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Sensor Interaction for Small Ship Tracking and Awareness in Harbour

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Defence R&D Canada – Atlantic

Technical Report

DRDC Atlantic TR 2011-238

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Canada

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The Project Sponsor is Defence Research and Development Canada - Centre for Security Sciences, Public Safety Technical Program, Border and Transportation Security community of practice.

In conducting the research described in this report, the investigators adhered to the policies and procedures set out in the Tri-Council Policy Statement: Ethical conduct for research involving humans, National Council on Ethics in Human Research, Ottawa, 1998 as issued jointly by the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada.

Abstract

This study examined the benefits derived by using interacting sensors for small ship tracking and awareness in harbour, so that port authorities could better understand the implications of deploying integrated security systems. The role of human operators in maintaining vigilance against threats arising from small craft was also examined. The study employed techniques from operations research, data analyses from a relevant scientific trial in the approaches to Halifax harbour, and interviews. These techniques resulted in the following findings:

Layered, overlapping sensors, deployed in an interacting manner, will produce a situational awareness picture that cannot be obtained by utilizing sensors in standalone configurations.

Despite using networked, interacting sensors, detecting and tracking small boats still poses a challenge within harbour environments.

There is still a reliance on human operators within port security regimes.

Cameras are an important sensor because they can validate what type of vessel has been detected and tracked.

In some Canadian harbours, there may be a lack of overlap between those organizations with the capability to monitor small craft activity and those with the mandate or responsibility to respond to small craft incidents.

These findings suggest that there is value in deploying overlapping sensors because multiple, networked sensors creates a situational awareness picture that cannot be achieved otherwise. Perhaps more importantly still, there is a need to ensure that those organizations with the best sensors for monitoring vessel activity and the people to monitor those sensors do more to share their information with the organizations responsible for incident response.

Résumé

La présente étude porte sur les avantages découlant de l'utilisation de capteurs interactifs pour assurer la surveillance des petits navires et la connaissance de la situation maritime dans les ports, afin de permettre aux administrations portuaires de bien comprendre les incidences du déploiement de systèmes de sécurité intégrés. On y traite aussi du rôle des opérateurs pour assurer une vigilance permanente en matière de menaces posées par de petites embarcations. L'exécution des travaux de l'étude reposait sur des techniques employées en recherche opérationnelle, l'analyse des données obtenues dans le cadre d'une expérience scientifique pertinente réalisée lors de manœuvres d'approche du port d'Halifax et les résultats d'entrevues. Voici une liste des résultats qui ont été obtenus à l'aide de ces différentes techniques :

Le déploiement de capteurs interactifs disposés en multiples niveaux, dont les zones de détection se chevauchent, permettra d'obtenir un portrait amélioré de la connaissance de la situation, ce qui est impossible dans le cas d'une configuration de capteurs autonomes;

La détection et la surveillance de petits bateaux dans un milieu portuaire constitue tout de même un défi de taille, et ce, malgré l'emploi d'un réseau de capteurs interactifs;

Les régimes de sûreté portuaire reposent toujours en partie sur la vigilance des opérateurs;

Les caméras constituent d'importants capteurs, car elles permettent de valider le type de bateau qui a fait l'objet d'une détection et d'une surveillance subséquente;

Dans certains ports du Canada, il peut y avoir absence de chevauchement entre les activités des organismes qui possèdent les capacités de surveiller le déplacement de petites embarcations et de ceux qui ont le mandat ou la responsabilité d'intervenir en cas d'incident impliquant ces petites embarcations.

Les résultats susmentionnés semblent démontrer l'efficacité du déploiement de capteurs ayant des zones de détection qui se chevauchent, car un réseau de nombreux capteurs permet d'obtenir un portrait de la connaissance de la situation qui, dans d'autres conditions, n'est pas disponible. Ils indiquent aussi, ce qui est peut-être encore plus important, qu'il est crucial que les organismes qui possèdent les meilleurs capteurs permettant de surveiller le déplacement des embarcations et le personnel qualifié pour surveiller les capteurs facilitent encore plus le partage de leurs renseignements avec les organismes responsables des interventions en cas d'incident.

Executive summary

Sensor Interaction for Small Ship Tracking and Awareness in Harbour

N. Leadbeater; R. Pelot; T. Hammond; DRDC Atlantic TR 2011-238; Defence Research and Development Canada – Atlantic; April 2013.

Introduction: Improving the detection of terrorist and illegal activity in and around Canadian harbours contributes directly to Canada's ability to undertake surveillance along its border. Such detection requires the effective deployment of sensors and data management systems in order to develop situational awareness in the minds of first responders. In a busy port, however, the sheer volume of activity complicates such awareness. Fortunately, monitoring vessel traffic has been simplified in recent years by the widespread use of the Automatic Identification System (AIS), especially on internationally bound ships over 300 gross tons. The advent of AIS has focused attention on ships that are not equipped with it, or that misuse it. Thus, this project looked at complementing the situational awareness picture provided by AIS by adding in the information about small ships not carrying it. Filling in the picture requires the effective use of data from multiple sensors.

Approach: This paper investigates combinations of persistent sensors, suitable both to the harbour setting and to the task of tracking small ships, with a view to identifying those combinations with the greatest potential to enhance situational awareness, principally through anomaly detection. The added value of grouped sensors is evaluated based on their capacity to help operators understand the traffic and identify anomalies. A significant portion of this evaluation also addresses the information and workload placed on the operators themselves. Furthermore, in looking at these sensor combinations, it is important to examine the processes or algorithms needed to make the interaction take place. Should the process take place in the minds of human operators or is it something that can be reliably automated?

Results: This study resulted in the following findings:

Layered, overlapping sensors, deployed in an interacting manner, will produce a situational awareness picture that cannot be obtained by utilizing sensors in standalone configurations.

Despite using networked, interacting sensors, detecting and tracking small boats still poses a challenge within harbour environments.

There is still a reliance on human operators within port security regimes.

Cameras are an important sensor because they can validate what type of vessel has been detected and tracked.

In harbours like Halifax, there may be a lack of overlap between those organizations with the capability to monitor small craft activity and those with the mandate or responsibility to respond to small craft incidents.

Significance: The project explored ways to fill the gap in situational awareness left by the low use of AIS on small boats and represents a shift in focus away from individual sensors towards

integrated systems. Consideration of sensor interaction also adds a new dimension to capacity planning in ports: it is not enough to consider only the coverage of individual sensors but planning their overlap can also be significant.

This study produced the following significant results:

- There is value in deploying overlapping sensors because multiple, networked sensors creates a situational awareness picture that cannot be achieved otherwise.
- It exposed the shortcomings of relying on individual sensors.
- It married scientific analysis with real-world experience by allowing serving port security operators to provide their perspectives on using technology to enhance small boat detection/tracking.

Those organizations with the people and sensors most capable of monitoring shipping activity should share information with organizations responsible for incident response whenever the two are different. It is not clear that any one organization holds both the responsibility and the capability to detect and respond to small boat incidents.

Sommaire

Sensor Interaction for Small Ship Tracking and Awareness in Harbour

N. Leadbeater; R. Pelot; T. Hammond; DRDC Atlantic TR 2011-238; Recherche et développement pour la défense Canada – Atlantique; avril 2013.

Introduction : La capacité de surveiller les frontières du Canada dépend directement, entre autres, de l'amélioration des dispositifs de détection des activités terroristes et illégales dans les ports canadiens et à proximité de ceux-ci. De tels dispositifs de détection exigent le déploiement efficace de capteurs et de systèmes de gestion des données, afin d'optimiser la connaissance de la situation des premiers intervenants. Toutefois, dans un port achalandé, le nombre considérable d'activités rend le tout très complexe. Heureusement, au cours des dernières années, l'utilisation généralisée de systèmes d'identification automatique (SIA) a permis de simplifier les procédés de surveillance du déplacement des bâtiments, particulièrement dans le cas des navires internationaux d'un tonnage brut supérieur à 300 tonnes longues. L'arrivée des SIA sur le marché a mis en relief le cas des navires qui ne sont pas équipés de SIA et de ceux qui en font un mauvais usage. C'est pourquoi les travaux du présent projet portaient sur les moyens d'améliorer le portrait de la connaissance de la situation fourni par les SIA, notamment en intégrant des renseignements sur les petits bateaux qui n'en possèdent pas. Pour obtenir un portrait exact, il est essentiel d'utiliser efficacement les données fournies par de nombreux capteurs.

Approche : Le présent article porte sur l'étude de combinaisons de capteurs permanents qui peuvent être utilisés dans un milieu portuaire et qui ont aussi la capacité de surveiller le déplacement de petites embarcations; l'étude avait pour objectif d'établir quelles combinaisons pourraient le mieux améliorer la connaissance de la situation, particulièrement grâce au processus de détection d'anomalies. La valeur ajoutée du regroupement de capteurs est évaluée en fonction de leur capacité de permettre aux opérateurs de comprendre plus clairement le déplacement des navires et d'identifier les anomalies. Une part importante des travaux d'évaluation traite aussi de la charge de travail des opérateurs et de l'information qu'ils doivent traiter. De plus, l'examen des combinaisons de capteurs doit tenir compte des processus ou des algorithmes nécessaires pour garantir que les capteurs fonctionnent efficacement comme dispositifs interactifs. Autrement dit, les processus de décision devraient-ils relever de la volonté des opérateurs ou peuvent-ils être automatisés avec un degré de fiabilité adéquat?

Résultats : Voici une liste des résultats qui ont été obtenus dans le cadre de l'étude :

Le déploiement de capteurs interactifs disposés en multiples niveaux, dont les zones de détection se chevauchent, permettra d'obtenir un portrait amélioré de la connaissance de la situation, ce qui est impossible dans le cas d'une configuration de capteurs autonomes;

La détection et la surveillance de petits bateaux dans un milieu portuaire constitue tout de même un défi de taille, et ce, malgré l'emploi d'un réseau de capteurs interactifs;

Les régimes de sûreté portuaire reposent toujours en partie sur la vigilance des opérateurs;

Les caméras constituent d'importants capteurs, car elles permettent de valider le type de bateau qui a fait l'objet d'une détection et d'une surveillance subséquente;

- Dans les ports comme celui d'Halifax, il peut y avoir absence de chevauchement entre les activités des organismes qui possèdent les capacités de surveiller le déplacement de petites embarcations et de ceux qui ont le mandat ou la responsabilité d'intervenir en cas d'incident impliquant ces petites embarcations.

Portée : L'exécution des travaux du projet consistait à étudier des moyens permettant de combler les lacunes en matière de connaissance de la situation qui sont attribuables à la faible utilisation de SIA à bord de petits navires; les résultats ont entraîné une réorientation de l'approche adoptée, passant de l'emploi de capteurs autonomes à celui de systèmes intégrés. Le fait de tenir compte du caractère interactif des capteurs ajoute une nouvelle dimension au processus de planification de la capacité dans les ports; il ne s'agit plus, en effet, de simplement établir la zone de détection de capteurs distincts, car il est maintenant tout aussi crucial de prévoir quelle est l'importance des zones de détection qui se chevauchent.

Voici les résultats importants qui ont été obtenus dans le cadre de la présente étude :

- Il est avantageux de déployer des capteurs dont les zones de détection se chevauchent, car de nombreux capteurs en réseau donnent un portrait de la connaissance de la situation qu'il est impossible d'obtenir dans d'autres conditions;
- Les lacunes de l'emploi de capteurs distincts ont été mises en évidence;
- La mise en oeuvre du projet combinait à la fois l'analyse scientifique et l'expérience de terrain, ce qui a permis aux opérateurs responsables de la sûreté portuaire de fournir leur point de vue sur l'utilisation de la technologie pour améliorer la détection des petits navires et leur surveillance subséquente;
- Les organismes qui possèdent les meilleurs capteurs permettant de surveiller le déplacement des embarcations et le personnel qualifié pour surveiller les capteurs doivent partager leurs connaissances avec les organismes responsables des interventions en cas d'incident, s'ils constituent des organes distincts. Il n'a pas été possible de clairement établir s'il existe effectivement un seul organisme qui possède à la fois la capacité de détecter les incidents impliquant de petits bateaux et les responsabilités connexes qui lui permettent d'intervenir en cas d'urgence.

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Acknowledgements

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1 INTRODUCTION

1.1 Purpose

This study, Sensor Interaction for Small Ship Tracking and Awareness in Harbour (SISSTAH), investigated combinations of persistent sensors to identify those with the greatest potential to track small boats and enhance situational awareness. Part of this evaluation also addressed the information and workload placed on the operators charged with maintaining port security.

Improving the detection, tracking and identification of small boats in and around Canadian harbours contributes directly to border security. Such detection requires the effective deployment of sensors and data management systems in order to develop situational awareness in the minds of port security teams. In a busy port, however, the sheer volume of activity complicates such awareness.

Fortunately, monitoring vessel traffic has been simplified in recent years by the widespread use of the Automatic Identification System (AIS), particularly on ships over 300 tons. The advent of AIS has focused attention on ships that are not equipped with it or that misuse it. This project looks at complementing the situational awareness picture provided by AIS by adding information about the ships not carrying it. We believe that the effective use of data from multiple sensors will create a more robust situational awareness picture to augment AIS.

AIS uses VHF radio to report a ship's position and identity at regular intervals from every few seconds while underway to every three minutes when moored. In addition to position, AIS provides a rich assortment of data fields that include the name, heading, dimensions, destination, hazardous cargo type, call sign, Maritime Mobile Service Identity and International Maritime Organization (IMO) number of the vessel.

Our study focused on sensor interaction because using information from interacting sensors can create important new capabilities. For example, AIS can add identity information to radar tracks and, conversely, radar can be used to detect spoofed or erroneous AIS reports. Photographs and video can verify the reported identity in AIS messages, while AIS can provide cargo information that is not readily discernible in a photo. Consideration of sensor interaction adds a new dimension to capacity planning in ports. It is not enough to consider only the coverage of individual sensors, but planning their overlap is also a significant activity. Carefully deployed, sensor interaction could be a force multiplier that augments the capabilities human operators through the effective use of technology.

1.2 Approach

Through operator consultations, a literature review, operations research and leveraging a field trial [1] for data analysis, this study explored ways to 'fill the gap' in situational awareness left by the low use of AIS on small boats and by AIS misuse. This paper describes, anecdotally, how individual sensors that were deployed as part of the Sensor Interaction for Close Coastal and Port Awareness (SICCPA) trial [1] worked in concert to enhance the degree of situational awareness within a harbour environment. The paper shifts its focus away from individual sensors towards interacting systems. It also focuses on the 'human in the loop' element inherent within port security regimes and the implications of the technology for the people involved. Thus, during the course of this study the team observed port security operators using technology in the course of their duties and conducted interviews pertaining to how they use technology, how it helps or hinders them and what would be useful for them in the future.

This paper:

- Provides a general overview of sensor and integrated systems capabilities;
- Highlights current security practices and observations regarding small boats from Canadian Port Authorities;
- Defines the 'small boat problem';
- Examines the role of humans and technology in port security;
- Identifies promising sensor combinations for small boat detection and tracking; and
- Demonstrates new capabilities created by using multiple, interacting sensors.

1.3 Project Team

The SISSTAH project team is composed of members from the following organizations:

Defence Research and Development Canada – Atlantic: DRDC Atlantic in Halifax is an agency of the Department of National Defence responsible for defence-related R&D in maritime situational awareness and is the lead government agency for this study. DRDC Atlantic served in a project management capacity, overseeing the efforts of Ultra Electronics, Dalhousie University and the Halifax Port Authority.

Ultra Electronics Maritime Systems: Ultra is a leading developer of port security systems. Ultra's systems integrate and process various sensor inputs to provide the user with a coordinated picture of the maritime environment.

Ultra served as the technical authority during this study, providing expertise on current port security operations and how they affect technological considerations.

Dalhousie University: The Maritime Activity and Risk Investigation Network (MARIN) at Dalhousie University have over 10 years of experience in processing maritime traffic data. It has developed algorithms for detecting anomalous vessel movements and analyzed patterns in small vessel traffic. It also has experience with human-machine interface studies, particularly on offshore platform operator effectiveness.

Dalhousie University served as the anomaly detection expert on this project and focused on the "human in the loop" element of marine security.

The **Halifax Port Authority** (HPA) served in an advisory capacity and participated in the Human Factors portion of the study.

1.4 Relevance to the Centre for Security Sciences

This paper aims to contribute to the body of knowledge pertaining to the Border and Transportation Security Community of Practice’s goal of enhancing security in and around Canada’s borders. As some Canadian harbours effectively represent borders, the team elected to focus on small ship tracking and awareness in harbour.

2 SENSOR KNOWLEDGE

In order to develop an understanding of what to expect from the sensors that formed part of the SISSTAH project, the project team conducted a literature review to familiarize itself with sensor functionality and the nature of integrated systems. This section provides a high level perspective on sensor capability and systems integration considerations. The intent was not to conduct an in-depth analysis of sensor performance and systems integration techniques, but to present an overview of sensor and system functionality.

2.1 Individual Sensor Capabilities

2.1.1 Radar

Radar is “a method of detecting distant objects and determining their position, velocity, or other characteristics by analysis of very high frequency radio waves reflected from their surfaces.” [1] Common radar types include navigation, surface search radar and air search radar.

Radar behaves as a non-discriminating and non-cooperative sensor (i.e., objects do not need to consciously engage with the radar to be detected and tracked) by picking up any detectable targets that are within range. It will detect objects within its area, but will not identify them. Operators must process the information that the radar provides, such as speed and size, in order to hypothesize what the contact actually is. In this sense, the effectiveness of radar is dependent on the skill of the operator. This skill helps the operator understand the sensor’s output, capabilities and limitations. It also facilitates adjusting the settings to adapt to prevailing conditions.

Limiting factors of radar effectiveness include, but are not limited to, beam path and range, noise, clutter and jamming.

2.1.2 Cameras

The definition of a camera that the team has opted to use is “a device that measures or detects a real-world condition, such as motion, heat or light and converts the condition into an analog or digital representation” [3]. In short, a camera provides a picture, whether it is still-frame or video. Cameras are the most intuitive sensors, as operators merely have to look at the image that is produced. They are designed to substitute for the human eye, and the close analogy with vision ensures that operators require less training.

Cameras tend to be one of the more inexpensive sensors based on per unit cost and among the easiest to deploy. Due to the “proliferation of inexpensive cameras and the availability of high-speed, broad-band wired/wireless networks, it has become economically and technically feasible to deploy a large number of cameras for security surveillance” [3].

There are a number of manufacturers of video cameras; a quick internet search results in links to many different companies including Bosch, Pelco and a number of resellers. The number of vendors offering cameras provides customers with a lot of choice and allows them to decide the trade-offs between performance and price. For example, the Bosch website lists a number of different camera types including Pan Tilt Zoom (PTZ) cameras, fixed cameras, IP cameras and extreme environment and specialty cameras. These selections are further subdivided into other categories such as general purpose, explosion protected and intelligent [4]. The result is that the consumer has to make a decision based on hundreds of choices. It is ultimately up to the operators to decide what type of camera meets their needs.

The performance of video cameras depends on many factors. Among these factors are the camera resolution, frame rate, whether it's analogue or digital, whether it's infrared or visible spectrum, camera placement and robustness. Robustness is a particular concern within harbour environments, as cameras will be subjected to adverse weather conditions, such as rain, snow, fog and high winds. Occlusion and signal loss are major issues, as these render cameras useless for monitoring purposes. These weaknesses suggest the use of redundant and overlapping sensors to provide a holistic situational awareness picture. That way, when cameras fail, operators will still have a situational awareness picture available to them. Relying solely on video, as many security regimens do, represents a single point of failure to the operator and the security regime [5].

The team's literature review turned up little information on how cameras are selected for security and surveillance applications. Ultra has indicated that, in its experience, the types of cameras selected depend on their specific application. Often, it is up to the end-user to specify camera requirements based on trade-offs stemming from purpose, capability and cost.

2.1.3 Underwater Acoustic Arrays

Underwater acoustic arrays are instruments that are composed of multiple sensors intended to detect sounds underwater. They "detect and locate objects by taking advantage of the behaviour of sound in water" [6].

Underwater arrays can be classified into two types: passive and active. Passive arrays "listen" for seismic events or mechanical sounds that represent surface ships or underwater vehicles (e.g., submarines, unmanned underwater vehicles). Active arrays, on the other hand, send out a 'ping' and listen for an echo that indicates there is an object in the area [6].

Acoustic arrays for harbour surveillance are often deployed in chokepoints and are connected via a cable to a shore station, where the data are collected, processed and displayed. There has been much work done on developing processing algorithms that will allow the acoustic signatures detected by underwater arrays to be classified into vessel-type [7].

Underwater sensors have the following performance challenges [8]:

- Underwater arrays require power as supplied by a hard connection or battery. Battery power is limited, so often a shore-based power connection is required to ensure ongoing functionality;
- The available bandwidth can be limited by the capacity of digital storage devices; and
- If not oriented on the sea-bed properly, their effectiveness may be degraded.

2.1.4 Underwater Electrode Arrays

Underwater electrode arrays identify magnetic fields emanating from steel. The intent is to detect the magnetic signatures of ship hulls. The limitation with electrode arrays is that they fail to detect vessels with fibre-glass or wooden hulls.

2.1.5 Automatic Identification System

The Automatic Identification System (AIS) is not technically a sensor, but it is valuable for identifying objects within the maritime picture. The system automatically transmits the position and speed of a ship underway every few seconds by radio. It also transmits additional information about the ship and its voyage (e.g., the name of the vessel, ship type and destination) every few minutes. For example, an AIS transponder deployed upon the Queen Mary 2 would have information specific to that vessel (e.g., identification numbers, call sign, dimensions), in addition to the navigation information that it gets from the Global Positioning System (GPS). The IMO requires that AIS be fitted aboard internationally bound ships of 300 or more tons and all passenger ships regardless of size [9].

Some of the shortcomings of AIS are:

- AIS can be turned off.
- AIS can be configured to send misleading information. AIS information, including vessel identity, heading, speed, and voyage data, can be modified.
- AIS allows those with malicious intent to perform counter surveillance. The system can be monitored over a long term basis to provide route and scheduling information on commercial targets, or can be used tactically to find targets of opportunity carrying valuable or dangerous cargo. When used in combination with radar, AIS can be used to identify law enforcement vessels, warning vessels to halt activity such as illegal fishing when law enforcers are nearby to avoid getting caught.
- AIS is susceptible to jamming. AIS runs on a fixed set of frequencies, and it would be a simple task to jam the system through a single, significantly powerful radio source. As well, the GPS system (which is used for positional information and message timing) has its own vulnerabilities. Jamming the GPS system would disrupt AIS as well.

AIS is provided in two types: Class A and Class B.

Class A transceivers operate using self-organized time-division multiple-access protocol. Class A systems must have an integrated display, transmit at 12 W, possess an interface capability with multiple ship systems, and transmit every few seconds. Class A AIS is mandatory for Safety of Life at Sea (SOLAS) ships [9].

Class B transceivers operate using the carrier-sense time-division multiple access protocol. They transmit at 2 W and do not require an integrated display. They can, however, be connected to most electronic chart display systems, where the received messages can be displayed in lists or overlaid on charts. The transmit rate is normally every 30 seconds. Class B AIS is carried by non-SOLAS class vessels.

2.2 Sensor Combination Knowledge

2.2.1 Sensor Fusion Knowledge

Sensor fusion is a broad term that describes merging data from multiple sensors into a single, output.

There are several main points pertaining to sensor fusion [10]:

Sensor activity must be tailored or directed to the audience for which its intended in order to maximize performance;

It is important to distinguish detection from identification;

When multiple sensors are used together, there is considerable potential to overload humans with information, reducing rather than improving effectiveness. Fusion requires selective presentation of information;

The computational requirements of automated data fusion can be significant, so architectural questions (e.g., is fusion done locally in distributed fusion nodes or centrally) can be important;

Results should be presented in a format understandable to the user.

2.2.2 Sensor Network Architectures

There are essentially four sensor-fusion architectures [11]:

A **fully connected architecture** is a network in which all nodes are connected to all other nodes. However, this architecture is not the most robust against failure. There are a number of communication links in this architecture, and if any fail then the system fails.

