for the technology. The objectives for this study were to identify the current and emerging technologies used in maritime surface surveillance operations along with their respective strengths and limitations, determine who are the major players in the field and find commercially available systems.

Scientific literature collected for this project shows that research in MSS is quite active. There was a peak in publications of both patent and literature in 2014–2015 further indicating that the field is probably mature but with continuing research and innovation activities. The peak can also be largely attributed to China’s activity in the field, which has been increasing continuously since 2013. There are only a few patents on the topic, however, which seems to indicate a field in which commercialization activity is not mature. MSS is one of many possible applications for sensing modalities and inventors may choose not to disclose information about specific applications in their patents in order to protect themselves, which makes finding patents on the topic difficult. To qualify the level of innovation on each modality found in the project, searches for each of them should be done in patents, regardless of the application.

The analysis of the literature and the patents shows that the main focus in both datasets was the exploration of different algorithms for automated imagery processing with the goal of fast and reliable ship detection.

The main sensing modality in the research literature is synthetic aperture radar which is, with the Automated Identification System (AIS), the backbone of a MSS system. The two types of synthetic aperture radar that are most often discussed in the literature are polarimetric SAR and X-Band SAR. However, these modalities have limitations and need to be complemented with other modalities to create a comprehensive surveillance system. Patents show that radars are one of the main modalities being added to the SAR-AIS combo, along with Global Positioning System data, acoustics sensors and cameras (mostly EO/IR cameras). The analysis of the emerging modalities in the research literature further indicates that there is an acceleration of research on infrared cameras and acoustics sensors; wireless sensors are also considered as an interesting addition to the mix. In addition, interferometric SAR and new radar operating modes are emerging in the literature. These current and emerging modalities show that MSS systems are not centred on a single technology and that none of them can do it all. There is a clear requirement for multiple modalities, each having a specific role, to build surveillance systems that will be able to detect, track, classify and identify all kinds of targets in all kinds of activities.

One objective of this study was to look at suitable modalities for specific targets. The analysis shows that patents and literature on non-cooperative targets are focused on finding better detection methods in traditional imagery. In terms of modalities, these targets are best detected with systems that include a variety of modalities such as sensors, SAR, radars and AIS. Wireless sensor networks are often mentioned for detection of non-cooperative targets. These networks complement MSS systems as they can contribute in detecting such targets as they are approaching coastal areas. Small targets, either cooperative or non-cooperative, pose specific detection challenges as they are not as easy to distinguish among sea clutter and do not emit the same signals as larger targets. To solve this issue, cameras, frequency-modulated continuous wave (FMCW) radars and Global System for Mobile Communication (GSM) passive radars are used in systems that are often integrating multiple modalities.

Another objective of the study was to look at suitable modalities for specific activities. Analysis shows that surveillance, early warning and intelligence activities all require more than one sensing modality to be efficient. The most frequently referenced modalities, both in patents and in the literature, are SAR, radars, sensors and AIS. High-frequency radars are often mentioned along with early warning activities because of their over-the-horizon coverage capability and continuous-time mode of operation. Ship detection was the only activity for which synthetic aperture radars were identified as the main sensing modality. However, a close look at the articles and patents on this activity reveals that SAR imagery processing is a key research topic in the area, with the goal to enhance detection rates of ships of all kinds.

The use of MSS in the Arctic region was of interest in this project but only a very small number of articles and patents on the topic were found. Further searches led to the understanding that, much like what is observed in general MSS systems, synthetic aperture radar and AIS are the backbone of MSS systems in the Arctic. However, research is showing a growing interest in complementary systems such as local sensor networks, EO/IR cameras and passive and active radars to enhance the surveillance of this critical and unique region.

The literature and the patents also discuss modality features that contribute to a better understanding of the field. Characteristics detected by sensing modalities, such as ship wakes and ship signatures, are among these features. These are best detected with synthetic aperture radars but assistance from sensor networks and cameras can help enhance the detection of these characteristics.

Locations are another feature discussed in the two datasets. The literature shows that modalities are often spaceborne or airborne while in patents, many are landborne and aimed at coastal and harbour surveillance. Unmanned aerial vehicles (UAVs) are also finding a place in the MSS area, as they are often referenced in both patents and in the literature.

Major countries in MSS are China, USA, Italy, Germany, Canada and South Korea. China clearly dominates the field as both their patents and publication volumes surpass the other countries. However, China exhibits collaboration and patenting profiles that indicate that their research and patenting activities are locally centred rather than international. Italy, Germany and Canada, on the other hand, have multiple international collaborations among their publications and patents protected in their territory are also largely protected elsewhere. USA shows a declining trend in its number of publications in recent years but their patenting activities are increasing. This can indicate a shift from research to commercialization.

Commercial available products found during the project mainly originate from American companies, further reinforcing the shift to commercialization for this country. Overall, 28 products were found, covering all sensing modalities. EO/IR sensors and cameras tend to be more mentioned than other modalities and many systems are airborne. However, the list is not exhaustive and cannot be considered as a complete representation of available products on the market. Only products marketed on the web, in English and mentioning maritime surveillance were found. Many others can exist but do not fit the search criteria used.

In summary, the analyses conducted for this scientometric project reveal a field in which a variety of modalities and technologies are used since no single one can survey all maritime surfaces in all circumstances. Improvements to individual modalities are not the main focus of patents and literature, although some specific modalities are being tested for applications in precise scenarios. The focus tends to be more on assembling systems that will be able to detect, track, classify and identify all kinds of targets in all kinds of activities. Most of all, the main focus is on finding efficient, automated and robust ways to process the extremely large amount of data produced by all these modalities, which is a crucial step in performing efficient maritime surveillance activities.

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10 APPENDICES

10.1 Attachments

The following attachments are provided with the report.

Table 4. List of Attachments

Filename	Description
Attachment 1—Maritime Surveillance—Subject Groups	List of all the groups created in the patent and literature datasets, along with the count of occurrences and the share of coverage for each dataset.
Attachment 2—Maritime Surveillance—Products on Market	List of products found for Key Question 3. The spreadsheet contains the following information: • Company/Organization; • Headquarter country; • Product name; • Product description; • Deployed from: ground, air, sea, or space; • Modality—Category; • URL; • Range and Resolution.

10.2Methodology

10.2.1 Searches

A literature search was conducted in Scopus, Inspec and NTIS, three research databases. In order to identify as many relevant papers as possible, the search was conducted at a very broad and high-level.

A similar search strategy was applied in the FamPat worldwide patents database from Questel-Orbit but selected patents were hand pick as all search strategy brought too much irrelevant patents.

The following table lists the concepts included in the search.

Table 5. Search Concepts and Terms—Literature and Patent Searches

Concepts	Terms
Maritime Surface	1. (Maritime OR Ocean OR Sea OR Coast* OR Harbour*) 2. (Arctic OR polar region* or (high latitude*)) 3. (Water ADJ surface)
Surveillance	4. (Surveillance OR (Search and rescue) OR ISR OR JISR) 5. (detect* OR monitor* OR Track* OR Imaging)