In a **tree-connected architecture** nodes communicate locally with those around them. There is only one path between a given pair of nodes, as extra paths would lead to the problem of double counting. However, this network is more robust than a fully connected architecture and is able to restructure itself.

A **hierarchical network** is a subclass of a tree-connected network; it involves a central node to which all information flows. Nodes along the way are used to simplify or compress information through intermediate processing (e.g., turning radar data into tracks). This type of architecture shares the same frailty as a tree-connected architecture, with added weakness due to a central node that can take out the entire system through its failure. As well, the tendency to specialize the roles of middle level nodes means that taking out a single key node can destroy entire functions within the system.

An **ad-hoc architecture** has no overall topology (e.g., a wireless mesh network), and with loops and cycles possible in this system, there is a great deal of redundancy within it. While these ad-hoc networks have the freedom to restructure themselves, and allow for very easy addition and removal of nodes, their constantly changing nature complicates the development of optimization algorithms for their fusion process.

2.2.3 Sensor Placement and Management

The following considerations need to be taken into account when addressing the issues of sensor placement and management:

How do overlapping sensors contribute to tasks that individual sensors can already accomplish?

When should sensors overlap?

What new capabilities do overlapping sensors provide?

Sensors can be both expensive and limited in their area of coverage. For economic reasons, the number of sensors required to monitor a defined area should be reduced as much as practical. Proper sensor placement and management is the best way to do this. Sensor placement is used either to maximize coverage for a given set of sensors, or minimize sensor requirements for a given coverage area. Sensor management, on the other hand, takes existing sensor networks and allocates monitoring or tracking tasks in order to get the most efficient use out of the network's resources.

Employing the optimum number of sensors often involves trade-offs between performance and cost. It is believed that overlapping sensors tend to provide the best interacting performance, but the extent of the overlap is often driven by factors such as the funding available to procure multiple sensors. Other considerations, including line-of-sight, also dictate where sensors may or may not be placed. For a system that requires tracking targets, a certain minimum of overlap is needed in order to facilitate handoff of the target from one sensor to another [12].

2.2.4 Human Factors

Human factors are often overlooked when designing integrated sensor systems and it was difficult to locate articles that examined the 'human in the loop' issue in great detail. However, the lack of detailed articles should not be interpreted as an indication that human factors are unimportant. Quite the opposite is true. Failure to consider human factors in the design process "leads to distrust between the human and machine, lack of adequate preparation in case of machine failure, and ultimate degradation of system performance as a whole" [13].

Two important inferences were drawn from the literature review:

First, while increasing the intelligence and functionality of a system is an attractive goal, displaying this increased intelligence is not always necessary, or even recommended. For example, displaying too much information may result in information overload and effectively reduce the effectiveness of an integrated picture.

Second, interface designers and operators can view the utility of the information being displayed quite differently. It is important for communication to occur between the two during interface design in order to create an end product that is intuitive and useful for the end user [13].

3 THE SMALL BOAT PROBLEM

3.1 What is a small boat?

There is no single definition as to what constitutes a small boat. According to Transport Canada, a small commercial vessel "is regarded as any commercial vessel up to 150 gross tons, in operation, carrying a maximum of 100 passengers" [14]. Small commercial vessels include tugboats, work boats and "special purpose vessels/non-conventional vessels, such as white water rafting, air cushion vehicles, amphibious and sail training vessels" [14].

The 2007 Report of the Department of Homeland Security Small Vessel Security Summit (SVSS) defines a small boat as "any watercraft, regardless of propulsion, which is generally less than 300 gross tons, and used for recreational or commercial purposes. Small vessels include commercial fishing vessels, recreational boats and yachts, towing vessels, or any other small commercial vessels in foreign or US voyages" [15]. The National Marine Manufacturers Association estimates that the number of small boats in operation in the US in 2005 was approximately 71.3 million [16].

A small boat could also be defined as a vessel that is not required to be fitted with an AIS transponder. According to the International Maritime Organization (IMO), some ships "in particular leisure craft, fishing boats and warships, and some coastal shore stations including Vessel Traffic Service (VTS) centres, might not be fitted with AIS" [17]. Some of these vessels might actually be quite large, but the point is to complete the picture provided by AIS.

Given the many choices, it is important to decide what will serve as the definition of a small boat. For the purposes of this study, a non-AIS vessel will be considered a small boat.

3.2 What is the "Small Boat Problem"?

The "small boat problem" is typically associated with terrorist threats and criminal activity (e.g., smuggling). One study suggests that the "small boat threat encompasses a variety of possible weapon-delivery vehicles, tactics and payloads. Vessels include everything from large craft such as small freighters, large privately owned yachts, fishing trawlers, and commercial tugs to dinghies, jet-skies and submarines, including mini-submarines like those used by the Japanese in the attack on Pearl Harbor" [18].

The 2007 SVSS identified the following as the advantages of terrorists using small vessels to launch their operations [19]:

- An extensive population of largely unregulated small vessels, which can be operated by people with minimal training;
- Broad, unfettered access to high-value targets located in coastal population centers;
- Routine operation in proximity to high value maritime ships and infrastructure;
- A complex maritime environment with overlapping jurisdictions, constraining effective law enforcement over large open spaces, waterways, and coastlines;

- Limited existing capabilities for identifying and monitoring small vessel operations including a lack of access to hull identification and registration data by law enforcement personnel, as well as limited credentialing of small vessel operators;
- Limited ability to screen small vessels for weapons of mass destruction and a relatively weak notification and enforcement process for small vessels arriving from abroad; and
- Limited oversight for vessels under 300 gross tons, which operate below the requirements of the Maritime Transportation Security Act (MTSA) of 2002 or international agreements such as the International Maritime Organization (IMO) International Ship and Port Facility Security (ISPS) Code, without safety and security regimes such as standard practices found in the general aviation sector for small aircraft.

The "small boat problem" does not need to take on a terrorist connotation. For example, cruise vessels represent a tourist attraction for boaters and the potential for small pleasure craft to be swamped by cruise vessels as they cast off is real. For this reason, it is important for port authorities to understand what is happening in port-adjacent waters, so they can warn small boat operators of impending ship movements. After all, "Port Authorities are potentially exposed to a wide variety of legal liabilities, including liability for damage to ships, cargo or property belonging to third parties, as well as liability for death or bodily injury to third parties" [20]. There are some real-world legal and financial implications that stem from the lack of small boat situational awareness in harbour.

The key to addressing the "small boat problem" is small boat detection and tracking. Most security threats pertaining to small boats stem from the fact that it is difficult to detect them in the first place. It is impossible to respond to small boat threats, if operators are unaware of them.

3.3 Addressing the "Small Boat Problem"

Small boats are difficult to detect due to their small size, high speeds and optional AIS requirements. As far as AIS requirements are concerned, Regulation 19 of SOLAS Chapter V on *Carriage requirements for shipborne navigational systems and equipment* sets out navigational equipment to be carried on board ships, according to ship type. In 2000, IMO adopted a new requirement (as part of a revised new chapter V) for all ships to carry AIS capable of providing information about the ship to other ships and to coastal authorities automatically.

The regulation requires AIS to be fitted aboard all ships over 300 tons engaged on international voyages, cargo ships of 500 gross tons and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004 [22].

As indicated previously, AIS is a self-reporting system and is only effective if it is turned on and the corresponding transponder information is accurate. As such, it is necessary to use non-self-reporting sensors to fill in the gaps that AIS cannot and provide an enhanced level of situational awareness. Non-self-reporting sensors include, but are not limited to video cameras, radar and various acoustic and electrode sensors.

3.4 Enhanced Situational Awareness

Using technology to increase situational awareness is an effective way to augment security forces and to provide a constant level of surveillance within port facilities. Port security staffs tend to be small, there is a relatively high turnover and financial constraints mean that simply deploying a large number of sensors in the field is not always a viable option for many port authorities.

The issues that need to be addressed are:

- How can sensor interaction be leveraged in a way to provide increased detection, tracking and identification capabilities that go beyond the level that can be obtained from standalone sensors?
- What, if any, is the incremental improvement in detection obtained through interacting sensors?
- How can automated, interacting sensors aid in anomaly detection?
- How can technology augment human operators in a way that will provide a greater degree of situational awareness?

4 COMMON PRACTICES IN CANADIAN PORTS

In support of the SISSTAH study, a number of Canadian port authorities (responsible for individual ports) were approached by the project team to uncover what security practices are currently employed. The intent was to identify and highlight what is currently in place within Canada.

In order to maintain the confidentiality of the participating ports, the contributing ports remain anonymous and a description of current practices is provided.

4.1 Methodology

A twenty-two question questionnaire was developed and then distributed to various Canadian Port Authorities. The questions covered a variety of security-related topics including current sensor utilization, staffing issues and training. The questionnaires consisted of a mix of binary (e.g., Yes or No) as well as open-ended questions. The purpose of the open-ended questions was to allow the ports to expand and provide non-formulated answers.

Responses were collected from three Canadian port authorities.

4.2 Perceived Needs

The ports surveyed indicated that their existing security regimen is appropriate to address their threat environment. Little priority was placed on enhancing the level of security within Canadian ports by incorporating new technology. Two reasons that foster the belief that the current level of security is "good enough" were mentioned:

- A comprehensive threat assessment has been conducted on these ports and a corresponding security apparatus was put in place to address the threats identified in the assessment.
- The threat to port assets from small boat operations is minimal.

Although respondents reported that their security posture was adequate to address their threat environments, they also indicated that deploying additional sensors would enhance their detection capabilities. When queried as to which sensors are worthwhile to deploy in support of port security operations, respondents identified:

- Video
- Radar
- AIS

Video analytics software was not identified as a desired security feature. This suggests that operators view having a "human in the loop" as essential to a robust security environment rather than relying on software to serve as their "eyes and ears".

4.3 Extent of Overlapping Coverage

There was little indication that port security sensors are currently deployed with the aim of providing overlapping coverage between sensor types (of the sort that would facilitate sensor integration). Instead, interactions with these ports suggest that sensors are deployed so as to maximize overall coverage. That having been said, AIS coverage (i.e., the area within which AIS messages are reliably received) in a port usually overlaps with any video or other surveillance capabilities available.

4.4 Vessel Traffic Profile

The diversity of Canada's ports has been highlighted by the port survey and has interesting implications for small boat and anomaly detection. While some ports regularly experience small boat traffic, other ports rarely do. In those ports that rarely experience small boat traffic, the mere presence of a small boat is an anomaly in itself. In ports with a high level of pleasure craft traffic, individual behaviour is analyzed by operators to determine abnormal behaviour. This analysis is done intuitively and experience plays a large role in the judgement.

4.5 Priority Problems

Priority problems identified through the survey are as follows:

- The infiltration of the criminal element within the port;
- A lack of technical expertise within the security staff;
- Container screening.

4.6 Staffing and Training

Security personnel at the participating ports are largely staffed on a contract basis by the Commissionaires of Canada and employ a mixture of full time and part time staff. For example, ports with a significant cruise vessel business employ part-time employees during the cruise vessel season to augment the baseline, full-time staff.

Security training varies across ports, with some operators receiving a full-week, specific course while others are trained on the job. In all cases, there is an element of on-the-job training provided.

All ports canvassed said they experience a "high" level of staff turnover. Such a turnover increases the training requirements and means that there is a constant learning curve. Not all security-related lessons learned may get written down. Thus, it is likely that some knowledge does not get transferred to new employees, when previous employees leave their positions.

4.7 Small Boat Tracking

While small boat tracking was not identified as a priority problem by the port authorities surveyed, this should not be taken as an indication that the "small boat problem" is solved. An interview with representatives from one port authority revealed that, although they may have some capability to detect and track small boats, they cautioned that:

It is difficult to ascertain the intent of small boat operators.

It is not a port authority mandate to track small boats within a harbour;

When they describe the threat from small boats as "minimal", they are thinking primarily of the threat to port assets and staff. Other threats that small boats may pose are not their responsibility.

This interview revealed an important potential issue that could crop up within the Canadian port security environment: it is theoretically possible that those responsible for the activities of small boats (e.g., police or Transport Canada) and those capable of tracking them (by virtue of their personnel and sensors) might, in particular cases, be sets with no intersection. In other words, it could be that nobody has both the mandate and the capability to track small boats. This paper does not have sufficient data to evaluate whether and where this theoretical issue actually arises in practice, but the survey certainly suggests it does occur.

5 INCREMENTAL CAPABILITIES GAINED BY USING SENSORS IN COMBINATION

Conventional wisdom suggests that the use of multiple sensors will be required to create a situational awareness picture that is robust enough for small boat detection and tracking. Given the limitations of individual sensors, it is unlikely that any one sensor will serve as a silver bullet that will solve the “small boat problem”. Using multiple sensors creates redundancy in the situational awareness picture in the event that one type of sensor is unable to detect and track a target.

The purpose of this section is to identify the incremental capabilities that can be created by using pairs of complementary sensors. This approach will provide an examination of the potential benefits of using sensors in concert by exploiting areas of overlapping coverage. Examining technology pairings will highlight what should be expected by utilizing a suite of sensors for small boat detection.

5.1 Radar and Camera

Radar serves as an alerting and tracking sensor. It can detect vessels relatively far away and it can alert operators that there is a vessel in a certain area. As indicated previously, radar does have its limitations. Depending on the prevailing weather conditions, size of the vessel and the radar settings, a vessel may or may not be detected. Though radar can illustrate the relative size of vessels, it will not provide conclusive evidence as to what type of vessel has been tracked. In this case, a camera can serve as a validation sensor by visually confirming that the radar detected a vessel by providing a visual of the vessel.

One of the key problems pertaining to cameras is occlusion. If a target is blocked from the camera’s field of view, then it cannot be captured by a camera. Inclement weather, like fog, is more likely to affect cameras than radar. In inclement weather or darkness, radar can serve as a sensor to keep track of vessels when cameras cannot.

5.2 Radar and AIS

While not a sensor per se, AIS can indicate how reliable radar information is by allowing operators to cross-reference information between the two. For example, as AIS is required to be fitted on ships over 300 gross tons, it can be used to validate the effectiveness of the radar (e.g., whether the mode of operation should be switched from long-range to short-range or whether the settings, such as gain, are optimized) as, in theory, most ships over 300 gross tons should be detected by the radar up to a certain range. If AIS contacts are regularly being detected without a corresponding radar track, then this could suggest that there may be an issue with the radar (e.g., the settings are not optimally configured) or an indication of spoofed AIS. Radar can also be used to suggest whether or not a vessel has turned its AIS transponder off.

Some systems fuse radar and AIS into one target on a screen. The reason for this is that it reduces the amount of clutter on a screen and results in fewer items being presented to operators.

5.3 Camera and AIS

AIS behaves as an alerting and tracking sensor, while a camera serves as a validation sensor. Cameras can verify that the AIS information being received is accurate by providing operators with a visual representation of what the AIS signal is reporting. For example, if the AIS signal indicates that an approaching vessel is an oil tanker, but the camera indicates that the approaching vessel is a small cabin cruiser, then operators can reasonably determine that the AIS report is misleading, either accidentally or as a result of deliberate spoofing.

AIS can also help maintain situational awareness when occlusion, darkness, fog and weather pose problems for cameras.

5.4 Radar and Underwater Arrays

Radar and underwater arrays (both acoustic and electrode) can interact to:

- Provide a more robust above water picture that detects a greater proportion of targets. Small boats (with engines) that may not be detectable by radar may be detected by underwater arrays, if the vessels are transiting close to where the arrays are deployed.
- Provide operators with both an above water and underwater picture. Radar will not detect divers or Unmanned Underwater Vehicles (UUV).
- May be able to distinguish between targets in close proximity (e.g., tug boats and cruise ships) whereas radar contacts may be occluded.

5.5 Electrode and Acoustic Arrays

Electrode arrays detect electric signatures from ships' hulls while acoustic arrays detect noise coming from vessels. Small outboard motors may not be detectable by electrode arrays because their electric signatures may not be large enough to trigger the electrode array. However, they may be loud enough for the acoustic arrays to detect them.

Another potential synergy may be detecting vessels towing barges. While an acoustic array will not detect a barge, it may detect a vessel towing a barge. However, an electrode array should be able to detect both the vessel and the barge.

It could potentially be useful to merge both electrode and acoustic detections into one target so as to minimize the number of items on a screen. This will prevent monitors from becoming too busy and present a single underwater picture for operators.

5.6 AIS and Underwater Arrays

As with radar, AIS provides a mechanism for operators to gauge how effective underwater arrays are by cross-referencing AIS targets with the number of detections by the underwater arrays. For example, if an AIS track transits directly over the location of an underwater array but the array does not register a detection, then there could be a number of explanations:

- The array is offline; or
- The vessel is of a type that may not be easily detectable by either acoustic or electrode arrays (e.g., a fibre glass sail boat not operating under power); or
- The AIS message is wrong.

Underwater arrays may also be able to distinguish between various engine and propeller types, which could then be cross-checked against AIS information. This could suggest whether or not AIS spoofing is occurring. The underwater array could also detect vessels that were not carrying or not operating an AIS transponder.

5.7 Camera and Underwater Arrays

As in the case of cameras augmenting both AIS and radar, the underwater arrays can alert operators that a vessel is entering harbour waters, while a camera can provide visual evidence to confirm the event and what type of vessel is transiting.

5.8 Fused Targets

Received data can be displayed as one target on a screen ("fused together") to create a single visual representation. The benefit to this approach is that it reduces the number of items on a screen and makes it appear less busy. The downside to this approach is that it makes it difficult for operators to determine if one of the sensor types is not functioning properly.

For example, a fused radar and AIS picture would eliminate overlapping targets on a screen at once. The downside to this is that if the radar is not functioning properly, then it may not be immediately obvious to the operator. This means that small, non-AIS vessels could go undetected for some time before it is noticed. If target fusion is enacted, it is important to be able to relay sensor status on the screen to alert operators when a sensor is no longer functional.

5.9 Sensor Interaction

While sensor interaction has the potential to enhance the degree of situational awareness within a harbour, it also has the potential to degrade it. A potential problem related to sensor interaction pertains to sensors that are configured to react to information obtained by another sensor. The cued sensor may be rendered useless, if the cueing sensor is disabled. For example, if video cameras are set-up to record all radar contacts within a particular area, they will cease to record specific events should the radar fail. In this case, the failure of the radar would have a cascading effect on the cameras.

5.10 Past Studies

A 2009 sensor fusion study examined the "human in the loop" element pertaining to integrated systems [23]. The first step in the process was to present human subjects with unfused imagery from optical and infrared sensors, after which they created an operator function model for target identification in both low and high stress situations. A fusion process was then created to mimic the methods the human subjects used, pulling the details from each sensor that the operators relied on in the decision making process. Though there was room for improvement, the subjects who were tested with the fused images unanimously agreed that the fusion system would make their jobs easier.

In 2010, an article detailing a system known as ScanMaris was published [24]. In this system's multi-agent approach, each target that the sensor network picks up is assigned an autonomous software agent. The agents compute a criticality constant, raising an alarm to the operator should the criticality constant rise above a given value. Agents are able to cooperate with each other, as well as a second multi-agent system which can track the locations of anomaly events. In the example given in the article, a single ship stopping just out of radar is not worth an alert by itself, but the behaviour drops a flag on both the target and the location at which it stops. When a second ship stops at the same spot as the first, the second ship's agent finds the previously placed stopping flag, making its own behaviour far more suspicious as a sign of potential illegal trans-shipment. In this way, ScanMaris is sensitive to slightly anomalous activities that would set off frequent false alarms if they were all considered important but isolated events.

The US Coast Guard's surveillance system, SeeCoast, integrates radar, AIS and video sensors to increase watch-stander effectiveness [25]. One point of interest is the system's ability to estimate ship size and position from video data alone. The benefits of such a capability are twofold. First, an identity can be attached to ships too small to be required to use AIS. Second, it can provide verification of the data presented with AIS, allowing for easier detection of AIS spoofing. The article also touches on human factors, specifically with regards to how alerts are presented. The system allows users to customize the information shown with an alert, keeping the information tailored to a level that the operator finds useful and not overwhelming. When possible, the system presents a snapshot of the target that generates an alert, allowing for the quick assessment of whether an alert warrants further attention.

5.11 Relevance

As different sensors generate different types of data, it is assumed that deploying a variety of sensors will provide a more enhanced situational awareness picture for operators. Allowing different sensors to augment one another should provide a degree of redundancy, if one sensor fails to detect, identify or track a target for any reason. These are the usual considerations for any port security system.

6 CASE STUDY: SICCPA TRIAL

There is a belief within the port community and industry that deploying multiple, overlapping sensors in the field results in a better detection, tracking and identification of small boats. The SISSTAH project team sought to determine if interacting sensors actually increased the ability to detect, track, and identify small boats. In this pursuit, the use of overlapping and interacting sensors is fundamental.

The team leveraged data that were obtained from a sensor trial in the approaches to Halifax harbour (Figure 1) that had similar goals with the SISSTAH study [1]. This trial, Sensor Interaction for Close Coastal and Port Awareness (SICCPA), was managed by DRDC Atlantic and involved participants from two additional defence research organizations.

The data generated by the trial have been used to question a number of assumptions related to using multiple sensors to track small boats in harbour. Namely:

Would deploying multiple, overlapping sensors actually enhance the detection, tracking and identification of small boats?

What is the impact of Human Factors on the effectiveness of sensor interaction?

6.1 SICCPA Sensor Trial

The SICCPA sensor trial was held in the approaches of Halifax Harbour between Ferguson's Cove and Sandwich Point from 29 September - 05 October 2010. The trial participants included representatives from DRDC Atlantic, DRDC Ottawa and FOI (Swedish Defence Research Agency). Representatives of Ultra and Dalhousie University attended portions of the trial as observers. The intent of the trial was to deploy a variety of sensors within the harbour approaches to see how well they detected and tracked small vessels operating in the area. The sensors were deployed in standalone configurations.

Figure 1: SICCPA Trial Area represented in Google Earth®.

The Seawatch Bed and Breakfast in Ferguson's Cove (Figure 2) served as the Command and Control Centre with additional personnel located at the NATO Sound Range in Ferguson's Cove and at the Canadian Forces Damage Control School in Herring Cove. Cables from the underwater systems were brought ashore at the Seawatch Bed and Breakfast, radars were deployed at the NATO Sound Range and at the Naval Engineering Damage Control School, and the Automated Ship Image Acquisition (ASIA) system on top of the NATO Sound Range tower (Figure 3).

Figure 2: Sea Watch Bed and Breakfast.

The sensors deployed included (Sensor owner in parenthesis):

ASIA Camera System (DRDC Atlantic)

Rutter Radar Systems (DRDC Ottawa)

Electrode Underwater Array (FOI)

Acoustic Underwater Array (FOI)

Starfish Array (DRDC Atlantic)

6.2 ASIA Camera Overview

DRDC Atlantic's ASIA camera system photographs vessels by using their AIS transponder as a trigger and point of reference. The system uses a high-resolution digital camera that can store images digitally into a database.

ASIA was designed to photograph every ship fitted with AIS that comes in range from a variety of viewing angles. It attempts to photograph the entire vessel but sometimes only captures part of the vessel or its wake.

Figure 3: ASIA Camera System.

6.3 Radar Overview

DRDC Ottawa's Rutter 100S6 Navigation Radar system is a non-coherent, X-band, marine navigation radar system with a peak transmitted pulsed-signal power of 25kW that is capable of Advanced Radar Plotting Aid (ARPA) functionality. During the trial, a radar system was deployed on the grounds of the NATO Sound Range (Figure 4). This system operated in Short

Range Mode (SRM) for the duration of the trial. The intent of the radar system was to augment AIS by detecting and tracking both cooperative (e.g., AIS-enabled) and non-cooperative (e.g., non-AIS-enabled) vessels.

Figure 4: Rutter Radar.

6.4 DRDC Underwater Sensors Overview

DRDC Atlantic deployed three multi-sensor platforms called Starfish Arrays (Figure 5). Each Starfish Array contains a three-axis acoustic dipole sensor, a three-axis Bartington magnetometer, two horizontal electric field sensors, a pressure sensor and a three-axis accelerometer. The Starfish nodes are cabled together, separated by 120 m, cabled to a processing can, and then cabled ashore with a 1.5 km telephone cable. The cable to shore is attached to communication hardware and computers for collecting and displaying the real-time data. The Starfish is designed to be deployable in 200 m of water.

Figure 5: Starfish Array.

6.5 FOI Underwater Sensors Overview

FOI (Swedish Defence Research Agency) contributed two types of passive underwater sensors: hydrophones and electrodes. The main objective of the acoustic system (Figure 6) was to improve the ability to track vessels in the area by bearing estimation. For the electrode system (Figure 7), the main objective was detection of vessels passing directly over the system.

Figure 6: FOI Underwater Array.

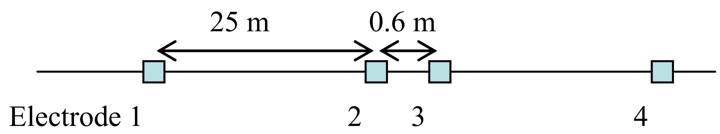

Figure 7: Configuration of the electrode system and a picture of a single electrode element mounted on the cable. The total electrode system contains 16 silver/silver chloride electrodes, which form 8 electrode pairs. The distance between the electrodes in an electrode pair is 25 m and the distance between consecutive electrode pairs is 0.6 m.

Two small, trial-dedicated vessels, one a dive tender (NORTHCOM) and the other a Coast Guard Research Vessel (SIGMA T), transited through the area regularly during the course of the trial. Both vessels were equipped with GPS transponders to ground truth their movements which could later be compared with the data collected by the deployed sensors. The vessels conducted a number of specified manoeuvres through the area including criss-crossing patterns and closing patterns (Figure 8 and Figure 9).

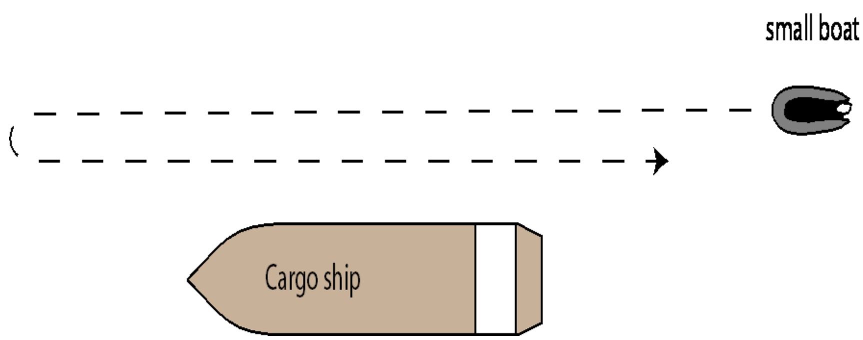

Figure 8: Small Boat Shadowing Pattern.

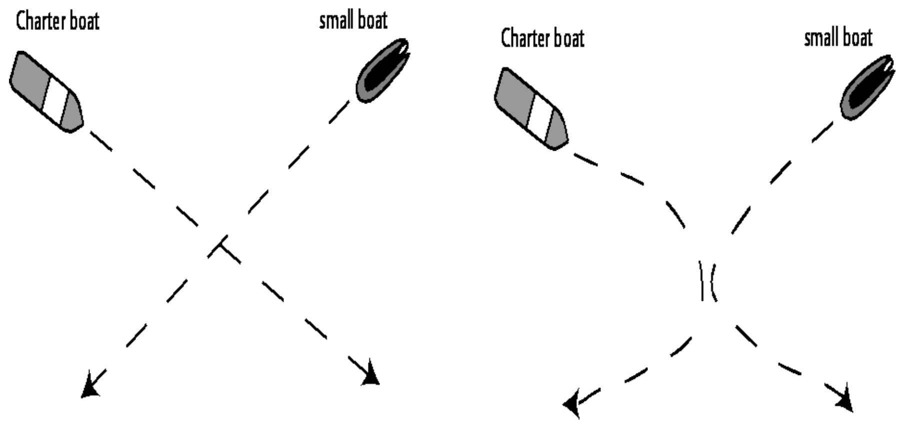

Figure 9: Small Boat Crossing and Close Approach Patterns

The sensors were deployed in a manner to ensure that there was overlapping coverage of the trial area. The intent of the overlapping coverage was to provide data that could illustrate synergies between the sensors.

Sensor data were collected in 10 – 12 hour shifts during daylight hours over the course of the trial (Figure 10). Sensors were turned off periodically during daylight hours during passage of Canadian Naval vessels so that the data would not become classified. Schedules of shipping activity provided by Queen's Harbour Master facilitated this process.

While there were some initial issues with sensor deployment, particularly the underwater arrays, the team managed to collect data from all deployed sensors over a three day period. The primary issue encountered was the deployment of the underwater arrays. The team had difficulty aligning the arrays perpendicular to the traffic lanes in the harbour approaches and had to re-orient them.

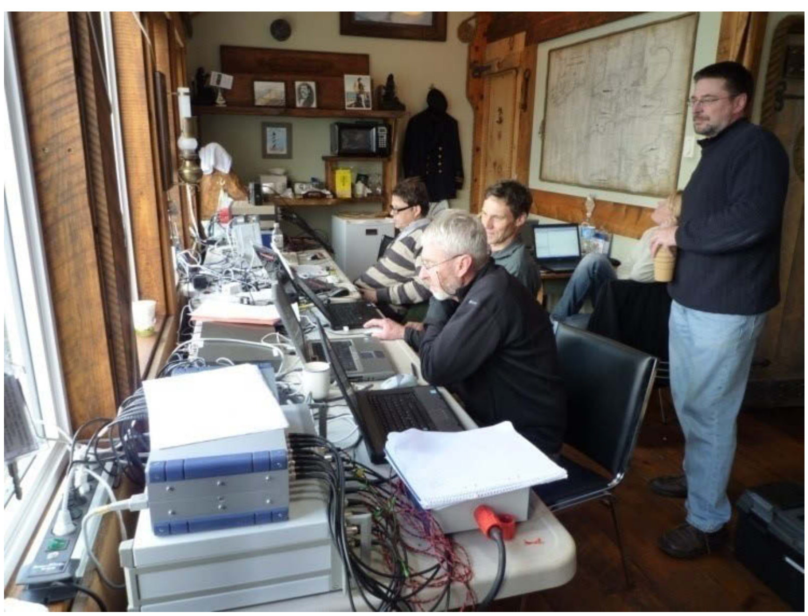

Figure 10: SICCPA Trial Participants in the Seawatch Bed and Breakfast.

One of the added benefits obtained from the SICCPA trial stemmed from the location of the trial itself. Given its position in the harbour approaches, the trial managed to collect data from a number of vessels that were not involved in the study including cruise vessels, fishing vessels and pleasure craft. Annexes A, B and C provide information about how trial data from various sensors was treated, formatted, and analyzed.

7 SENSOR COVERAGE AREA

While the SICCPA trial was held in the harbour approaches, sensor detections were not entirely limited to the area in the harbour adjacent to Ferguson's Cove. Some of the sensors managed to detect vessels well outside of the trial area. In order to analyze events so that the degree of sensor interaction could be examined, the team sought to identify the actual coverage area of each sensor to ensure that selected events occurred within areas with overlapping sensor coverage. The term coverage area is used here to indicate the area in which most contacts occur; it does not necessarily indicate that a sensor would not be able to detect ships outside the coverage.

The methodology used to analyze the data can be found in Annex A. Google Earth was used as the Graphical User Interface (GUI) to display the collected data.

7.1 Radar

Ten radar data files (each representing about two hours worth of data) were selected that were generated from the SICCPA trial in order to determine the effective radar coverage area. The data points from each file were then plotted in Google Earth as small dots (each dot represented a detection). A polygon was drawn around the dots manually, after which the dots were deleted, as the large number of data points was difficult for Google Earth to handle. Figure 11 shows the dots plotted from a single file in blue. The polygon that was drawn around these dots appears in white underneath them. Once a polygon was created for all ten files, the polygons were made red, semitransparent and overlaid with each other. This process indicates the most reliable radar coverage areas in solid red. The result is the second image in Figure 11.

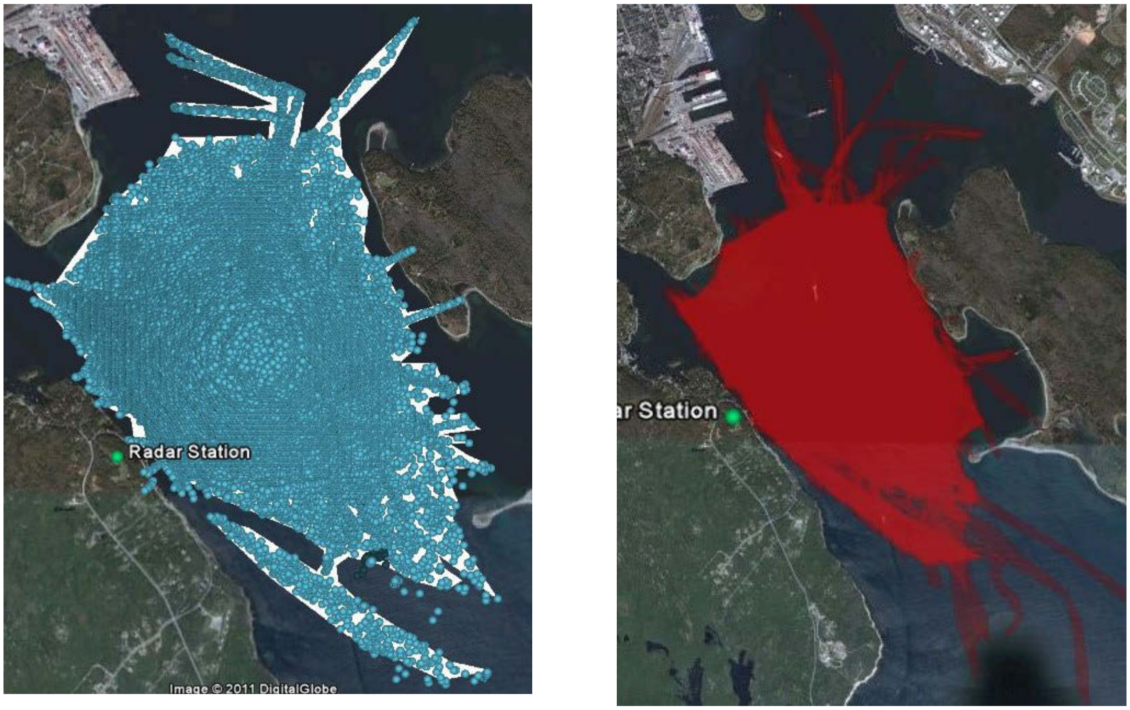

Figure 11: Radar Coverage Area plotted in Google Earth ®.

From this set of polygons, the maximum detected point is clear. The furthest point at which a detection was made was approximately 4.5 km from the radar station. Given the geographic constraints, this should not be taken to indicate the maximum range of the radar.

Determining the effective coverage area (the area where the majority of the contacts occured) of the radar required further analysis (based on frequency of detections). Closer inspection of the radar data revealed a triangular section in the bottom corner of Figure 11 in which few vessels were detected. The triangular shape is consistent with an obstruction in the radar's field of view. Figure 12 indicates the frequency of detections made by the radar within the trial area (red squares have the most detections, dark green the least). The circled area in that figure shows a region with few detections in dark green against a background of lighter green.

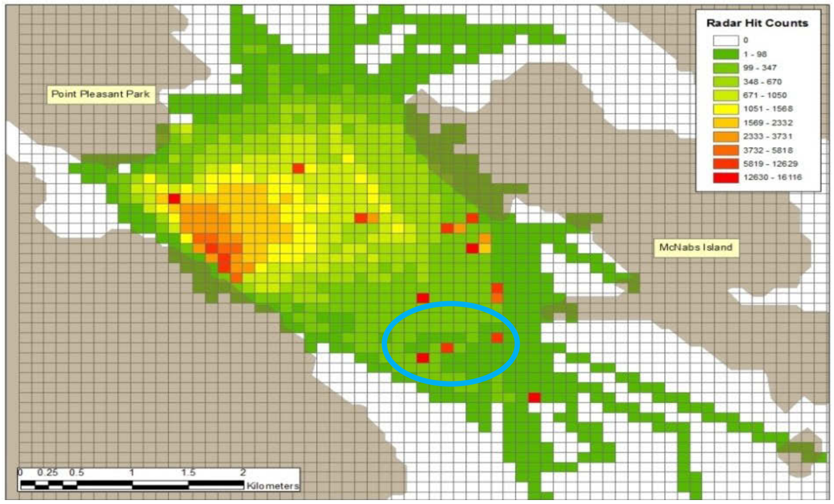

Figure 12: Radar Detection Frequency.

Figure 13 displays the traffic patterns in the trial area (from AIS). Traffic in this area tended to follow two lanes. In the harbor, these lanes are clearly defined by a set of navigational buoys, appearing (in that figure) as red and green dots within the orange square. These navigation buoys explain the three red rectangles within the blue ellipse of Figure 12.

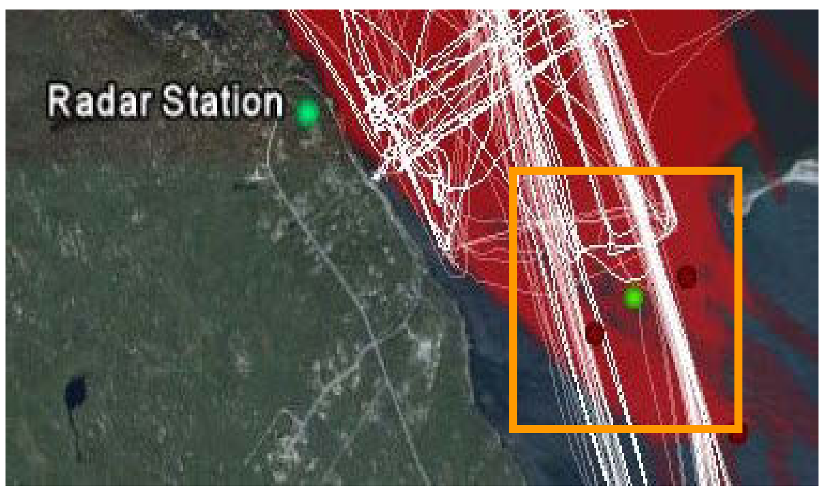

Figure 13: Traffic Patterns from AIS overlaid on the radar coverage area (in Google Earth).

There were also a small number of detections made at the north and south tips of the radar polygons (Figure 14). To determine if the radar was reliably detecting vessels in the area, radar tracks from the same time window as each of the polygons' radar data were plotted in Google Earth. Any tracks that fell outside of the polygons were marked in orange to highlight them and a green polygon was drawn at a radius 2.3 km as this is where the majority of contacts occured.

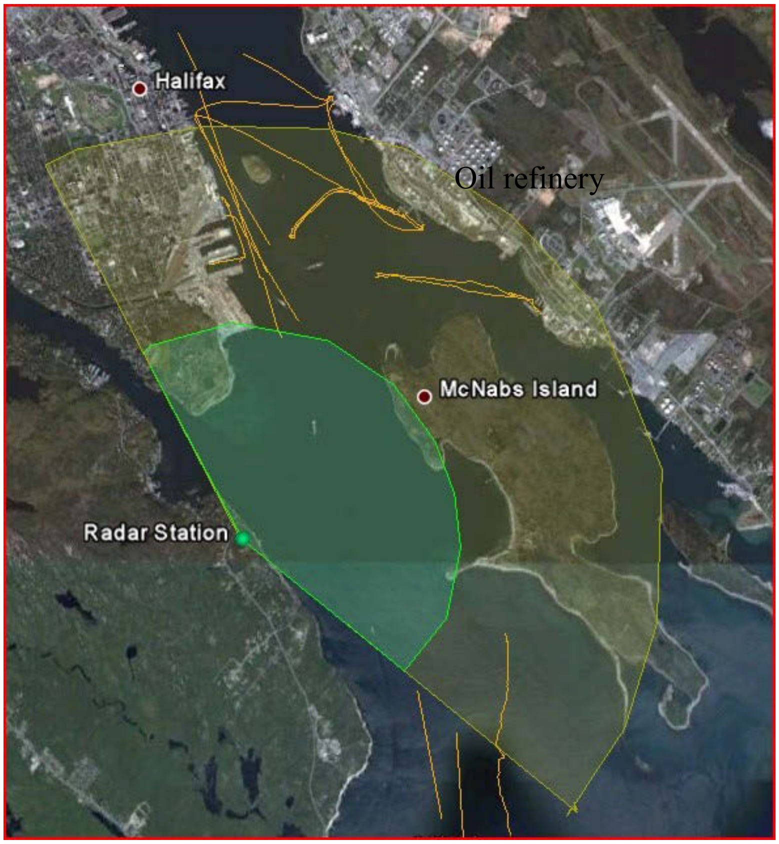

Figure 14: Effective radar coverage plotted in Google Earth.

Many of the tracks within the 4.5 km polygon (yellow area) fell outside of the radar detection polygons (green area) and thus can be considered outliers. This suggests that the effective radar coverage area for the trial was 2.3 km (the range where the majority of contacts occured) which corresponds to the immediate trial area. This relatively short range is explained more by geographic constraints than by sensor performance.

7.2 Starfish Array

A coverage area was not determined for this sensor, but passive underwater systems typically have shorter detection ranges than above water sensors.

7.3 AIS

Using Google Earth, several files worth of AIS tracks (collected by the ASIA camera's AIS receiver at the NATO Sound Range (Figure 3)) were plotted and depicted as orange lines in the following figures.

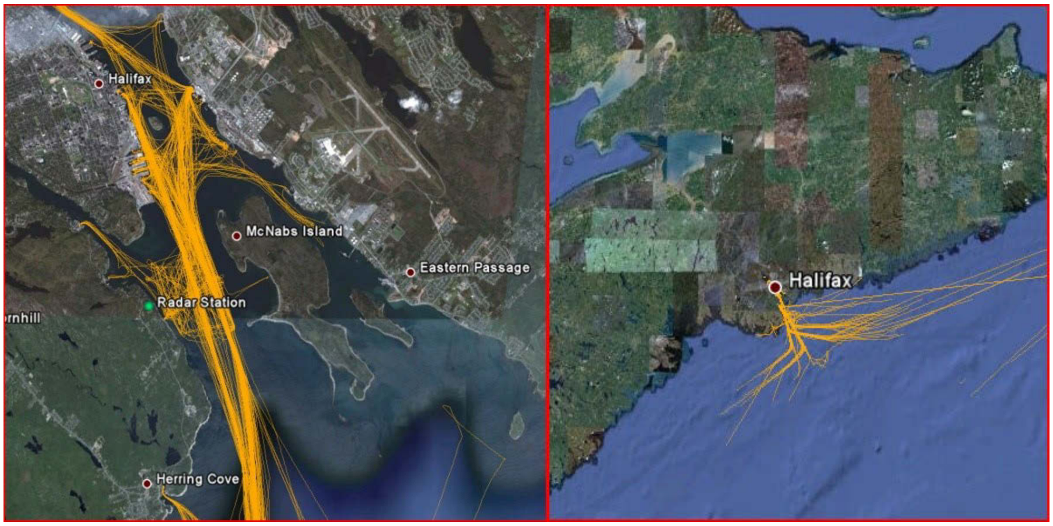

Figure 15: AIS Detections plotted in Google Earth.

In Figure 15, it is clear that AIS detections are made far outside of Halifax Harbour. Some tracks were detected approximately 50km from the harbour. It also indicates that there were no detections made to the east of McNabs Island. While it may appear as though there may be a blind spot behind McNabs Island, the most likely explanation is simply a lack of traffic. Nautical charts reveal that the water behind the island is only one or two meters deep in some areas, with several wrecks and other underwater hazards present. Thus, it is not surprising that AIS-carrying ships (which are typically more than 300 gross tonnes) would not be travelling in those waters.

In order to analyze events that were subject to overlapping sensors (e.g., the effective radar range), a polygon corresponding to the 2.3 km effective radar range was drawn around the AIS tracks.

7.4 ASIA

The ASIA camera has a pre-defined coverage area over which it takes pictures, displayed as a yellow polygon in Figure 16. To ensure that this coverage area accurately represented the camera's range, the locations of all ASIA photographs were plotted, shown below as peach coloured dots.

Figure 16: ASIA photograph locations plotted in Google Earth. The photo shown was taken at a range of 7.5 nautical miles from the ASIA camera.

An ASIA-generated photo was selected to determine whether ASIA was reliably taking photos at the outer edges of the coverage area. This picture is annotated in Figure 16 with a large green dot (photo of the vessel inset). Not only did ASIA manage to capture an image of a vessel, but the vessel is below the horizon, suggesting that the maximum range of the ASIA system may not have been reached.

7.5 GPS

While GPS was not one of the sensors trialed, GPS data were used to ground truth other sensor data (e.g., radar, ASIA, underwater arrays).

Since GPS uses satellites to determine position, theoretically, the whole harbour should be within its coverage area. However, since the collected GPS data focus only on the two ground truth boats (SIGMA T and NORTHCOM), the area of interest is the area covered by these boats' tracks. To produce a rough coverage area based on this criterion, a polygon was drawn around the area covered by the GPS tracks. This produced the image in Figure 17 with the tracks appearing as orange lines. This coverage area is displayed in purple.

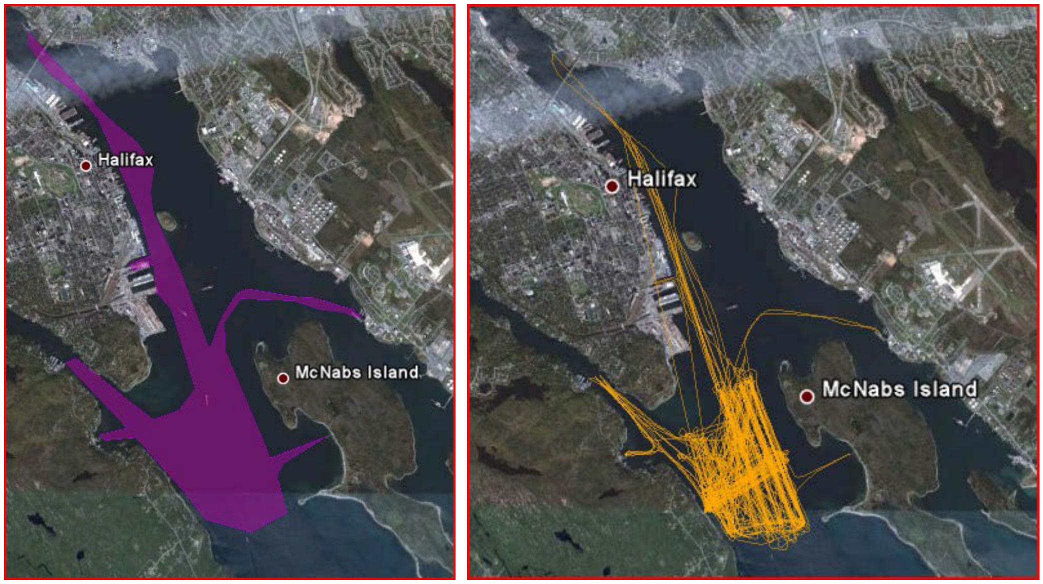

Figure 17: Area covered by reference targets shown in Google Earth.

7.6 Electrode Array

Eleven events were selected to identify the effective coverage area for FOI's electrode array. For each event, a timestamp was selected manually by identifying the event's midpoint. Next, the data for all ships close to the sensor between two minutes before and after the event timestamp was processed to determine the minimum distance between each ship and the sensor. These minimum distances were compared to identify the ship with the smallest minimum distance for each event. The location of the smallest minimum distance for each event was plotted on GIS and an oval was drawn around the data points (Figure 18).

The circle around the minimum distance points represents the approximate coverage area of the electrode array sensor, as determined by data generated during the SICCPA trial.