	6. ("Early warning" OR Signature*)
Modalities	7. (sensor or sensors or sensing OR Radar*) 8. (AESA OR "electronic scan*" OR "phased array*" OR Doppler OR "EO/IR" OR "Electro-optical" OR "EO" OR Infrared OR "IR" OR Thermal OR SWIR OR LWIR OR MWIR OR NIR OR FLIR) 9. Waveform* OR (Passive ADJ1 (imaging OR camera*)) OR Acoustic* OR Seismic* OR Infrasound OR infrasonic OR sonic OR Magnetic* OR (Electro-magnetic*) OR EM 10. Chemical* OR CBRNE OR Hyperspectral OR multispectral OR Radiofrequency OR (RF) OR (Passive coherent location) or PCL OR Bistatic OR bi-static OR multi-static OR multistatic 11. Multiband OR multi-band OR MIMO OR (multiple input multiple output) OR (Over-the horizon) or OTH OR OTH-B OR (High frequency surface wave) OR HFSWR OR (HF SWR) 12. (Beyond line of sight) OR BLOS OR (Focal plane array*) OR FPA* OR Polarization OR Polarimetric* OR (Induced magnetic field) OR LADAR OR laser radar or optical radar OR LIDAR OR laser rang* OR SAR OR ISAR or synthetic aperture OR (Radar cross section) OR RCS OR NFIRE OR (near field IR) OR (large aperture)
Threats	13. Ship OR Ships OR shipping OR Boat* OR Vessel* OR Cargo/TI/AB 14. Clutter OR Threat* OR Target* OR Traffic OR Object*/TI/AB

Using the keywords defined above, several search sets were created, ranging from the more precise to the more general. A brief description of the strategy employed for each of these search sets is given below.

Search set	Search strategies
1	(1 and 4) and (7 OR 8 OR 9 OR 10 OR 11 OR 12) AND (13 OR 14)
2	1 and (5 OR 6) AND (7 OR 8 OR 9 OR 10 OR 11 OR 12) AND 13
3	(2 OR 3) AND (5 OR 6) (7 OR 8 OR 9 OR 10 OR 11 OR 12) and 13

10.2.2 Excluded Documents

Some documents (articles and patents) were retrieved with the above search strategy without being relevant to the key questions. These were removed from the datasets. Table 6 lists the main type of documents removed and the reason for removal.

Table 6: Removed Documents

Document Type	Reason
Documents on oil spills detection and ice detection	Detecting oil spills and/or ice is a topic often discussed in maritime surveillance. However these topic do not fit the project description.
Documents not monitoring a specific target	When there was no specific object (ship or boat or target) explicitly monitored or detected in the article, it was removed from the dataset.
Documents on ship noise	Detecting ship noise and its effect on the environment is a topic often discussed in maritime surveillance. However this topic does not fit the project description.
Documents where the detection was for underwater objects.	Many articles discussed detection of underwater objects with detecting means that were shipborne or despite ship noise. This does not fit the project description.
Documents on detecting methods were exposed no detecting means	When only algorithms or methods for detections were discussed without a mention on the modality used to detect, the document was removed.

10.2.3 Analysis

All of the literature and patent references were downloaded into VantagePoint software for analysis. VantagePoint enables the creation of various groupings, statistical analyses, matrices, graphs, and cross-correlations to analyze the data and profile the activities of the major players.

Different analytical tools were used to generate graphs based on statistical operations performed in VantagePoint. Tableau software was used to generate bubble graphs and bar charts.

10.2.4 R&D Momentum

The R&D Momentum indicator is designed to identify rapidly rising subjects with relatively few publications. The challenge of identifying such subjects lies with the publication volume as a confounding factor, for their rapid growth and evolution is dwarfed by the high volume of established subjects. Specifically, the notion of "emerging" consists not only of a sharply rising trend line but also of a small footprint in the domain of interest. A *relatively* small footprint is the reason emerging subjects are often overlooked until their disruptive impacts become obvious. In the Momentum indicator, the two parameters correspond to (1) growth rate which is the slope of a subject's trend line (right-left axis), and (2) volume which is the cumulated total number of publications (vertical axis).

Once growth rate and volume are separated, a two-dimensional coordinate can be used to plot a group of subjects. To do so, the two parameters have to be normalized with z-scores. The normalization process converts two sets of values in different units into the same measure by means of standard deviation, which also standardizes the variations for each of the two parameters. The four-quadrant visualization provides a structured view of the relative position of these subjects within the group.

10.3 Categories and Groups

All the groups and their categories are shown below in Figure 22 and Figure 23.

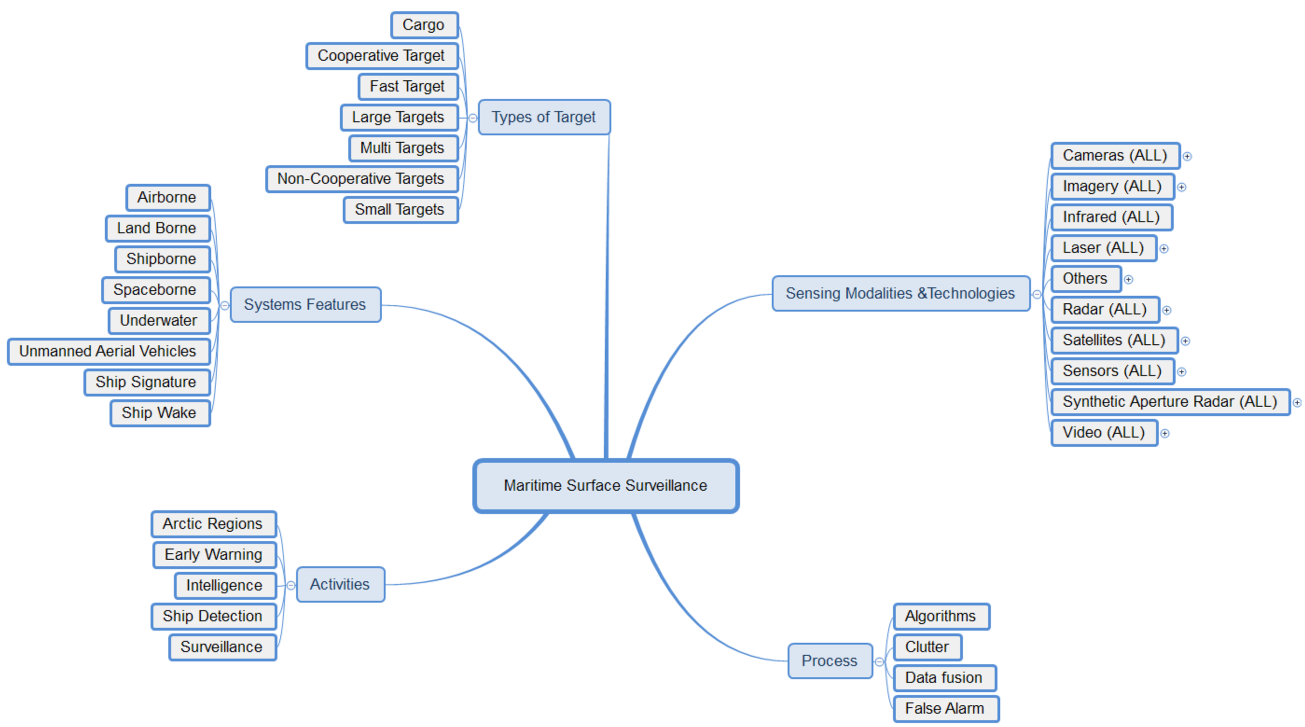

Figure 22: Categories and Groups (Part 1-Main Sensing Modalities & Technologies)