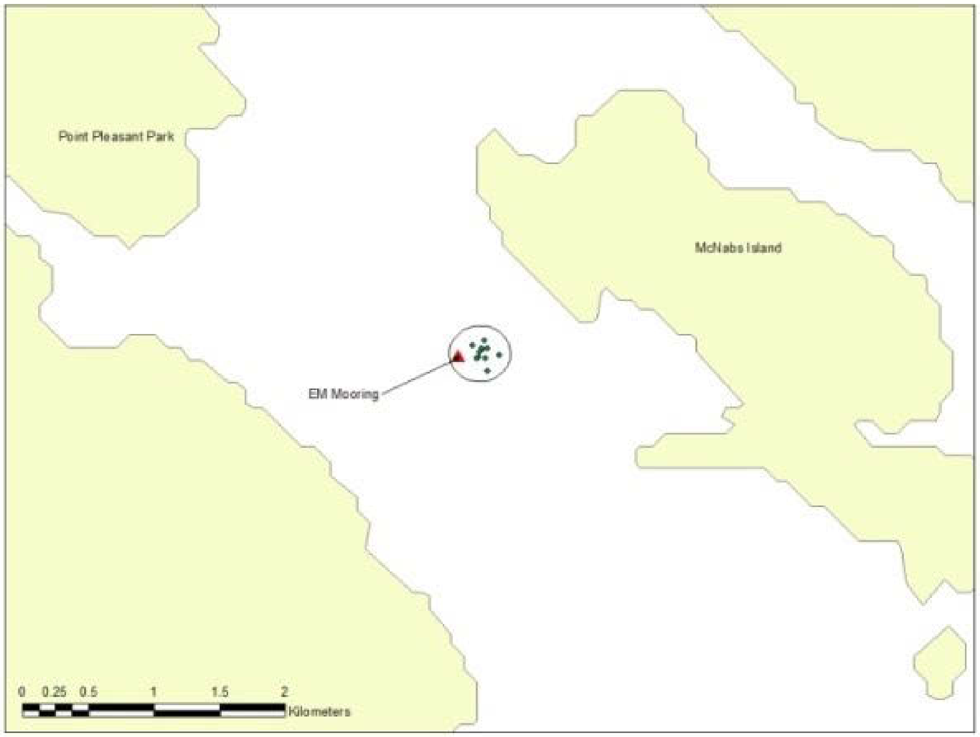

Figure 18: Electrode Array Coverage Area.

7.7 Acoustic Array

The effective coverage area for the Swedish acoustic array was not determined.

8 DATA ANALYSIS

Although the sensors deployed during the SICCPA trial were deployed in standalone configurations, the data analysis was conducted in a manner that treated these sensors as if they were one system. The reason for this was to identify synergies between these sensors that could enhance the detection, tracking and identification of vessels within a harbour environment.

As a starting point, the team wanted to analyze events that occurred when multiple sensors were active. The chart in Figure 19 indicates when each sensor was active during the SICCPA trial. The team was able to select appropriate events to analyze by visually displaying when multiple sensors were active. This allowed the team to ignore events when multiple sensors were not available and to focus on events that had the greatest chance of being detected by all of the sensors.

An analysis of Figure 19 indicates that multiple sensors were online and available on 02 and 03 October 2010. Thus, this is the two day period where the project team has focused its data analysis. All time stamps have been adjusted to Universal Time Coordinated (UTC).

An event was classified as an occurrence where a vessel transited through the trial area and was either detected or not detected. Events were initially identified based on time-stamped photographs captured by the ASIA tracking system. The rationale for this is that a photograph provides conclusive proof that a ship transited through the trial area and it is fairly simple to match the time-stamped photo up against the other sensors to see whether or not the other sensors managed to detect the same event.

However, it was recognized that this approach had a couple of limitations. The first limitation is that if a vessel is not equipped with an AIS transponder (e.g., a small boat) then ASIA would not capture it. The second limitation is occlusion. There were instances where natural and manmade structures or condensation on the camera meant that even though ASIA detected an AIS signal, a useable photograph was not produced that conclusively confirmed the presence of a vessel.

The team then used the ground-truth GPS data from both the NORTHCOM and SIGMA T to identify ‘events’. Given the difficulty in identifying ‘events’ based solely on GPS data, the team matched time-stamped data from both vessels to identify close passes between the two vessels. The data generated by the participating sensors were then checked to see whether or not the sensors detected the occurrence.

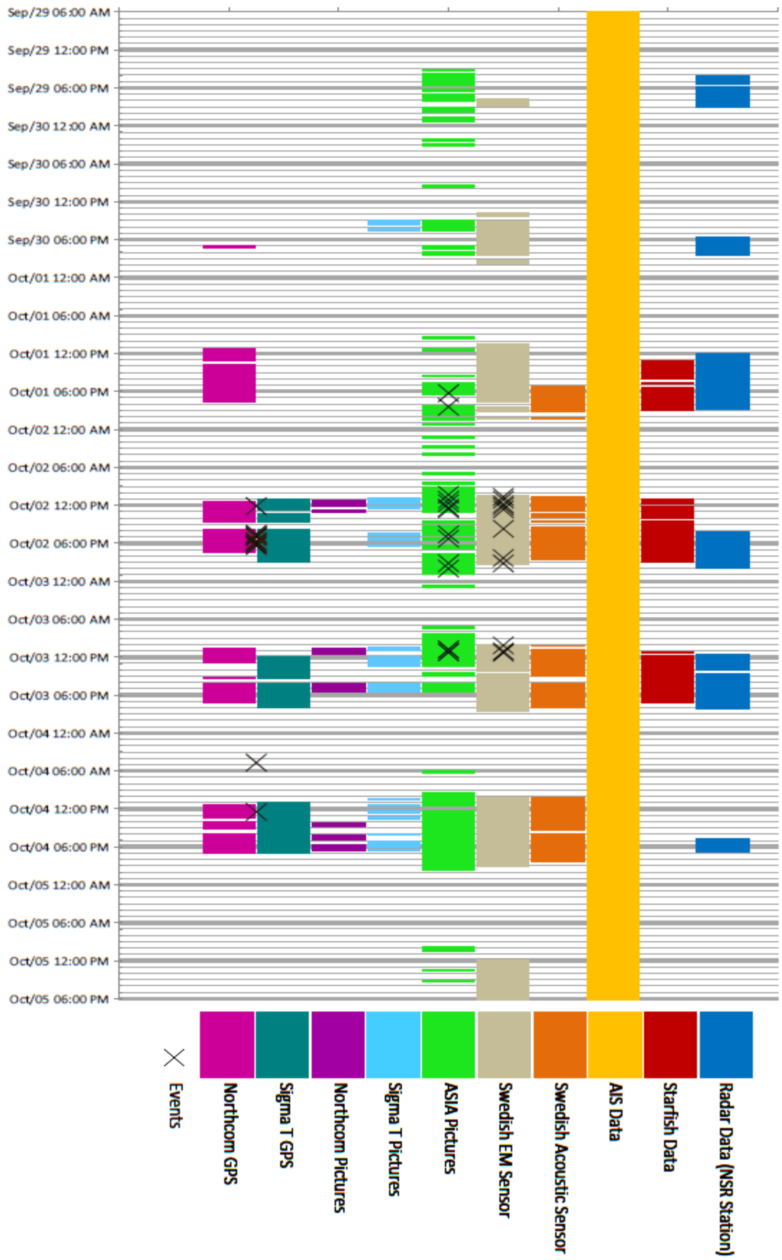

Figure 19: Overlapping Coverage Timeline.

The events selected for analysis provide a sample by which to examine the benefit of deploying overlapping, interacting sensors for small boat detection. These events demonstrate how the sensors interacted to provide a situational awareness picture that would not be achievable, if they were acting in a standalone configuration.

While the team sought to identify and track vessels in its data analysis, it became apparent that detecting vessels with more than one sensor is challenging. As such, the team primarily focused its efforts on vessel detection, with identification and tracking as secondary priorities.

Vessels were detected by the participating sensors in the following way:

- The AIS component of the ASIA camera system provides latitude and longitude information of the detection along with a photograph of the event. The photograph taken by ASIA not only detected a vessel but was a means to clearly identify the vessel under most conditions.
- Radar provides latitude and longitude information of where the event was detected. Radar was useful for detection and tracking, but very limited for vessel identification.
- The Starfish Array provides the bearing of the event relative to the positions of the three starfish nodes. The Starfish Array was useful for vessel detection, but the data recorded at the SICCPA trial were not processed in a way that would facilitate vessel identification or classification. The data were processed to allow the strongest acoustic signal to be tracked in bearing relative to each of the three starfish nodes. The fact that there are three starfish nodes allows for triangulation of the target position. So long as a given ship remains the strongest acoustic signal in range, the Starfish Array can track it. This type of processing can lead to difficulties when there are multiple targets in range at once because different vessels might provide the strongest signal at different times.
- Underwater Acoustic Array data can be represented using a Bearing Time Record (Figure 20). In such a figure, bearings from which louder sounds are coming are annotated by a dark red colour within the heat map. In Figure 20, a vessel track from AIS for the CANADA EXPRESS was overlaid on the Bearing Time Record using magenta dots. The underwater array was useful for detection and tracking (in bearing) but, as with the starfish array, the data were not processed to facilitate vessel classification. The Underwater Acoustic Array data differs from the Starfish Array in that it can follow multiple ships at once (in bearing), but the Underwater Acoustic Array does not allow for triangulation of target position, unless it is used in conjunction with other sensors.

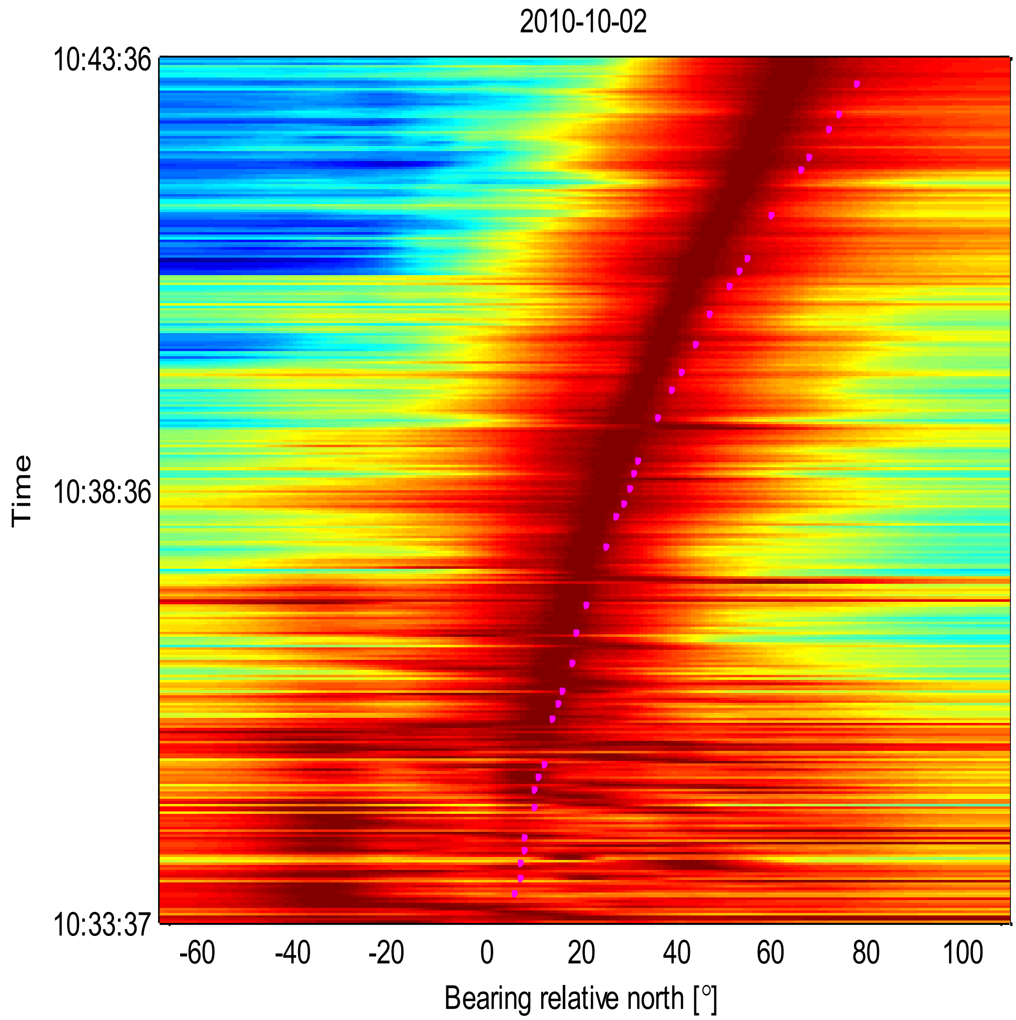

Figure 20: Acoustic Array Heat Map. The pink dots are from the AIS system on CANADA EXPRESS.

Data from the Underwater Electric Array can be represented using the electrical field strength (in V/m) on each of 8 channels (Figure 21). Electric field strengths greater than the threshold level (dashed line in that figure) indicate the presence of ship target. The Electric array was able to detect vessels that transited directly above it, but did not have sufficient range or directional resolution to allow for tracking. It is possible that the pattern of electrical field strengths might allow for target classification or even identification, but this was not attempted here.

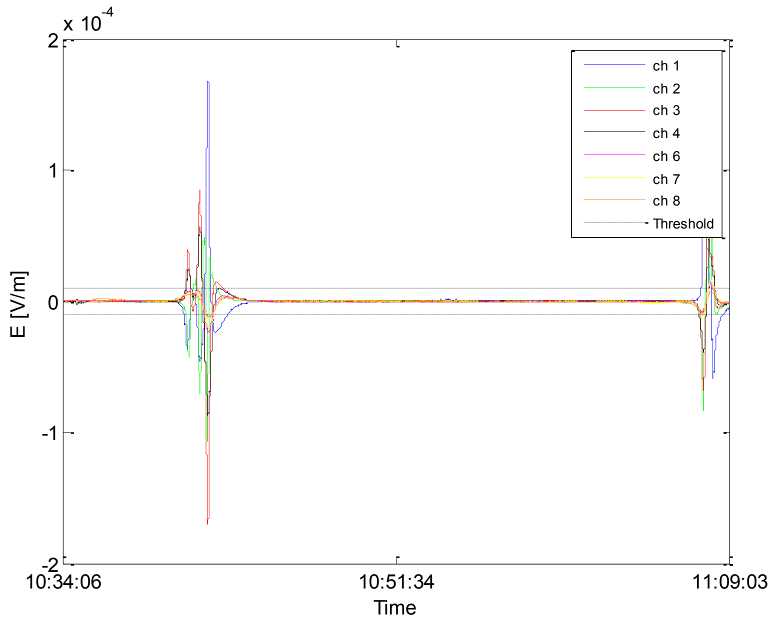

Figure 21: Electrode Array time series of electric field strength over each of the 8 channels.

AIS information (if available) is annotated with identified events. Also, ground truth GPS information of both the SIGMA T and NORTHCOM is included where appropriate.

9 SENSOR INTERACTION DESCRIPTIONS

9.1 An Event-Oriented Analysis

This section consists of eleven separate events identified using the ASIA photographs. These events provide a condensed overview of the SICCPA trial, narrowing it down into a few of the more interesting moments. Most types of surveillance for security purposes entail vast stretches of time during which nothing special happens, interrupted very occasionally (if at all) by short bursts of anomalous activity. These events were chosen (to the extent possible) to mimic such short bursts of more unusual action, though a reader who expects cinematic drama will be disappointed. One of the main challenges of surveillance is to focus human attention, which naturally flags during the long, dull stretches, on such short events. Thus, the reader is invited to imagine that these events involved illicit or dangerous activity (admittedly, some suspension of disbelief is required) and focus on what it would have taken to alert a human operator, whose attention is very likely elsewhere, to the fact that something unusual was happening. Which sensor would contribute most to this? Would alerting have been possible at all? When is it necessary to use a combination of sensors? In this way, this paper hopes to illustrate both the difficulty of dealing with the small boat problem and the extent to which sensor interaction may or may not be able to contribute.

9.2 Event #1

Event Date: 02 October 2010 (17:17:00 UTC).

Figure 22: SIGMA T and NORTHCOM crossing paths.

Event Description

The two trial vessels, SIGMA T and NORTHCOM, are engaging in a crossing pattern in close proximity (Figure 22). This is representative of some of the types of behaviour exhibited by small boats in a harbour environment due to their high manoeuvrability.

How the Sensors Interacted

The event was detected by ASIA, radar, the Starfish Array and the Underwater Acoustic Array. The Underwater Electrode Array did not detect the event. The ground truth data from the GPS sensors on the two vessels is shown in Figure 23, for a ten minute window starting at 17:12:54 UTC (five minutes before the picture in Figure 22).

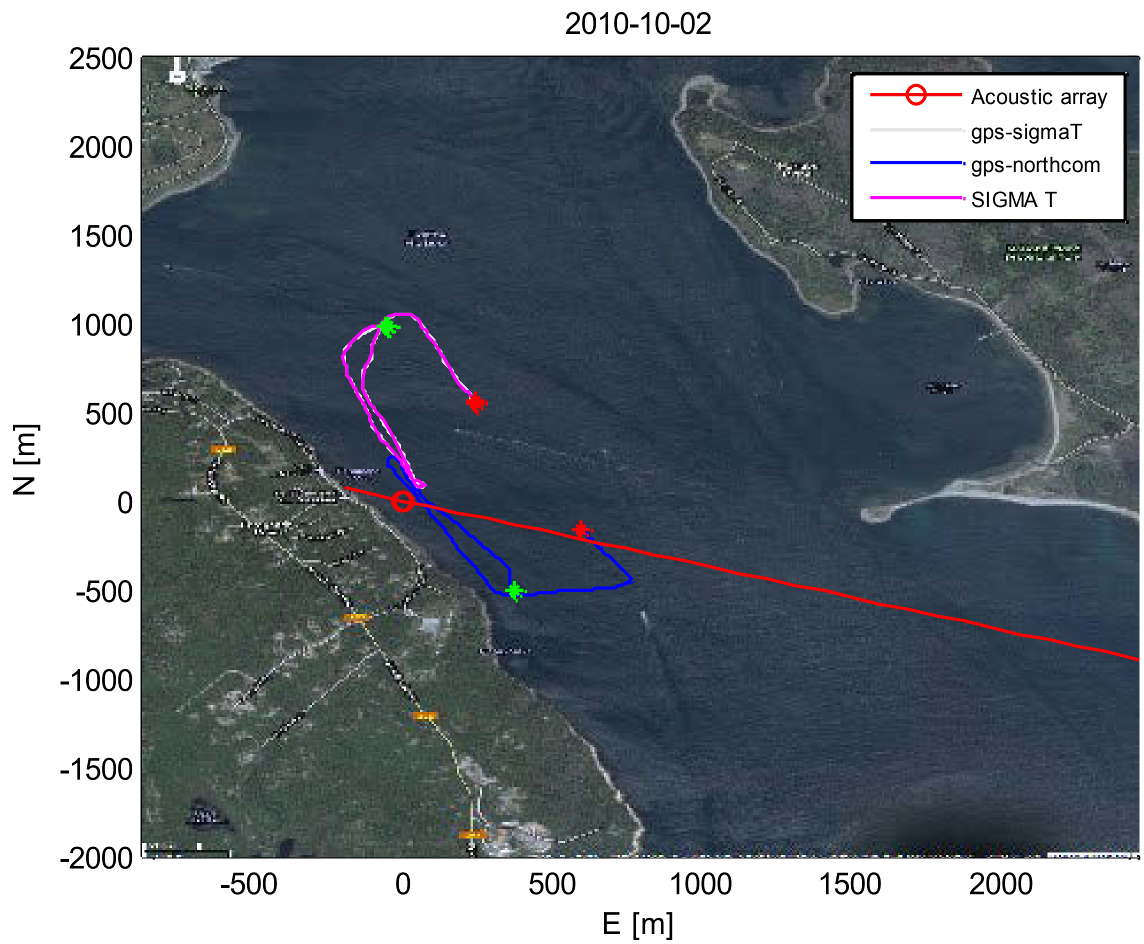

Figure 23: Event #1 GPS Tracking for ten minutes starting at 17:12:54 UTC on October 2nd. A red circle indicates the position of the Swedish array and a dashed line shows its orientation. A green star indicates the start of a track while a red star indicates the end. This figure was produced in Google Earth ®.

Significance

Due to the weather conditions, as well as where the event took place relative to the sensors, the event was detected by the majority of the sensors.

While the radar and underwater sensors were able to detect that an event took place, their data were not processed in a way that would allow an operator to do more than detect that something was happening. Without further signal processing (for example, extracting attributes useful in target classification), these sensors cannot identify the types of vessels involved in an event. The point here is that, from an operator's point of view, sensor capabilities depend not only on sensor characteristics, but on processing decisions about what to present to the operator and what to hide.

The photograph captured by the ASIA camera system was required to provide conclusive information as to what vessels were involved in the event.

While the radar and underwater sensors provide utility, by alerting operators that there is something occurring that may be of interest (see Figure 24), they act mainly as early indicators. A photograph or video serves as a validation sensor and provides more information to operators by identifying what or who is involved, provided that there is sufficient visibility. This additional information allows operators to determine whether or not an event should be responded to.

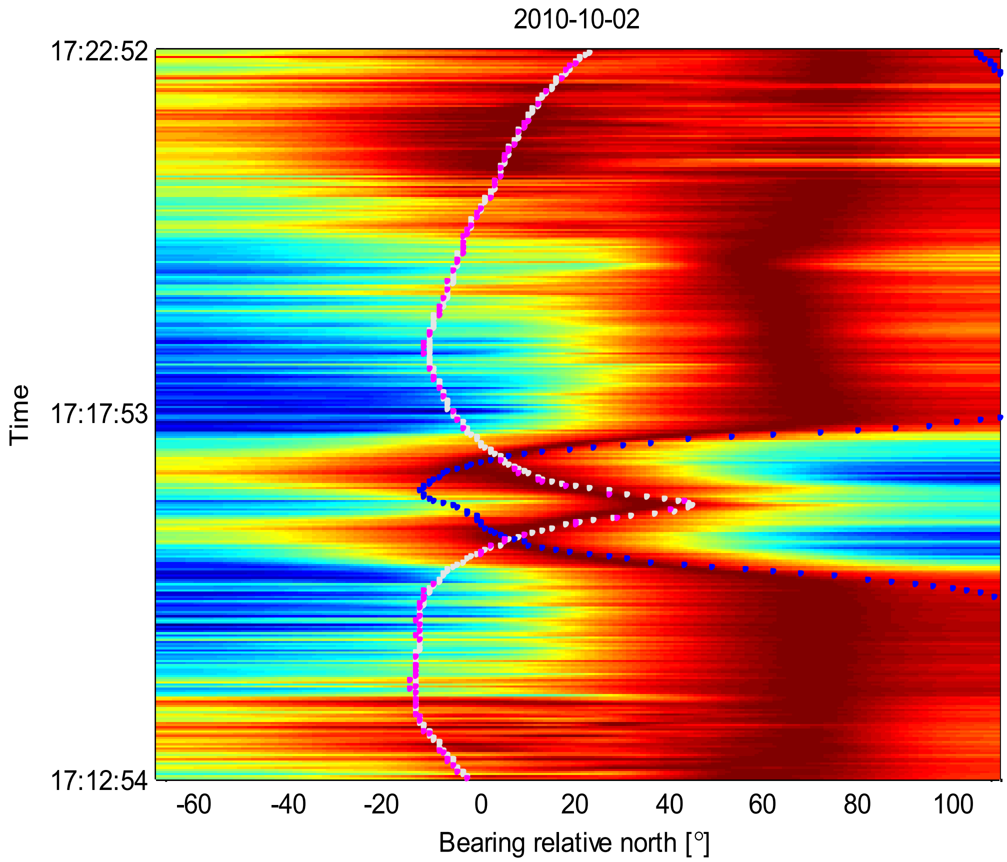

Figure 24: Event #1 Acoustic Bearing Time Record. The pink and white dots are overlaid GPS and AIS data from the SIGMA T, while the blue dots are overlaid GPS data from the NORTHCOM. Darker red areas indicate the direction of strong acoustic signals.

9.3 Event #2

Event Date: 01 October 2010 (18:18:07 UTC).

Figure 25: Two vessels transiting in close proximity. They are the cargo ship CANADA EXPRESS (the target vessel for ASIA) and the pilot boat APA 18.

Event Description

A small vessel is transiting through Halifax Harbour in close proximity to a large container vessel (Figure 25). Small boats often pass close to larger vessels, whether out of curiosity, or, as in this case, in pursuit of their business.

How the Sensors Interacted

The event was detected by ASIA and the Underwater Acoustic Array. Radar, the Starfish Array and the Underwater Electrode Array did not detect the event. Figure 26 gives the GPS and AIS tracks for a ten minute window around the event.

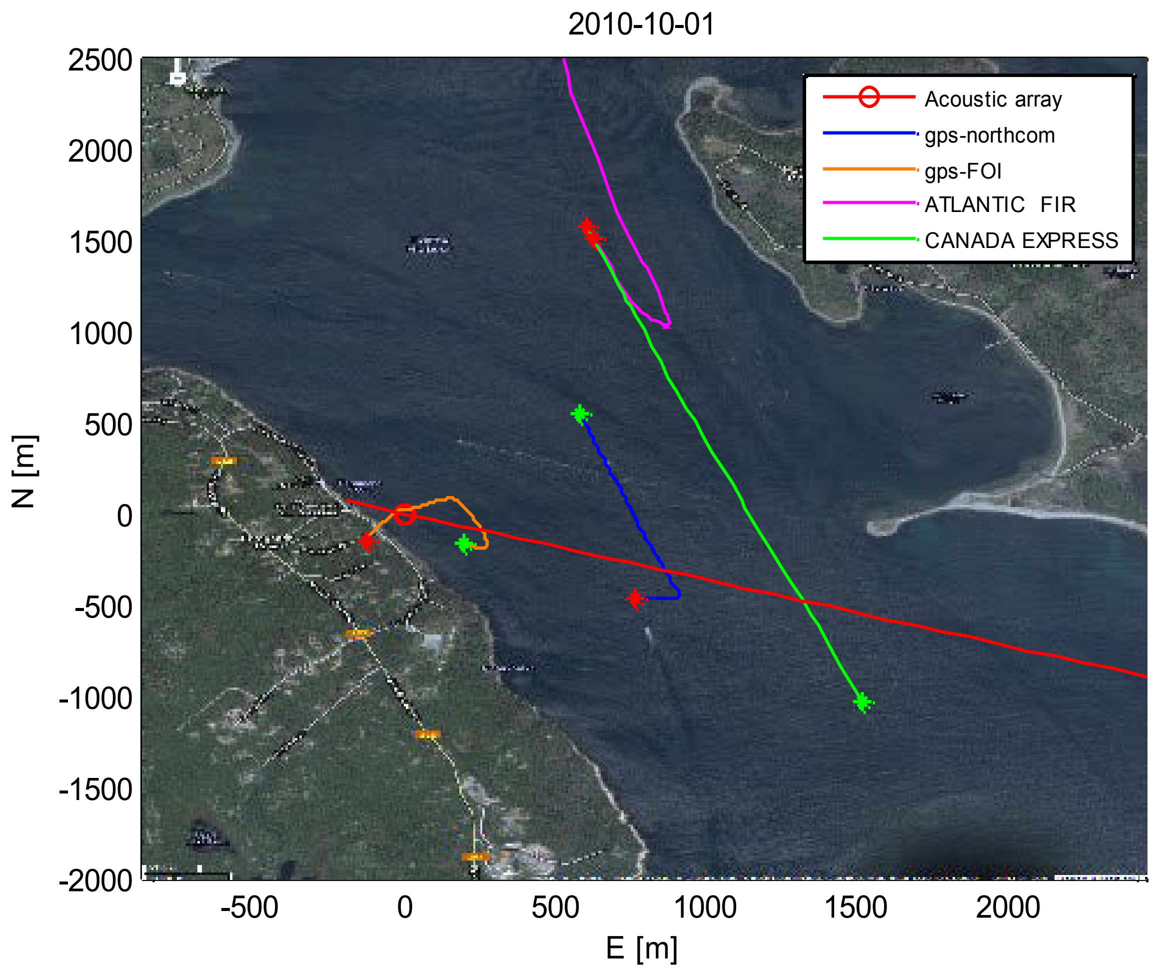

Figure 26: Event #2 GPS and AIS Tracking. The orange 'gps-FOI' track is for a Boston Whaler from the Fleet Diving Unit called FDU04. These tracks are for a ten minute time window starting at 18:16:21 UTC on October 1st. This figure was produced in Google Earth ®.

Significance

This event highlights the utility of overlapping sensors, even though there were technical difficulties. Unfortunately, Radar data were not available from the day of this event (October 1st), because processing of these data concentrated on October 2nd and 3rd.

The event was detected by ASIA but only because of the AIS signal emitting from the CANADA EXPRESS.

Neither the Starfish nor Underwater Electrode Arrays detected the event. The Underwater Acoustic Array managed to detect and track some of the ships involved, as shown in Figure 27. In that figure, however, the strongest acoustic returns (look for the darkest red from FDU04 and ATLANTIC FIR) seem to come from vessels that are not in the ASIA picture at all. The big container vessel CANADA EXPRESS is not really registering in the acoustic signal. This is probably because the FDU04 was driving right over the array at the time, swamping out other signals.

This event reinforces the utility of having more than one type of sensor deployed in an overlapping configuration, as it provides redundancy. If multiple sensors are not deployed in an overlapping manner, there is a danger of not being able to detect, track and identify small boats, if the sensor covering the area is down.

Although ASIA was able to photograph the vessels involved, this would not have been possible in foggy weather, as the fog would obscure the vessels.

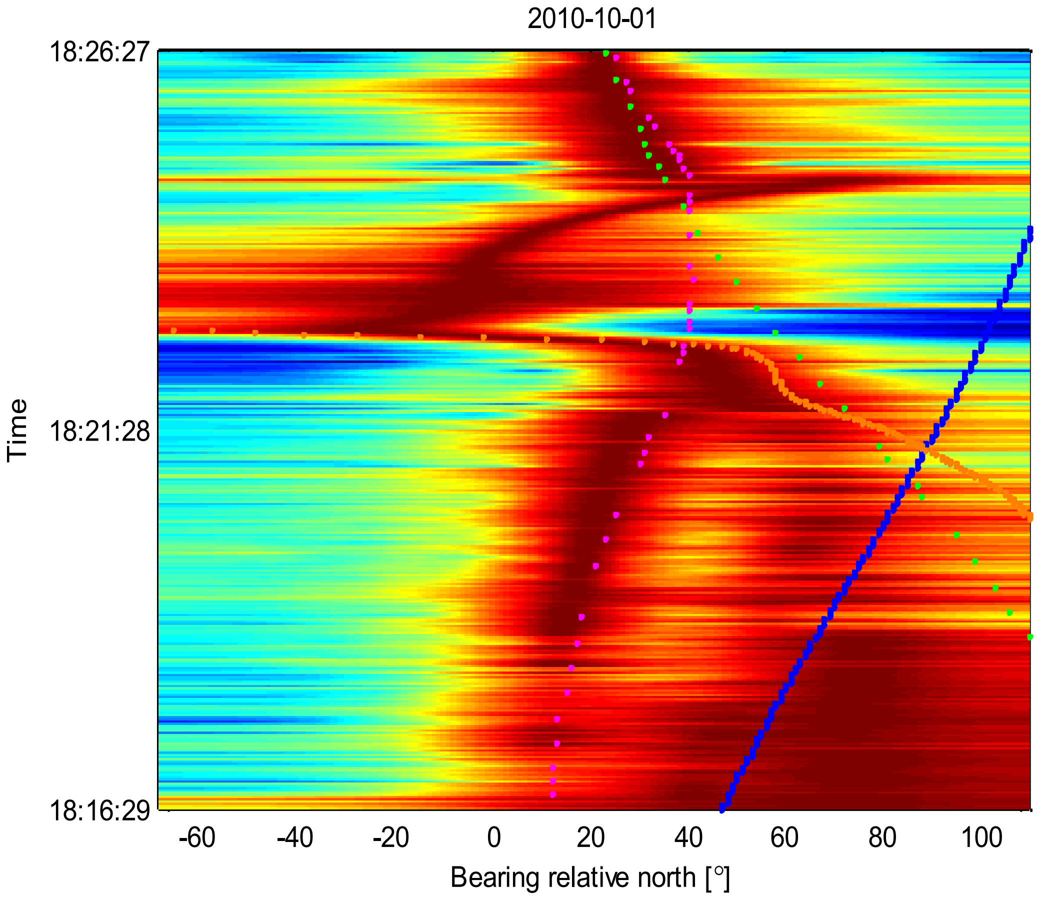

Figure 27: Event #2 Acoustic Bearing Time Record. The path of the CANADA EXPRESS (from AIS) is shown with green dots, while GPS tracks from the NORTHCOM are in blue and from the FDU04 in orange. The pink AIS track is for the ATLANTIC FIR tug boat.

9.4 Event #3

Event Date: 01 October 2010 (20:35:11 UTC).

Figure 28: FUSION being tailed closely by FDU04 (the latter is just appearing at the left edge of the photo). ASIA here is aiming at the FUSION, cutting off her bow slightly.

Event Description

A small vessel is transiting in close proximity to a bulk carrier (Figure 28). This is representative of smaller boats shadowing larger vessels.

How the Sensors Interacted

At the time of the photo, another vessel, namely the pilot boat APA 18 was transiting in the foreground (out of the photo), as indicated in Figure 29. The radar and the Starfish Array did not detect the event (radar data were not processed for October 1^{st}), but the pilot boat is showing up on the Swedish Acoustic Array (Figure 30).

The Underwater Acoustic Array detected the pilot boat APA 18, but not the FUSION (Figure 30). In this event, the Underwater Electrode Array managed to detect the FUSION, when it eventually passed directly over the array (Figure 31).

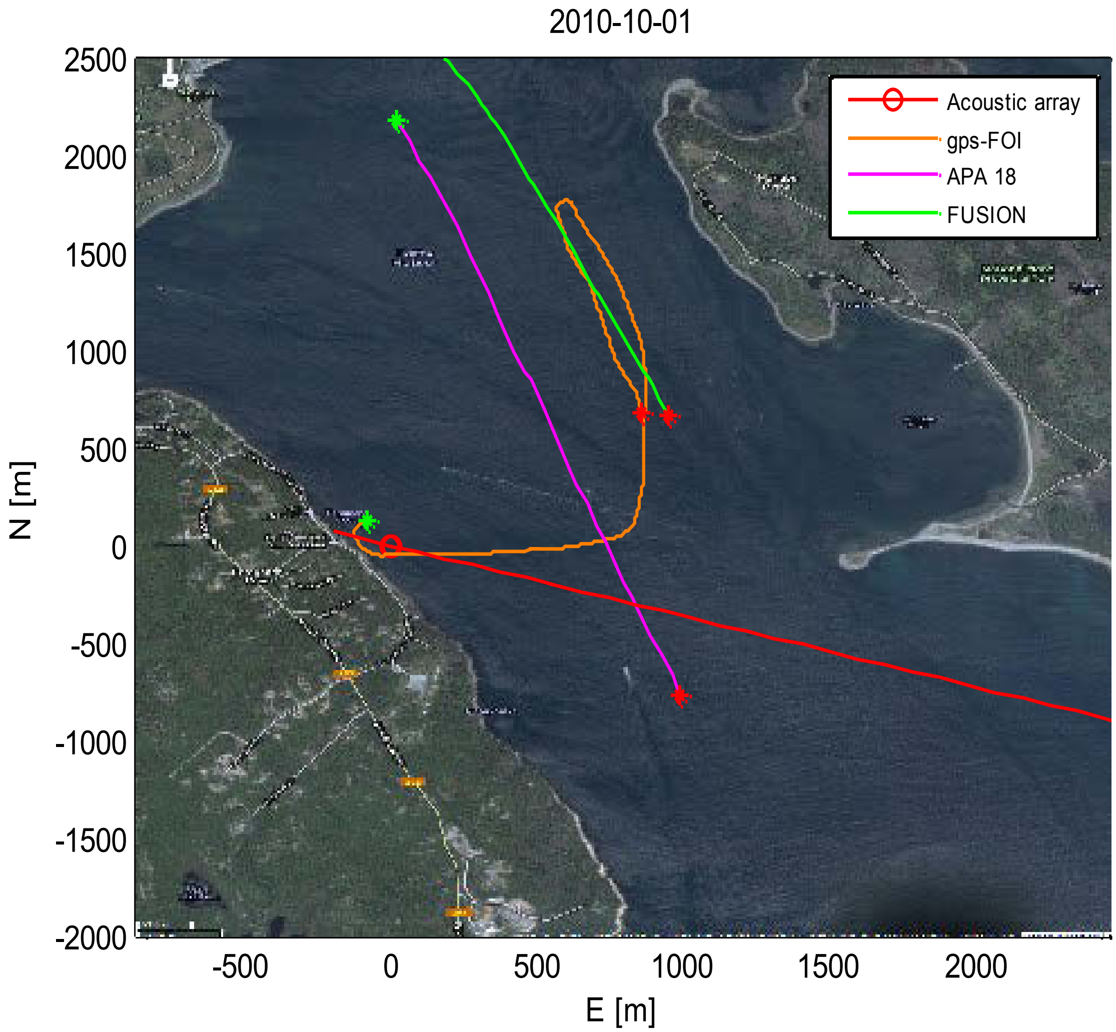

Figure 29: Event #3 GPS and AIS Tracking for a ten minute time window starting at 20:26:29 UTC on October 1st. The 'gps-FOI' track, in orange, refers to the trajectory of the FDU04 dive boat. This figure was produced in Google Earth ®.

Significance

ASIA provided a visual of the event, but that representation did not fully capture what was going on, as the pilot boat went by in the foreground without being seen in the picture. The other sensors in this scenario provide redundancy against limitations such as this.

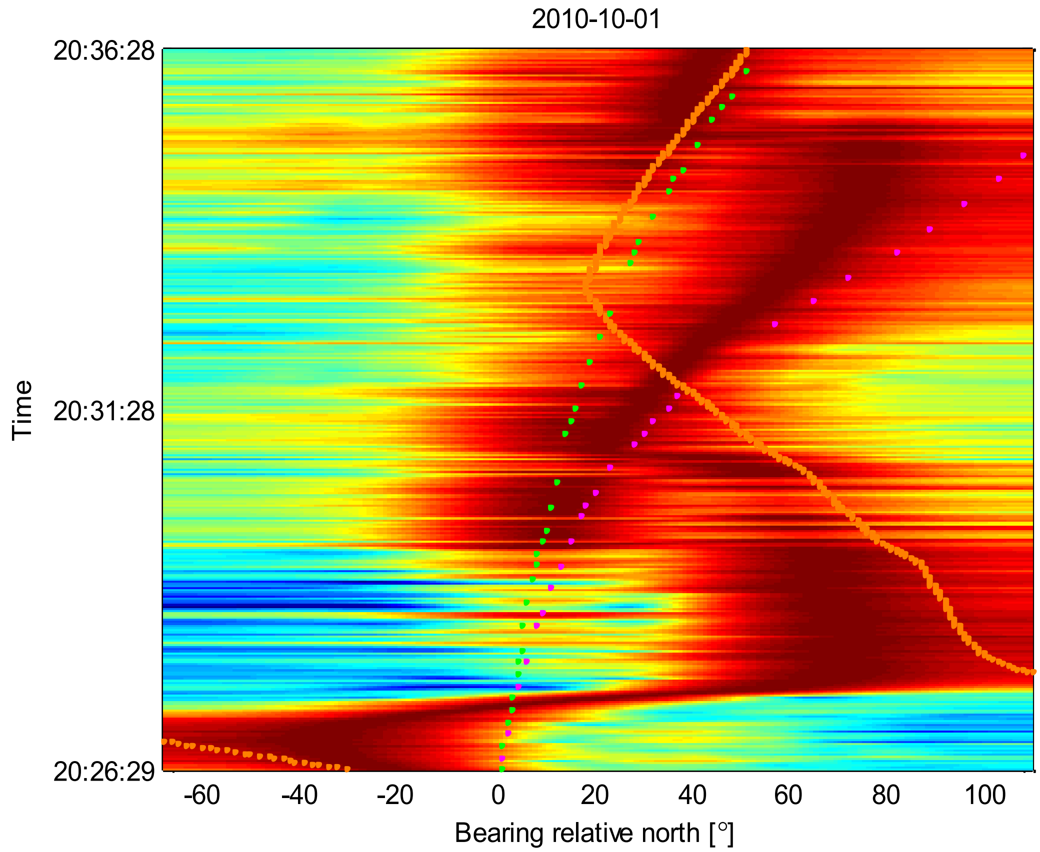

Figure 30: Event #3 Acoustic Detection Bearing Time Record, starting about ten minutes after the photo above. The green dots show the FUSION (from AIS), while the magenta dots show the path of the pilot boat APA 18. The orange dots represent the path of the dive boat FDU04 (from GPS).

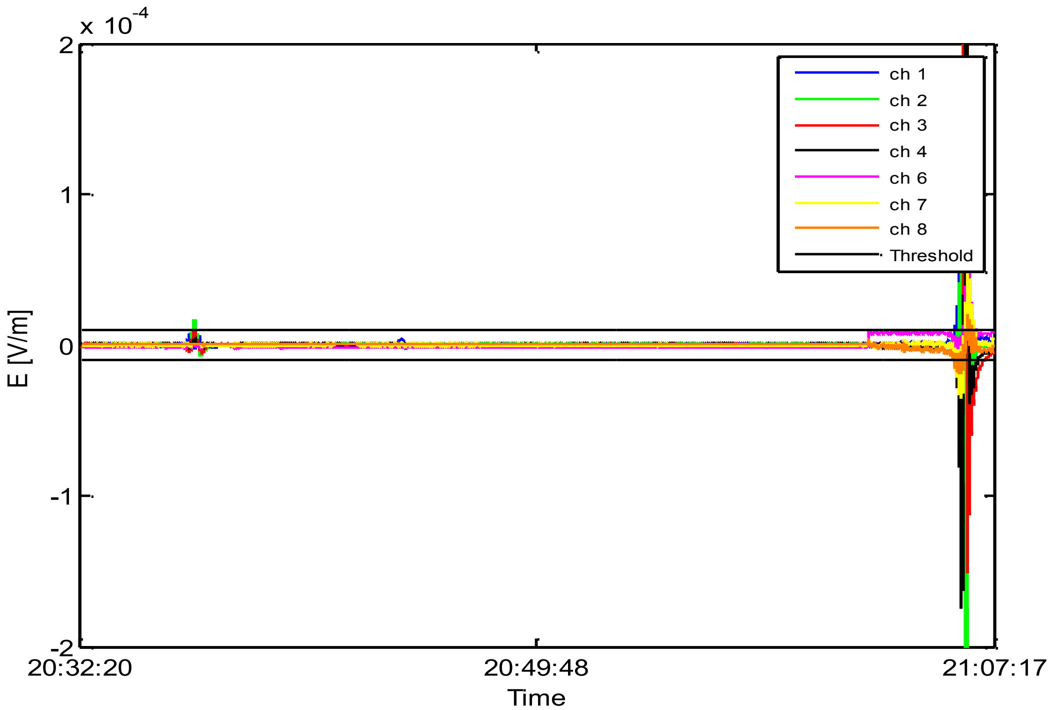

Figure 31: Event #3 Electrode array detection. Here the leftmost electric field spike represents the passage of the FUSION (a fact determined from AIS), while the rightmost spike represents the later passage of the MAERSK CHALLENGER.

9.5 Event #4

Event Date: 02 October 2010 (11:08:58 UTC).

Figure 32: Here the tug boat ATLANTIC FIR is guiding the cruise vessel THE WORLD out of the harbour.

Event Description

A small vessel is transiting in close proximity to a cruise ship (Figure 32). This is representative of smaller boats shadowing larger vessels.

How the Sensors Interacted

The event was detected by ASIA, the Starfish Array, the Underwater Acoustic Array and the Underwater Electrode Array. Radar did not detect the event.

Significance

In this event, the Underwater Electrode Array indicated a single spike for both vessels (Figure 33). According to AIS, both vessels transited almost directly above the Electrode Array's position. The AIS tracks are shown in Figure 34.

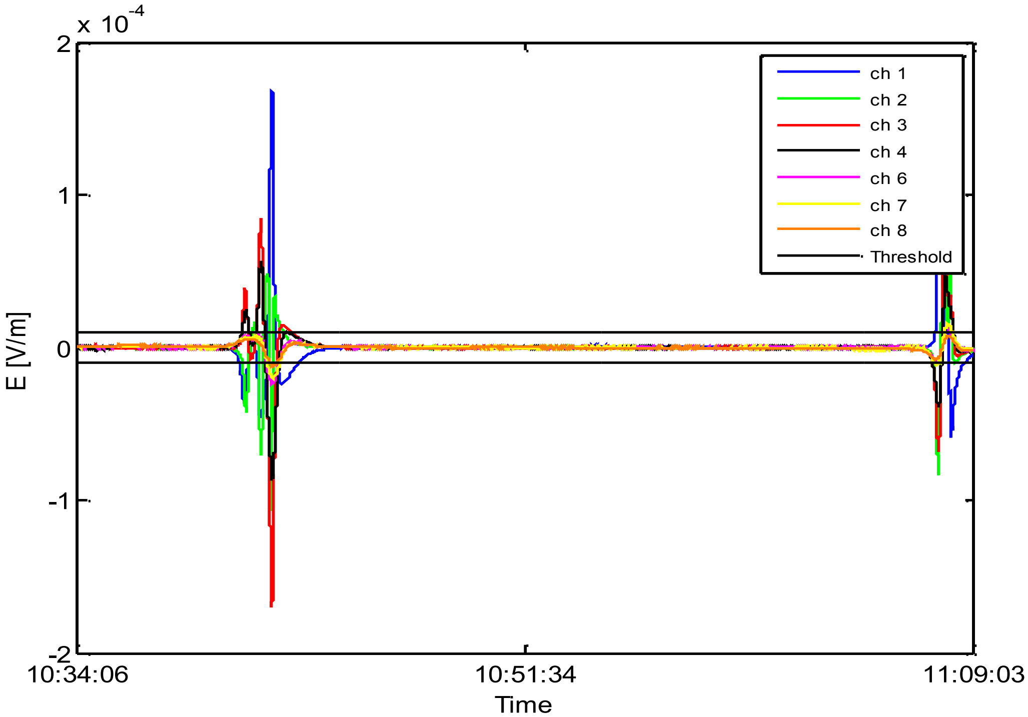

Figure 33: Event #4 Electrode Array Detection. The leftmost spike here is from the passage of the container ship CANADA EXPRESS, while the rightmost spike comes from the passage of THE WORLD (and ATLANTIC FIR).

The downside of the Electrode Array that the team identified is that it is only useful for detecting objects that pass almost directly over it. The electrode array data were not processed in a way that would permit an operator to identify or classify vessels.

The Underwater Acoustic Array managed to detect the event, as did the Starfish Array. Neither was able to determine that there were, in fact, two vessels in close proximity. Given the early detection role of these types of sensors, it may be enough that they are able to alert operators that an event is transpiring that may require their attention.