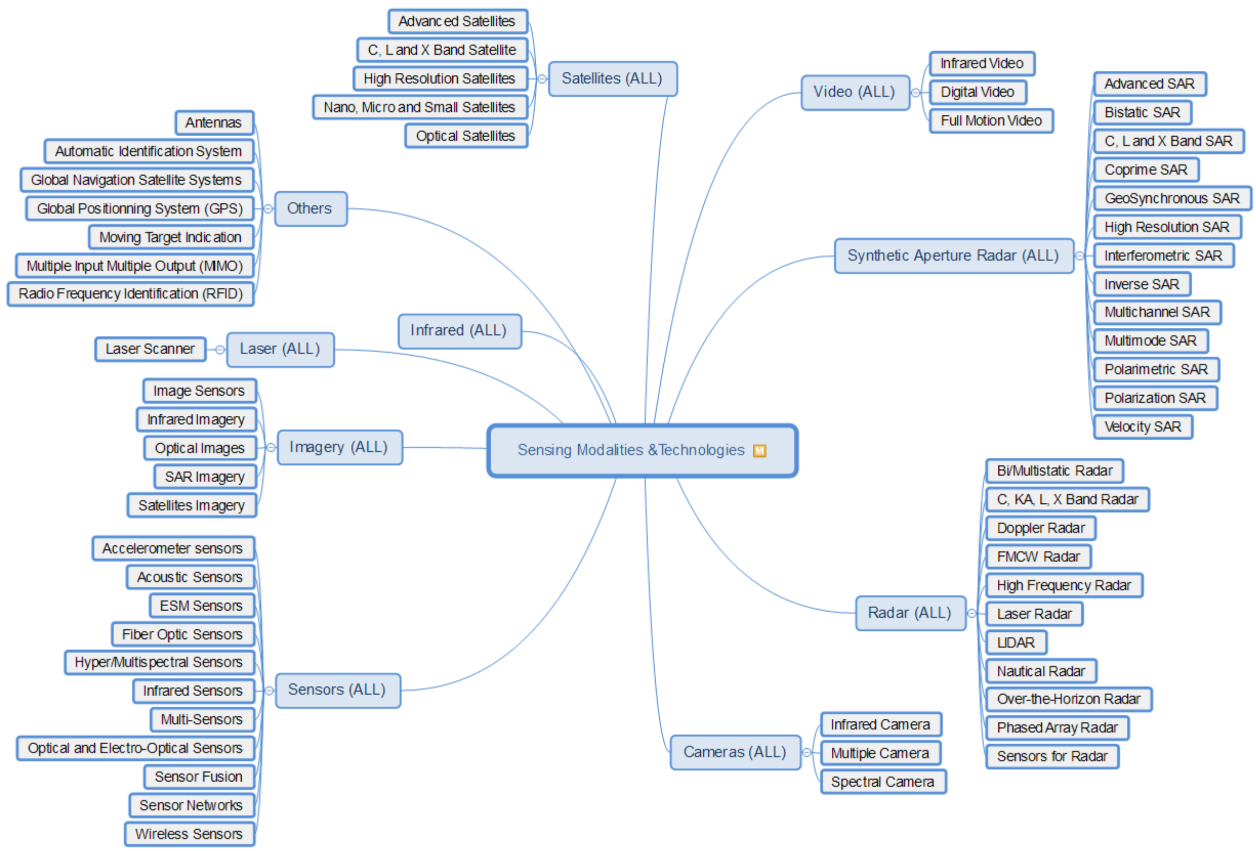

Figure 23: Categories and Groups (Part 2- All Sensing Modalities & Technologies)

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This scientometric study was commissioned by Defence Research and Development Canada (DRDC) to provide a high level overview of technological trends in the field of Maritime Surface Surveillance (MSS). The study will assist DRDC in establishing future research priorities in this domain. To answer a series of three questions, searches were conducted in multiple data sources. A total of 1,166 publication records and 436 patent families were retrieved and analyzed using text mining software and a variety of analytic and visualization tools.

All sources and analyses indicate that synthetic aperture radar (SAR) along with Automatic Identification Systems (AIS) will continue to be the principal technologies used for maritime surveillance for at least the near future. However, the limitations seen in these technologies are calling for complementary sensing modalities. These are necessary to build efficient and comprehensive surveillance systems. No single system or technology will suffice to protect against all threats and in all conditions. Therefore defence agencies interested in maritime surveillance will be required to monitor and invest in multiple technologies.

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Maritime Surface Surveillance, Scientometric Study, ADSA