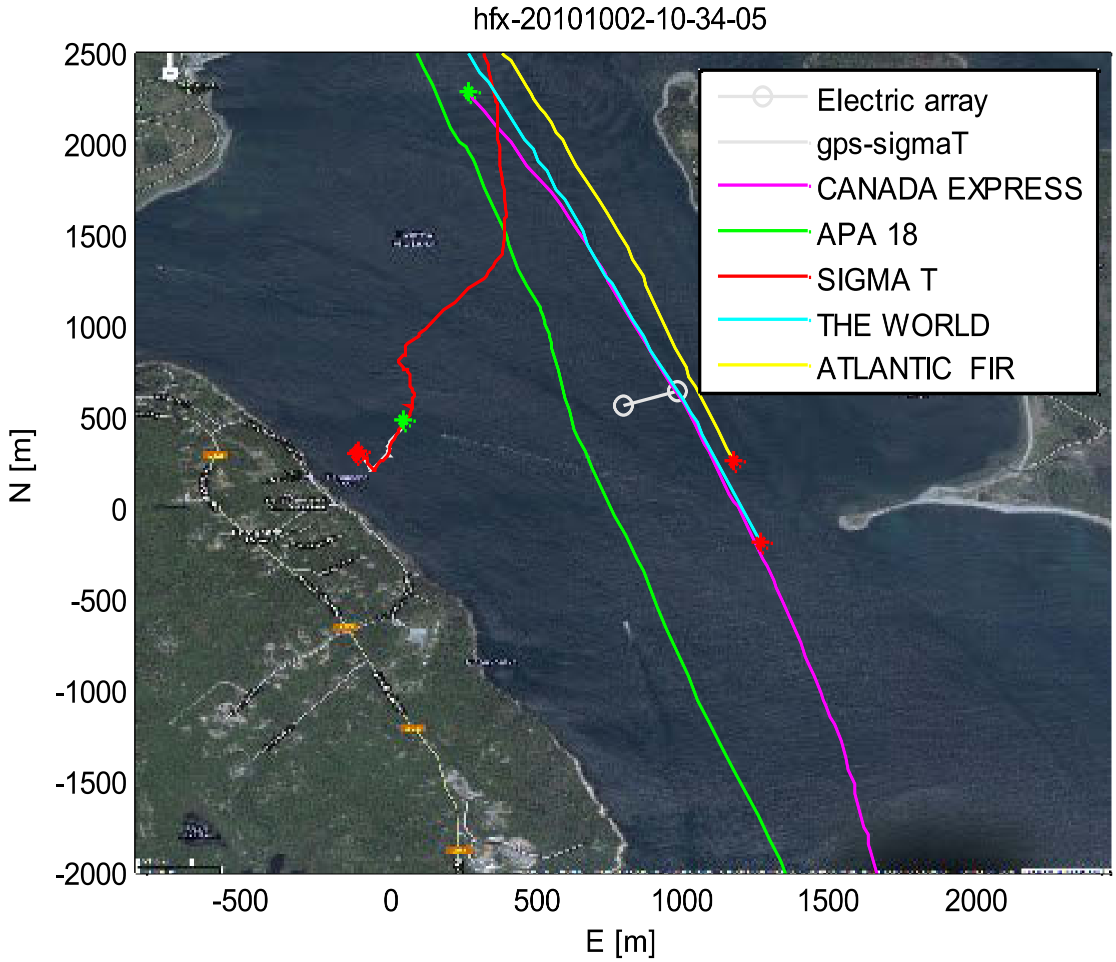

Figure 34: The figure shows GPS and AIS tracks around the time of Event #4, starting at 10:34:05 UTC and continuing until 11:09:03 (the same time period as the previous figure). The container ship CANADA EXPRESS passed through prior to the event photo, as did the pilot boat APA 18. SIGMA T was one of the reference targets. This figure was produced in Google Earth.

ASIA managed to provide a visual of the event; however, the ATLANTIC FIR is occluded by THE WORLD. This makes it difficult to detect, identify and track with a camera.

The other sensors in this scenario provide redundancy against limitations of optical sensors, such as occlusion and relatively poor visibility.

9.6 Event #5

Event Date: 02 October 2010 (11:40:46).

Figure 35: SIGMA T being tailed closely by NORTHCOM.

Event Description

The NORTHCOM is trailing closely behind the SIGMA T. This is representative of some of the types of behaviour exhibited by small boats in a harbour environment due to their high manoeuvrability.

How the Sensors Interacted

The event was detected by ASIA, the Starfish Array and the Underwater Acoustic Array. Radar and the Underwater Electrode Array did not detect the event. The radar was not turned on at the time.

Significance

Both ASIA and the underwater acoustic array managed to detect and track the SIGMA T and NORTHCOM, as they manoeuvred in the Halifax Harbour approaches. The graphic in Figure 36 shows the GPS track for the NORTHCOM (blue dashes) as it trailed the SIGMA T (white dashes). Figure 37 shows the acoustic tracks in darker shades of red.

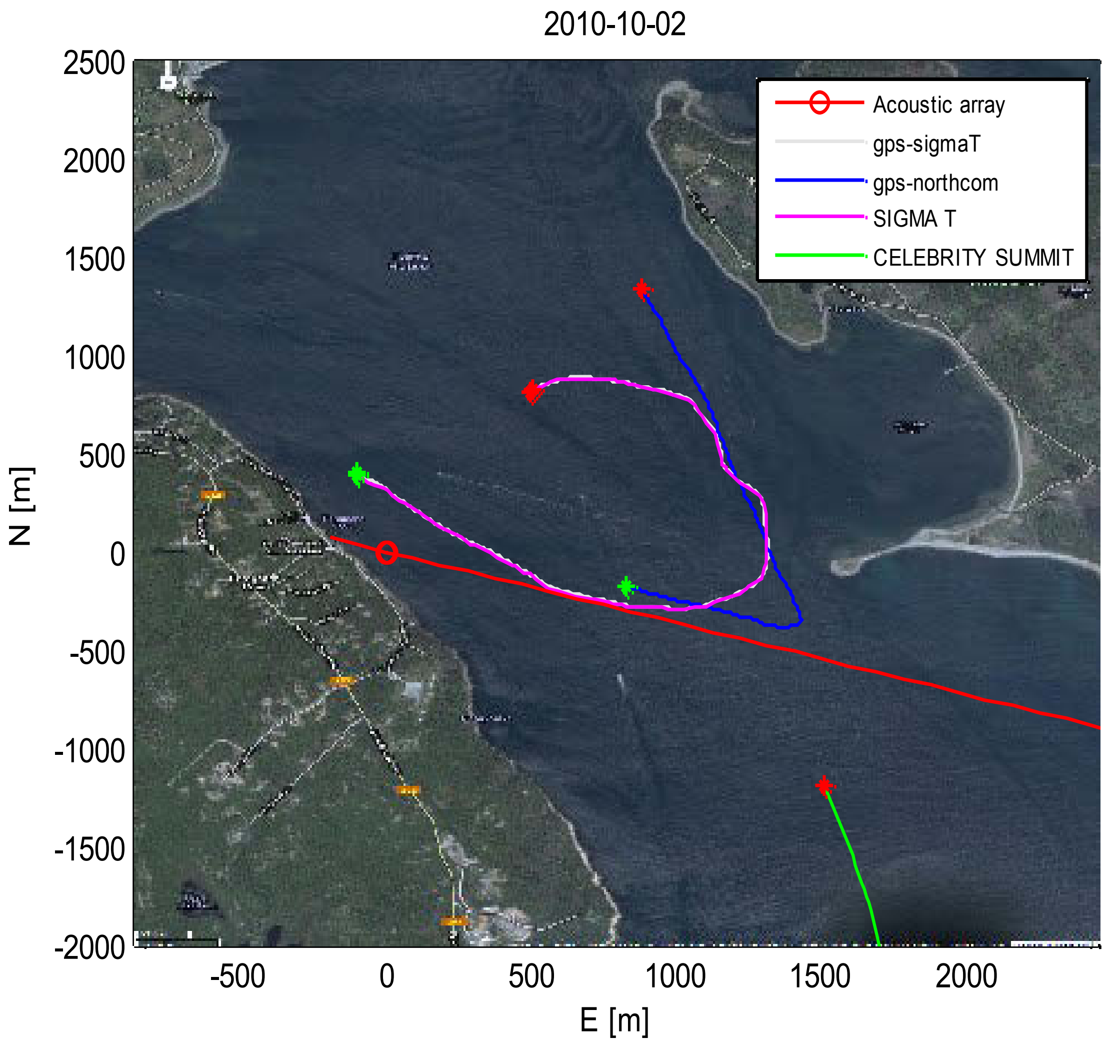

Figure 36: Event #5 AIS and GPS Tracking for a ten minute time window starting at 11:33:36 UTC on October 2nd. This figure was produced in Google Earth ®.

ASIA clearly identified the SIGMA T and NORTHCOM to anyone familiar with these vessels, but someone unfamiliar with them would certainly not have been able to read their names from the photo in Figure 35, although SIGMA T is clearly a coast guard vessel. Thus, identification of ships is related to both the sensor data and the knowledge of the operator.

This event reinforces the utility of networking sensors into an interacting system, as the synergies created by sensor groups compensate for individual sensor limitations. Integrated systems create the capability of detection, tracking and identification.

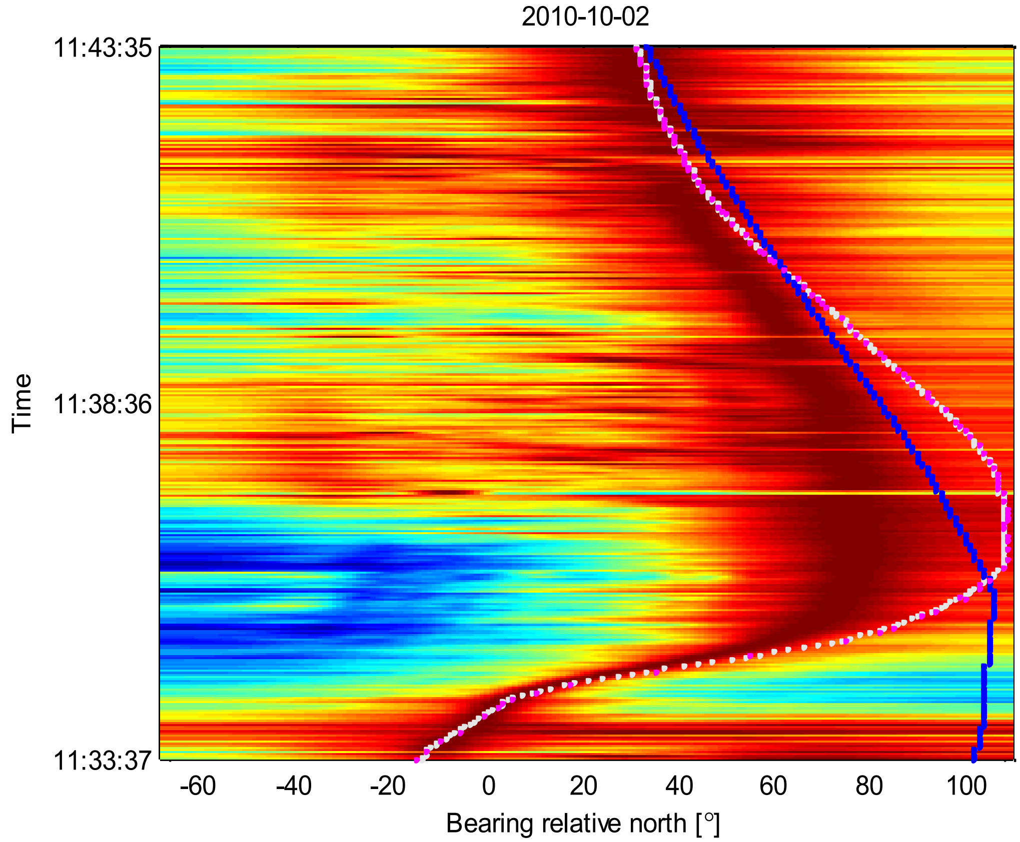

Figure 37: Event #5 Acoustic Detection Bearing Time Record. The blue dots are from the NORTHCOM, and the white dots are from the SIGMA T. It seems the SIGMA T track is not resolved from that of the NORTHCOM after the 11:35 mark.

9.7 Event #6

Event Date: 02 October 2010 (12:41:40 UTC).

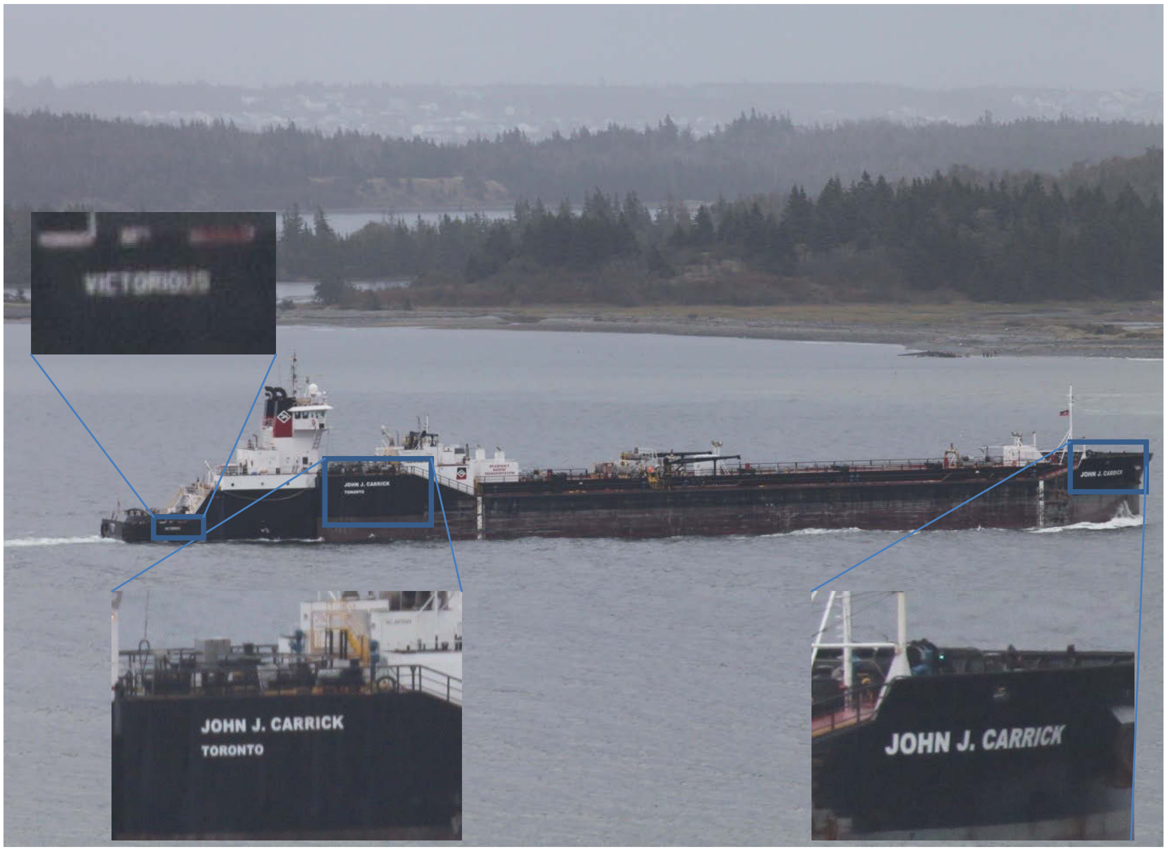

Figure 38: In this figure, an operator might well imagine that this vessel is the JOHN J CARRICK because of the name printed on the side and bow. AIS, however, identifies this ship as the VICTORIOUS (and so ASIA associates this name with the ship). The discrepancy has an innocent explanation because the ship also shows the name VICTORIOUS, somewhat inconspicuously, in very small letters near the stern.

Event Description

A vessel is reporting a name by AIS (Figure 38) that does not match the name that is most conspicuously painted on the vessel.

How the Sensors Interacted

The event was detected by ASIA, the Starfish Array, the Underwater Acoustic Array and the Underwater Electrode Array. The Radar was not operating at the time. The red dashed track in Figure 39 shows the trajectory of the vessel targeted in Figure 38.

Figure 40 shows the electrode array detection and Figure 41 shows the acoustic bearing time record for the event.

Significance

AIS is not guaranteed to report the truth, and checking what is reported on AIS against imagery, or other sensors and information sources, is an important safeguard against spoofing.

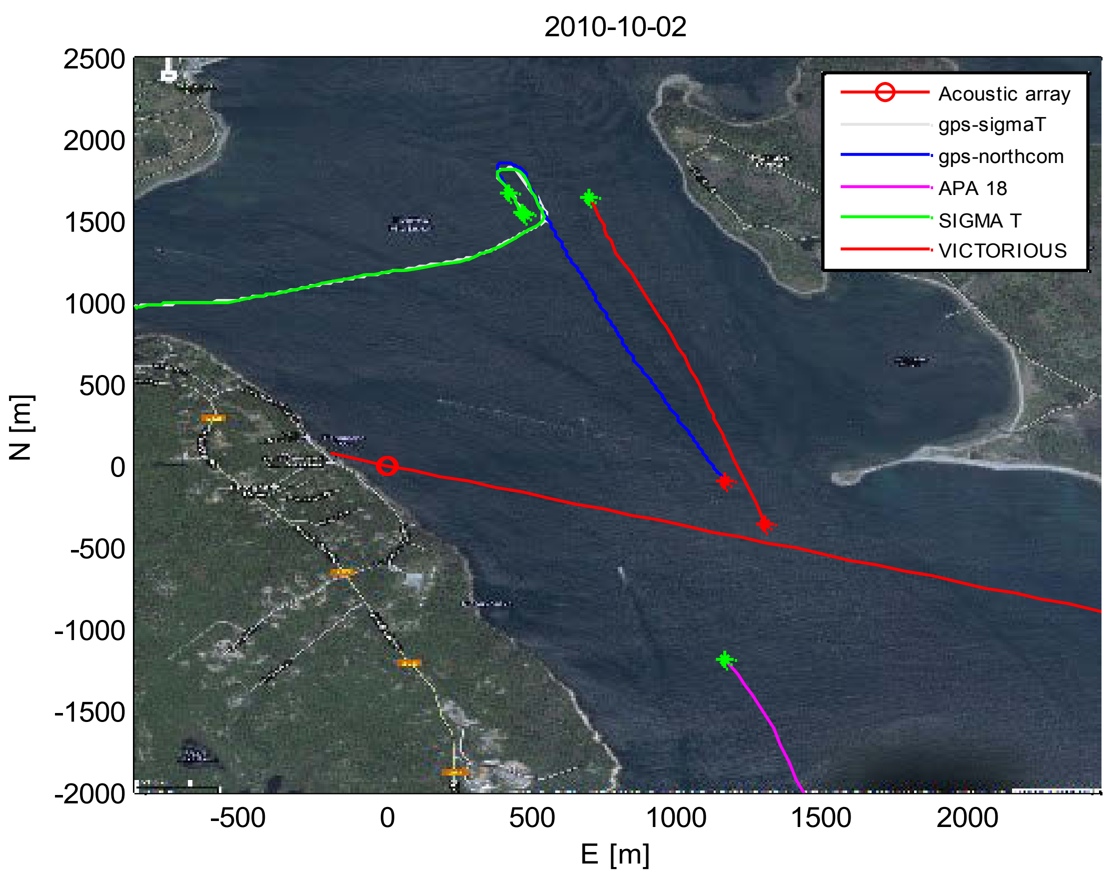

Figure 39: This figure shows GPS and AIS tracks for a ten minute window starting at 12:33:46 UTC. There is no AIS track for the JOHN J CARRICK, but there is one for VICTORIOUS. This figure was produced in Google Earth ®.

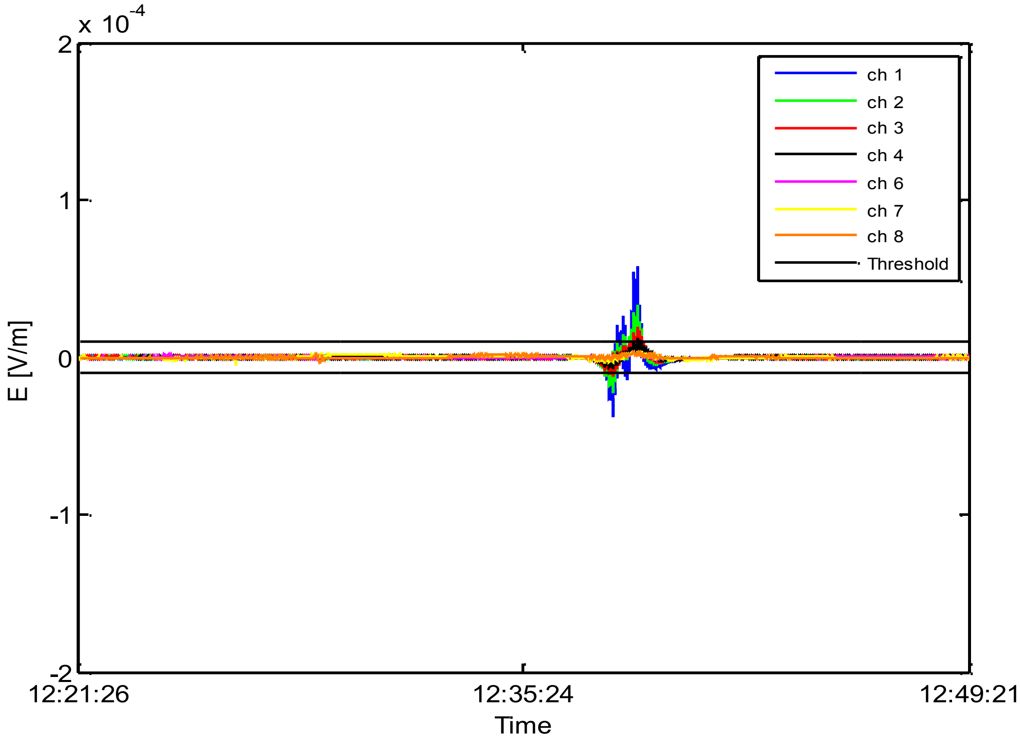

Figure 40: Event #6 Electrode Array Detection. The time of the electrical field spike is consistent with the passage of VICTORIOUS.

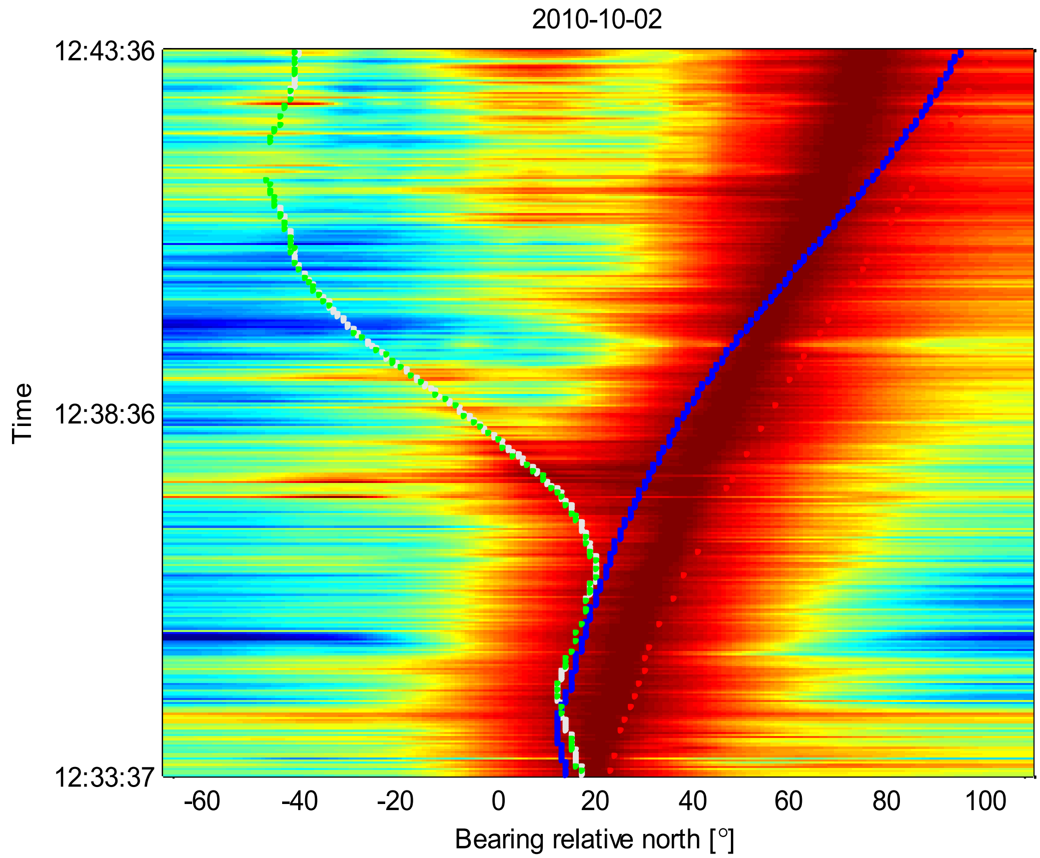

Figure 41: Acoustic Bearing Time Record overlaid with AIS tracks shown as dots. The red dots are from the VICTORIOUS, the blue from NORTHCOM, and the pale green from SIGMA T.

9.8 Event #7

Event Date: 02 October 2010 (16:35:53 UTC).

Figure 42: SIGMA T amongst several sailboats.

Event Description

The SIGMA T is transiting in close proximity to several sail boats (Figure 42). This is representative of the high concentration of pleasure craft in Halifax Harbour during the summer months. As shown in Figure 43, these small boats are generally not transmitting on AIS.

How the Sensors Interacted

The event was detected by ASIA, and the Underwater Acoustic Array (Figure 44). One node on the Starfish Array managed to detect the event. Radar and the Underwater Electrode Array did not detect anything (radar data were available).

Significance

This event demonstrates the difficulty of effectively detecting small, non-motorized vessels in the marine environment. Since sail boats are small, often built out of fibreglass rather than steel, and may or may not be operating using their engines, it presents a real challenge for widely-used, commercial sensors to detect them.

The only reason that ASIA managed to capture the sail boats was due to the AIS transponder signal of the SIGMA T in relation to the sail boats. If the SIGMA T were not in the area, then it is unlikely that the sail boats would have been detected.

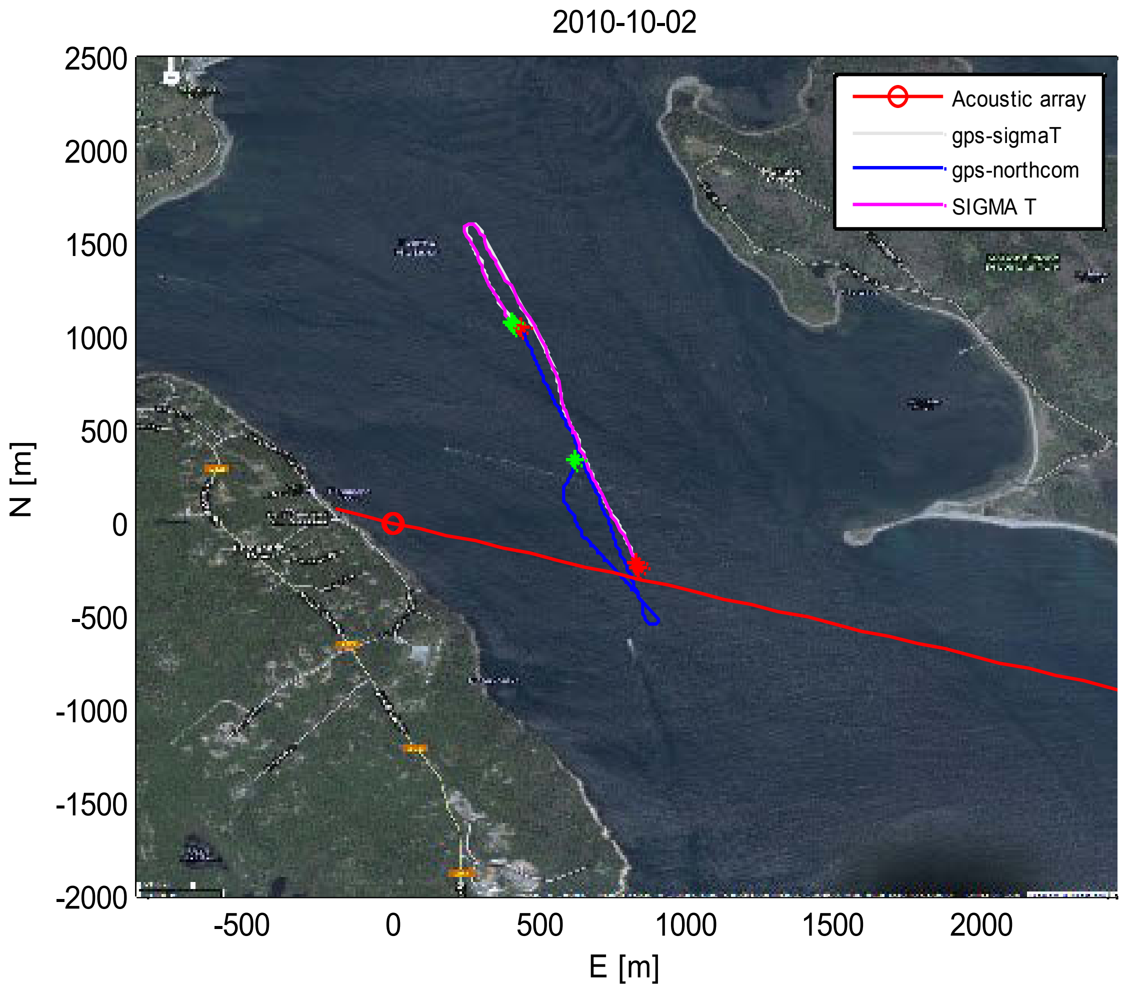

Figure 43: Event #7 GPS and AIS Tracking. This figure is for a ten minute window starting at 16:32:52 UTC. The sailboats from the event photograph are not transmitting on AIS. This figure was produced in Google Earth ®.

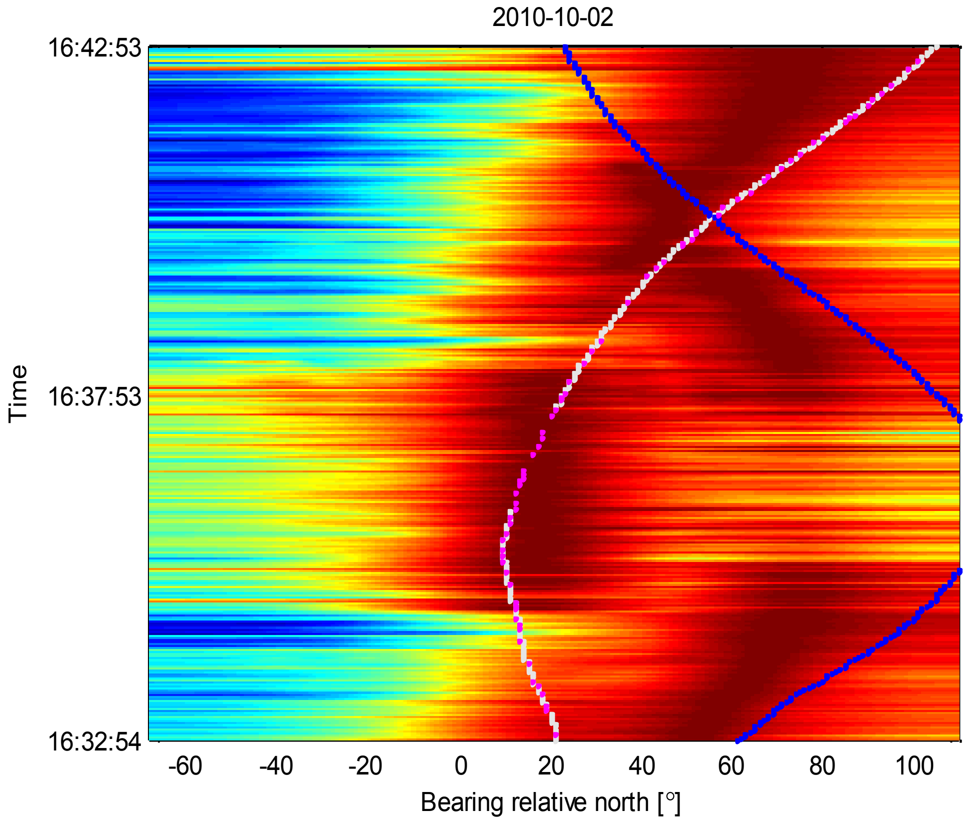

Figure 44: Acoustic Bearing Time Record overlaid with AIS tracks shown as dots. The blue dots are from NORTHCOM, and the pink and white ones from SIGMA T.

9.9 Event #8

Event Date: 02 October 2010 (21:10:23 UTC).

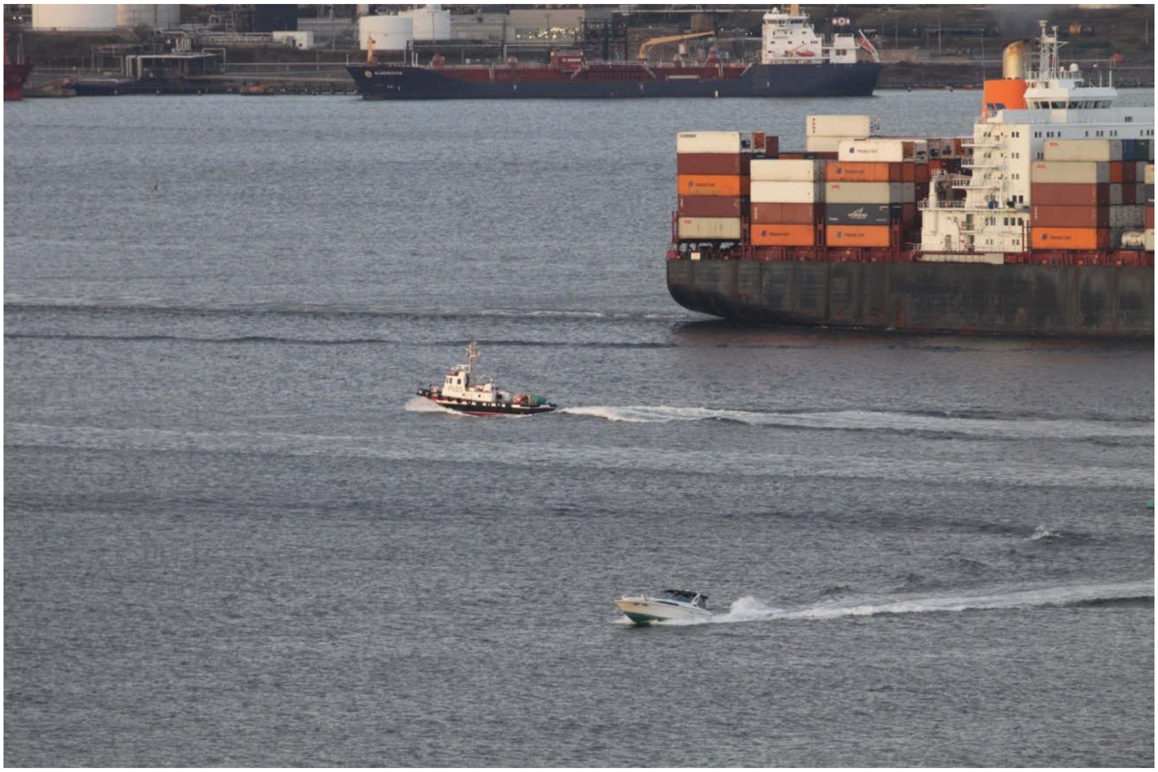

Figure 45: Small vessels in close proximity to a container ship. Here ASIA is targeting the pilot boat APA 18. The container vessel is the LEVERKUSEN EXPRESS. The motorboat in the foreground remained unidentified.

Event Description

Small vessels are in close proximity to a container ship (Figure 45). Figure 46 gives the AIS tracks for a ten minute time window containing the event photo.

How the Sensors Interacted

The event was detected by ASIA, radar and the Underwater Electrode Array (Figure 47). The Starfish Array and the Underwater Acoustic Array did not detect the event.

Significance

Typically, the Underwater Acoustic Array was highly reliable and managed to detect vessels regularly, but it was switched off for the night just prior to the completion of this event.

The radar and Underwater Electrode Array managed to detect the event with the radar being able to track the vessels.

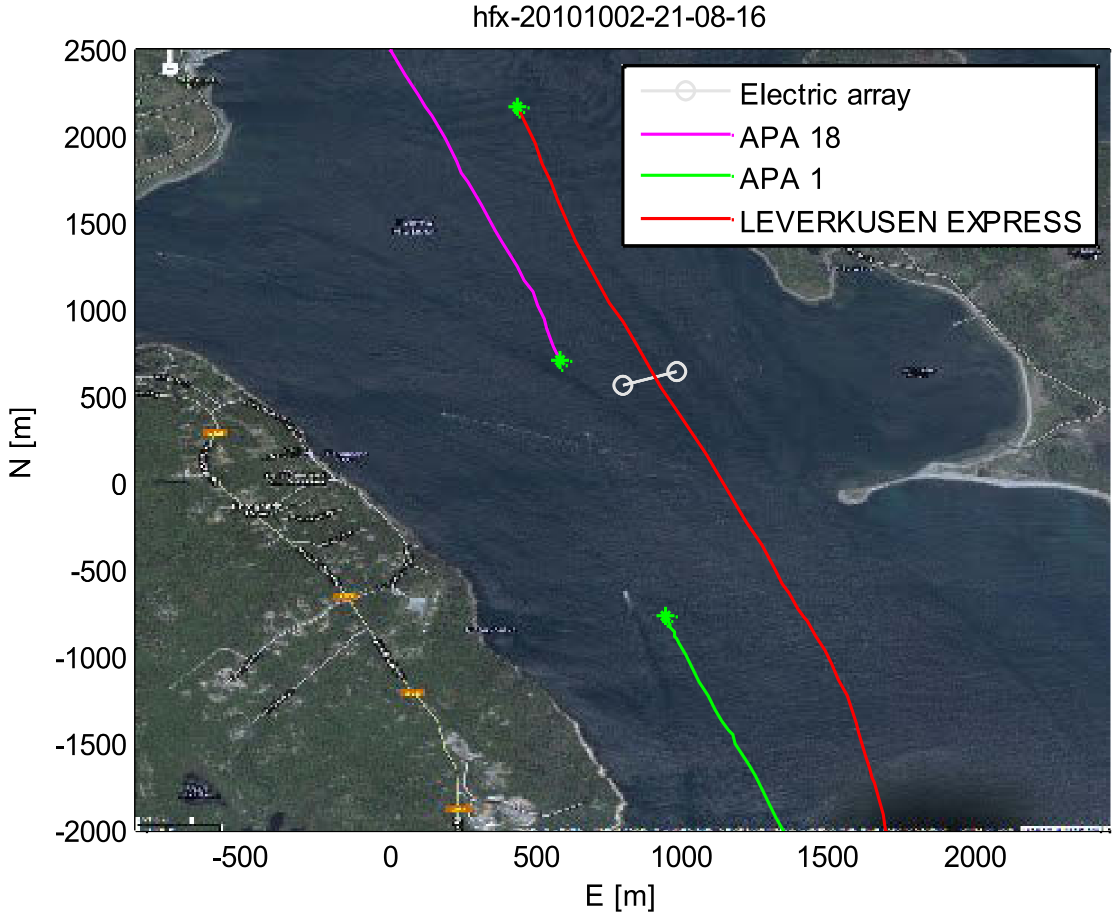

Figure 46: Event #8 AIS tracks from 21:08:17 UTC until 21:19:52 UTC. The LEVERKUSEN EXPRESS goes right over the Electrode Array. This figure was produced in Google Earth ®.

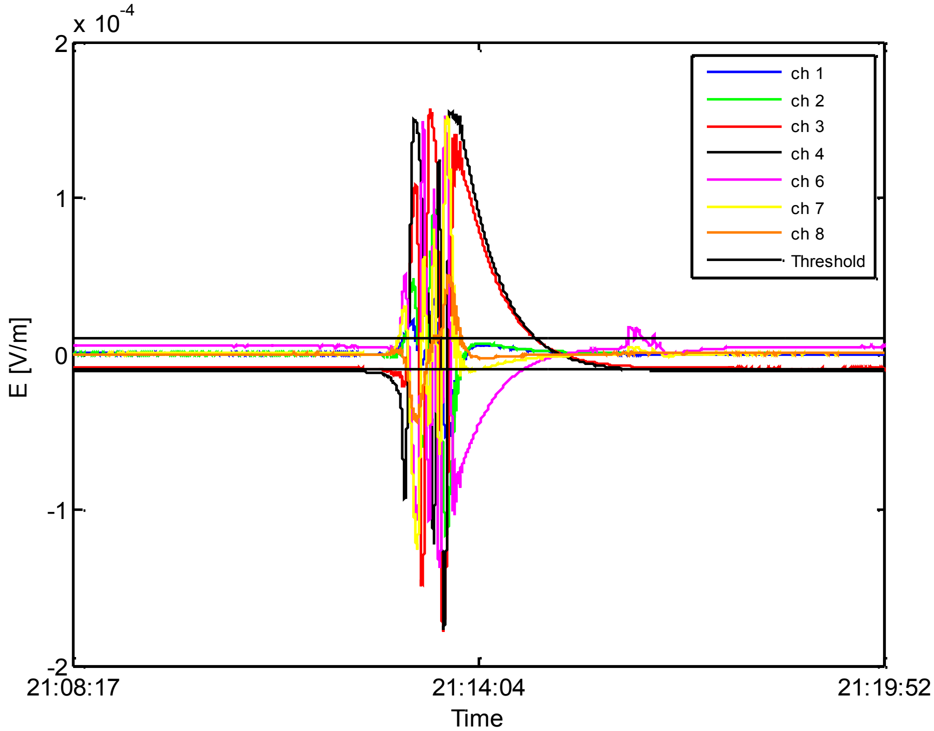

Figure 47: Event #8 Electrode Array Detection.

9.10 Event #9

Event Date: 03 October 2010 (10:48:44 UTC).

Figure 48: SIGMA T in close proximity to the tanker VINLAND (labelled PENNEY UGLAND).

Event Description

The SIGMA T is transiting in close proximity to the tanker VINLAND (Figure 48). This is representative of close passes by small boats in Halifax Harbour to tankers at the Imperial Oil refinery (see Figure 14 for the refinery location).

How the Sensors Interacted

The event was detected by ASIA, but there were few other AIS tracks at the time (Figure 49). Radar, the Starfish Array, the Underwater Acoustic Array and the Underwater Electrode Array did not detect the event.

Significance

This event took place outside of the SICCPA trial area, so the underwater sensors and radar did not detect the event.

Ideally, radar would have picked up the SIGMA T as a way of supplementing ASIA in case of inclement weather such as heavy rain, snow and fog. If the weather were inclement at the time of this event, then it is unlikely that ASIA would have identified the SIGMA T and the VINLAND and this event would have gone unnoticed.

This event further reinforces the need for multiple sensors in order to obtain a degree of redundancy within a harbour surveillance regime to guard against adverse weather conditions that may impact sensor functionality.

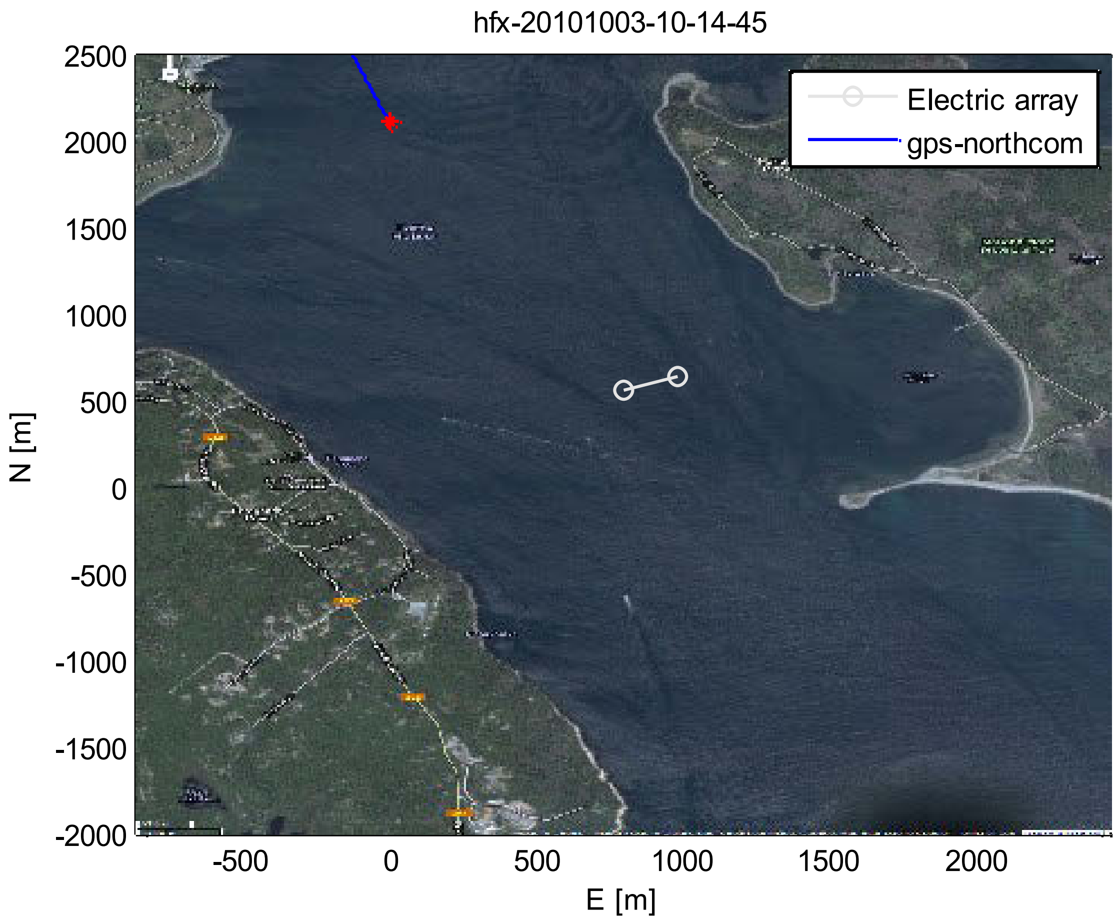

Figure 49: Event #9 AIS Tracking from 10:14:45 UTC until 10:49:42 UTC. The NORTHCOM is incoming from the north. This figure was produced in Google Earth ®.

9.11 Event #10

Event Date: 03 October 2010 (11:11:43 UTC).

Figure 50: The pilot boat APA 18 passes in close proximity to the cruise ship ARCADIA.

Event Description

In Figure 50, a small vessel is transiting in close proximity to a cruise ship. Figure 51 shows the AIS tracks for a time interval containing the event photo. This event is representative of smaller boats shadowing larger vessels.

How the Sensors Interacted

The event was detected by ASIA and the Underwater Acoustic Array. Radar, the Starfish Array, and the Underwater Electrode Array (Figure 52) did not detect the event.

Significance

The Underwater Acoustic Array detected the event, at least for part of the time (Figure 53). The pilot boat APA 18 was tracked over some of its passage. Given the early detection role of these types of sensors, it may be enough that they are able to alert operators that an event is transpiring.

ASIA provided a visual representation of the event. Again, the other sensors in this scenario provide redundancy against limitations of optical sensors such as occlusion, poor visibility and weather.

The Starfish and Underwater Electrode arrays failed to detect the passage of APA 18, at least for part of the time. Of particular note is that the electrode array did not detect anything, despite the fact that the pilot boat APA 18 passed immediately above its position. Note that the pilot boat is relatively small, as can be seen in Figure 50. The detection threshold used for the electrode array was selected so that all bigger ships are detected but no false detections were made throughout the trial period. So the detector was tuned not to detect this type of boat.

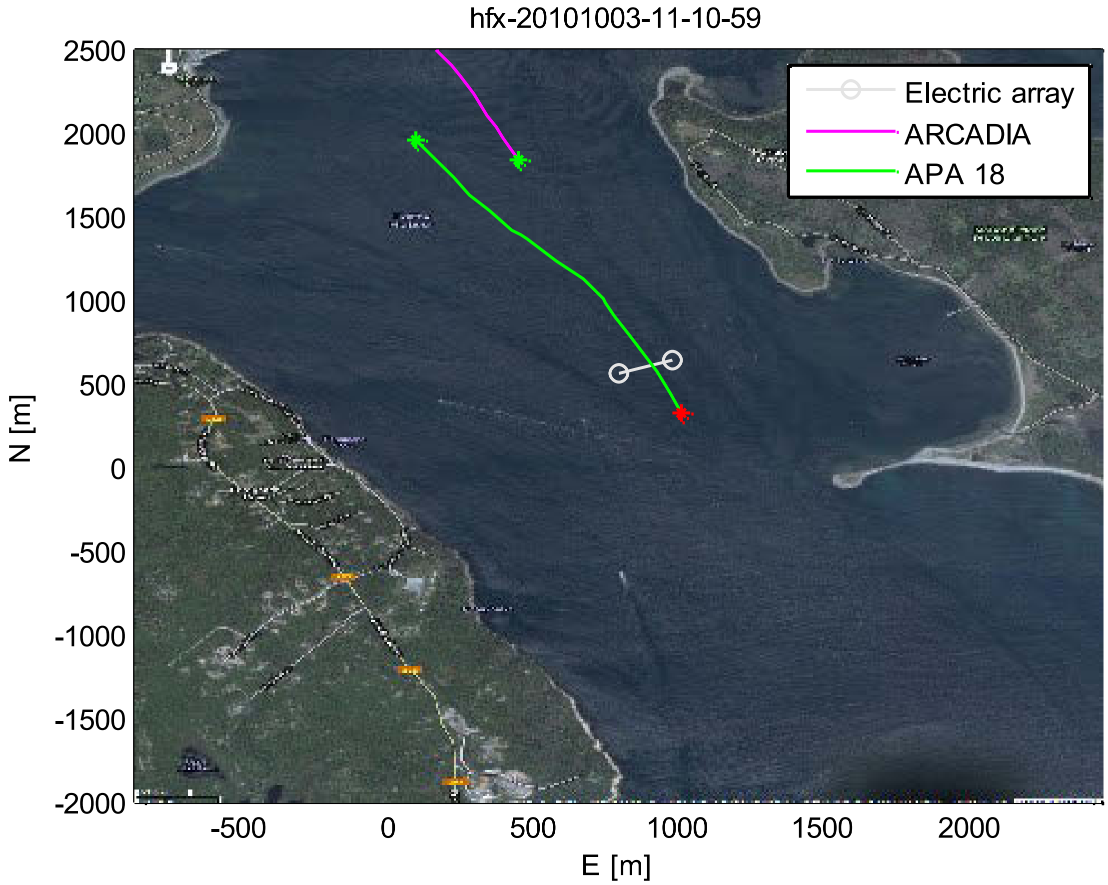

Figure 51: Event #10 AIS Tracking from 11:10:59 UTC until 11:15:59 on October 3rd. This figure was produced in Google Earth ®.

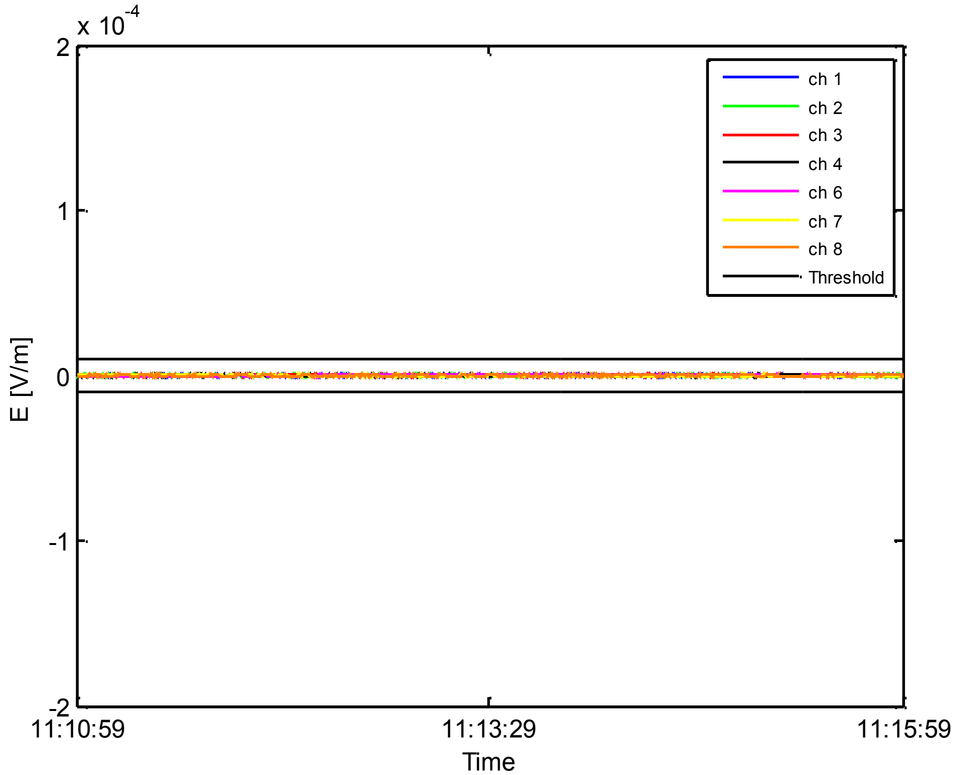

Figure 52: The Electrode Array made no detection at all, even though the pilot boat APA 18 sailed on top of it.

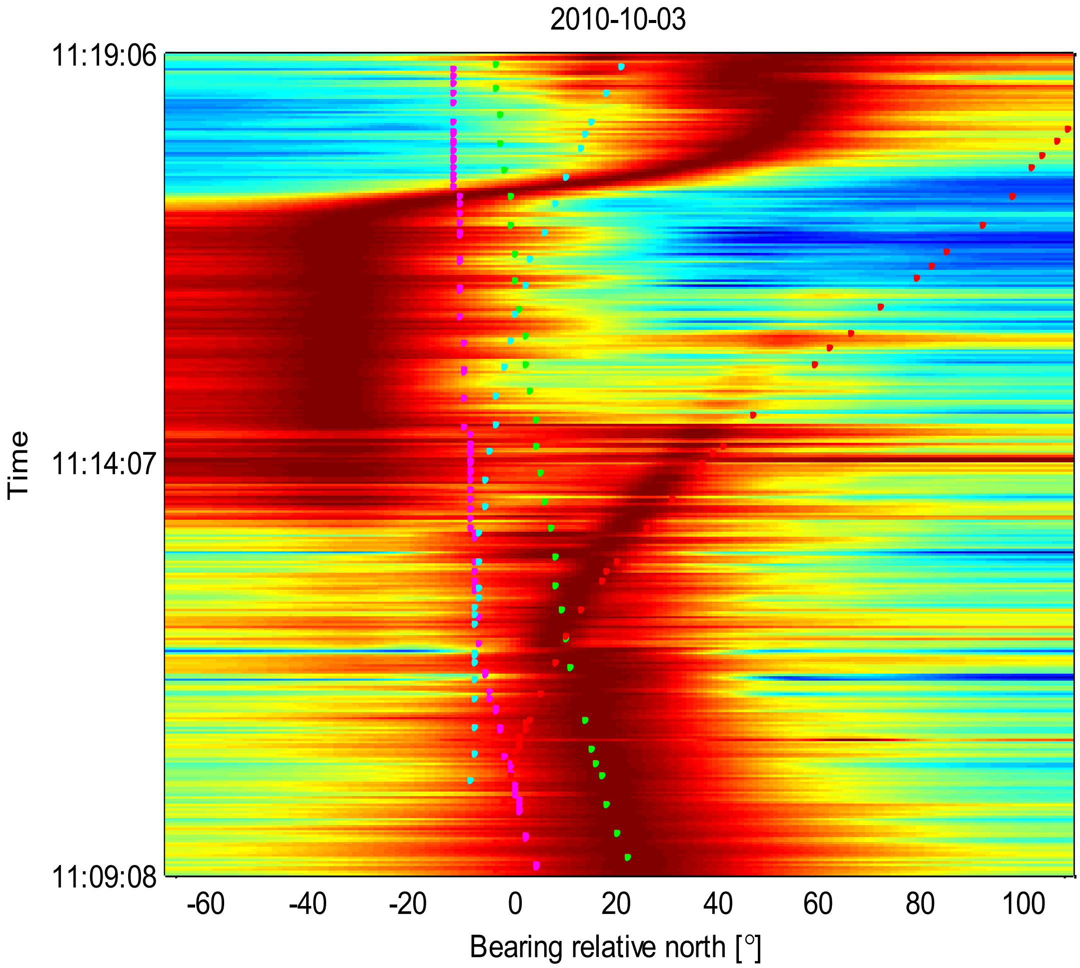

Figure 53: Acoustic Bearing Time Record overlaid with AIS tracks shown as dots. The magenta dots are from the pilot boat APA 1, the pale green from ARCADIA, the red from pilot boat APA 18 and the pale blue ones from DEEP CYGNUS.

9.12 Event #11

Event Date: 03 October 2010 (11:15:52 UTC).

Figure 54: The DEEP CYGNUS, which describes itself via AIS as 'engaged in dredging or underwater operations', is passing close to the cruise ship ARCADIA

Event Description

A small vessel is transiting in close proximity to a cruise ship (Figure 54). This is representative of busy traffic conditions in harbour. This event took place shortly after the previous one.

How the Sensors Interacted

The event was detected by ASIA and, to a very limited extent, by the Underwater Acoustic Array. Actually, as this event followed so closely on the last one, the acoustic bearing time record has already appeared above (Figure 53), as did the AIS data (Figure 51). Radar, the Starfish Array, and the Underwater Electrode Array did not detect the event.

Significance

The significance of the fact that the pilot boat could sail over the Electrode Array without being detected was noted above.

10 OPERATOR USE OF MULTIPLE SENSOR DATA

Multiple data types and technologies may provide port authorities with a robust situational awareness picture. Sophisticated algorithms can be used to analyze and mine these data. While automatic detection of anomalies is desirable because humans have flagging attention span and sensory limitations, typically, a human operator is still required to digest information and make informed decisions. The objective of the human factors portion of this study is to develop a sense of whether small boat anomaly detection can be fully automated within software or whether it is best left to operators. Having evaluated the nature of individual and combined sensors in the previous section, the investigation turns to the issue of effective use of such multi-sensor information in practice. This is resolved into three key issues: (1) how operators could use multiple types of overlapping sensors to improve the monitoring of small boats in harbours; (2) how such monitoring could help in detecting problems associated with vessel location and/or movements (i.e., anomaly detection); and (3) what role does or should the human operator play in detecting anomalies versus computer-flagged irregularities (human-in-the-loop).

The overall rationale for this project is to improve the ability of port authorities to respond to and plan for adverse and illegal small-boat activity in ports and harbours. At present, multiple types of data and technologies are used to obtain situational awareness in certain harbours. This thrust examines how technology contributes to human effectiveness in gauging small-boat-related threats. Some of the questions that we will attempt to answer are as follows: how much information should be displayed, how it should be displayed, what information needs to be processed by operators and what can be automated.

10.1 Background

Although many aspects of human-computer interaction (HCI) for improved situation awareness have been explored before [26], the growing need and capability for multiple sensor monitoring is one developing thrust. A formal definition of situational awareness identifies three levels: (1) perceiving critical factors in the environment; (2) understanding what those factors mean; and (3) understanding what will happen with the situation in the near future [27]. In the context of our study, this translates into noticing a small boat that is behaving in an unusual manner, assessing whether the abnormal behaviour may be of any consequence for security purposes, and if so, predicting what may happen next.

Although the deployment of enhanced multiple sensors to detect vessels would provide more data, it is imperative that the cognitive and decision-making abilities and limitations of the human operators be accounted for when designing the system. Effective computer processing of the data and delivery of the information is required to yield benefits. Using visual displays to consolidate information from large datasets, situation awareness is enhanced "by allowing the user to readily see the big picture" [28]. It is further suggested by Human Factors specialists that visual noise (i.e., excessive distracting information that is not relevant) should be kept to a minimum, as this will reduce the amount of time it takes to locate the most critical information [29].

The Australian Department of Defence performed an extensive literature review on algorithms for ship detection in Synthetic Aperture Radar (SAR) imagery [30]. Crisp makes recommendations on which algorithms to use, prefaced with a note that there is a "lack of rigorous performance evaluation which makes comparison of the various approaches difficult". The argument made in our study is that the performance measures for evaluating the different sensors alone and in combination must extend beyond strictly technical measures to include HCI concerns, as the effectiveness ultimately depends on the enhanced situational awareness.

10.2 Target Users

While port security is of concern to a diverse set of stakeholders, including the general public, there is no single authority that is responsible for monitoring traffic throughout the Halifax Harbour. Site visits were conducted to the Marine Communication and Traffic Services (MCTS) centre in Dartmouth, the Queen's Harbour Master (QHM) facilities in Halifax, and the Halifax Port Authority (HPA). Each of these entities has a mandate to monitor a subset of the port traffic, depending on vessel categories and location. Similarly, other stakeholders around the port, such as CFB Halifax and private shipping terminals, monitor traffic near their facilities to protect specific interests. Finally, many agencies, including Transport Canada, the RCMP and the Canada Border Services Agency (CBSA), play a role in harbour safety and security, acting as regulators, first responders and operators. For the purposes of assessing the benefits and application of multiple sensors for improved Small Boat Detection, the Halifax Port Authority volunteered to participate through meetings and interviews. This small sample of representative potential users of enhanced sensor capability provided feedback and expert opinion to supplement the information from the port survey that was reported on in Section 4.

10.3 Human Data Acquisition Process

Research Ethics applications were made to DRDC and Dalhousie University, in compliance with requirements for conducting research with human subjects. Once approval was obtained from both Ethics Review panels, sessions were held with two operators during their respective shifts. This permitted the researchers to:

- Observe the operators in their working environment;
- Ask about the variety of tasks that they do;
- Elicit comments on the use of their existing port security monitoring system;
- Ask about the procedures during critical events;
- Ask about the types of maritime traffic anomalies that they encounter;
- Ask about what types of anomalies may be of concern regarding small boats;
- Ask about what role the operator does/should play in detecting anomalies versus automated detection by the security system; and
- Ask how multiple sensor types could assist with situational awareness.

A final meeting with HPA managers was conducted to:

- Go over the results from the interviews with the operators;
- Ask for clarification for certain issues that came up during the interviews; and

Get a more complete description of the role of HPA with respect to waterside security.

The managers at HPA were given the opportunity to review this section of the report to vet it for confidential information or inaccuracies.

10.4 Current Security Monitoring System at HPA

The HPA is responsible for monitoring certain activities on the water and on the land. The latter will be disregarded in this report, except to the extent that it impacts on observations about issues of general interest for this study, such as human-computer interaction (HCI) or operator overload. Note that the opinions of the operators do not necessarily reflect the official position of the Halifax Port Authority on any particular issue, nor is their description of parts of the operation perforce accurate, as they were asked for their personal perspective.

10.4.1 Tasks and Procedures

The operators use a number of technologies to facilitate their duties including, but not limited to a bank of close-circuit televisions (CCTV), a Geographic Information System display of harbour features with some traffic icons for larger vessels, and various communication devices. On the water side, one of the primary tasks of the operators is to monitor unauthorized boats entering or approaching designated Restricted Areas. The operator's role is monitoring, and detection of circumstances requiring investigation or action. If any response is needed, the operator will follow through with the prescribed procedures for the particular incident or circumstance. Thus, with respect to anomaly detection, the operator's responsibility is detection, interpretation to some extent, and taking prescribed action as required.

10.4.2 Multiple Inputs

Video cameras placed strategically along HPA property are amongst the primary sensors providing situational awareness to the HPA. Some of them are fixed while others are PTZ (pan, tilt, zoom) and can be remotely controlled either by the operators, or triggered by other sensors,. A bank of CCTV monitors provides views on several critical locations at once, and the operator can select which cameras to display. An integrated system described in Section 6 produces a GIS display resulting from the acquisition and processing of multiple sources of information. The HPA operations centre can track vessel traffic through AIS/RADAR feeds. Relevant information on vessel activity or unusual events is also relayed to the operators via voice or email from pertinent parties such as MCTS or the cruise ship operators.

The system can indicate if certain sensors are out of commission. Maintaining a sensor system that is up-to-date and current was identified as a key challenge. New and improved devices are being developed all the time, and acquisitions for replacement or expansion do not always conform well to the existing equipment set. This is a general consideration for the use of multiple sensor types for harbour monitoring.

10.4.3 Operator Profiles

In terms of anomaly detection, there are two aspects of the operator's job that are noteworthy. First, they must assess situations in an appropriate context, and second, they must use all the information available to them to best advantage to maximize their situational awareness. Thus, an operator's background and experience in security and/or marine operations are important considerations to assist with the first aspect. As discussed further below, a key facet of the human-in-the-loop process is the operator's ability to interpret extraordinary information and judge whether to pursue it or not. These human cognitive processes will be much more effective if the operator has the required training, basic knowledge of the environmental factors, and a history of encountering comparable situations. Furthermore, the criticality of the human decision phase highlights the importance of employee retention, as learning through time on the job improves the ability to make a correct response to an anomalous situation.

Facility with the monitoring system requires the ability to master the features of the system for both selecting and operating sensors (to observe areas of interest), and for taking advantage of the functionality of the automated system (to monitor traffic and deal with alerts). This training strategy relies on low staff turnover. Operators who have some computer expertise would take best advantage of a multi-sensor system. This will be discussed further below in the HCI (human-computer interface) section.

10.4.4 Small Boat Detection

Given that no single authority has the mandate to track small boats throughout the harbour, the HPA operators were asked about their specific tasks in this regard, and about what might constitute suspect behaviour for small craft. Their first, and easiest, indicator of suspicious intent is location-based: a vessel in or approaching a restricted area (a static benchmark). This can be easily implemented through an automated warning system, subject to having sensors that can track the small vessels position accurately enough to make the necessary determination. Visual monitoring can achieve the same goal, but certainly demands the attention of the operator to all the sensitive areas quite frequently, to see if a perimeter has been breached.

With respect to HPA's specific interests, they are supposed to receive advance notification of small boats that have business with a visiting ship (for diving jobs or garbage collection, for example). Hence, an anomaly is flagged if an unreported boat appears, although it is generally resolved as an omission in the notification.

Another measure available through remote sensing is the small vessel's movement characteristics. The interviews yielded several indicators of normal or abnormal vessel behaviour. For example, speedboats tend to careen across the harbour at a relatively high speed and in a straight line. Therefore, a sudden unexplained veer could warrant closer observation. Vessels that linger in an area for no apparent reason would be unusual. Erratic boat movements are also suspicious. Perhaps due to the complexity of defining them, it is a task best served through human observation and interpretation. However, as noted above, the difficulty is that the harbour area is too large to monitor the minutiae on a constant basis. Operators would get overwhelmed by the volume of information during the busy boating season. Thus, a suggestion was made that only vessels over a certain size should be monitored and translated onto the GIS display (assuming such a distinction could be made), so that the level of detail in the map would remain manageable.

If vessel characteristics were available from the sensor suite, then this could be regarded as a simple filtering problem. Unfortunately, however, not all sensors provide indications of length. There is a balance to strike between having more information available and mitigating against operator overload. This balance is at the crux of the HCI issue for multiple sensor use and integration, as discussed below.

10.5 Human-Computer Interaction Issues

Insights were gleaned into various aspects of HCI, including the use of multiple sensors, the degree of control over the sensors by the user, and display configuration.

10.5.1 Multiple Sensors: Uses and Limitations

As presented in Section 5 of this report, various benefits can ensue from using multiple sensor types for vessel detection. One of the key ones is that, because each sensor type has limitations on its range or operation under certain environmental conditions, coverage by complementary devices is beneficial. Camera views can be occluded by certain weather conditions, whereas a subsurface sensor, such as an acoustic array, can track many vessel types in adverse weather, although they may not provide any identification information. The HPA operators were not asked to comment specifically on the sensors tested in this study, since they would not have much familiarity with them. However, based on their current working environment, they were queried on the advantages and limitations of using multiple sensors, and in particular on the role of computer systems versus the human operator in providing the best holistic approach to small vessel monitoring.

The consistent response was that, for general, persistent monitoring of a large area, the sensors and computer system should be set up to flag anomalies. The limited number of operators cannot watch the entire harbour, even if it were within their mandate. Aside from the well-known issues of operator fatigue and overload from watching a screen intently over a long period of time or having too much activity to pay attention to, there are issues specific to the HPA.

Should multiple, diverse, complementary sensors be used to detect and track more small vessels, the issue becomes how to convey all relevant information to the operator. Certainly, the raw signals from the tested sensors (electrode, acoustic, and radar) are not very useful in the observation room. Even displaying the information on a GIS map, as tracks or moving positional dots, may have little added value. As one operator opined, “Small boats would clutter up the screen”. How could such information be used then? If an anomaly signal should be triggered by proximity to sensitive areas, or due to a vessel’s movement pattern, then this task of detecting an abnormal situation is best achieved through a computer algorithm. The signal should be conveyed to the operator in a clearly apparent, unambiguous way, such as a visible warning on the GIS screen. Then a challenge becomes how to avoid too many false alarms.

The operators independently commented, on several occasions, that they expected the system to draw anomalies to their attention, upon which they could pay specific attention to that event to interpret its significance. Although it was hypothesized at the start of this project that certain small boat anomaly detection and pattern recognition tasks were more suitable for human processing and others for computer processing, it appears that these two tasks should be automated to the extent possible. When aberrations are brought to the attention of the operators, the multiple monitors and computer-generated views of positions and/or tracks serve to provide greater observation power. Then the human skill of deciphering the threat level and inferring the intent of the vessel can be brought to bear. This is why the HPA operators can effectively monitor the cruise ships; the focus of their attention has already been dictated by the circumstances of the ship's presence at their pier. Extrapolating this to the implementation of complementary sensor types, it suggests that the new detecting devices would serve primarily to trigger camera tracking of unusual behaviour, in favourable environmental conditions. If this is not possible, at least diverse sensors can help confirm or reject the abnormality of the vessel's behaviour, so that further action can be taken.

10.5.2 Control Actions by Operators

From one simple perspective, the operator's task of detecting abnormal behaviour can be broken into two parts: monitoring specific activities or events, to identify problems; and monitoring the general situation in and around the harbour, to spot anomalies. The control and use of the overall monitoring system in the first case is straightforward. The sensors (primarily cameras) and operator's attention are focused on the prescribed target over a fairly well-defined time period. The operator can adjust the cameras' positions and zoom and select which views to show on the monitor banks to maximize their performance.

It is the second part of the task that presents challenges. How does an operator choose what to watch, and when, to discern a chance anomaly in the harbour? Through training and experience, the operators learn which views may be useful to capture the most representative picture of the harbour activities, but there is no optimal strategy. Each operator has established a "palette", a user-selected set of default camera views that the operator may initiate when their shift starts. Perhaps one setup may be more effective in the long run than another for improving the chances of anomaly detection, but it is hard to define an optimal strategy. Palette set-up may also be event or risk driven. Furthermore, the traffic dynamics and weather factors are sufficiently variable that a "static" guideline for default views is likely counterproductive. To address the observational deficiencies associated with any set of camera views, part of the protocol is for the operator to sweep through all available views every couple of hours to survey the larger domain. These difficulties in maintaining a high level of situational awareness point again to the value of having computer-driven anomaly detection, followed by human vetting and interpretation.

Thus, operators want control over the camera positions to the extent possible, so they can focus in on events or areas when needed, but also adjust the cameras for general observation.

10.5.3 Displays

The displays themselves are invaluable (CCTV and GIS views), but also present human factors challenges. Much as the integrated system is designed to do, adding new varied sensors for small boat detection would also require a seamless integration of the new stream of diverse information, which would automatically adjust some views as required or guide the operator's attention to certain types of activity (as opposed to showing all detected vessels). Otherwise, the operators would be overloaded with information, and could not investigate most unpredicted activity in the harbour.

10.6 General Comments

The usefulness of multiple sensors for small boat detection in the harbour depends on several factors including:

- Who would use them?
- How could their outputs be effectively delivered for improved situational awareness?
- What is the overall value of additional and/or mixed sensors?

At this time, no single entity has responsibility for monitoring small boat traffic throughout the Halifax Harbour, although this situation may evolve over time. Nevertheless, various stakeholders may have a vested interest in such capability, such as private operators along the waterfront, agencies concerned with critical infrastructure protection around the harbour, and perhaps higher levels of government. Thus, improving capability for small boat detection should be commensurate with the need to use such information. A related point is the capacity for response. Anyone monitoring small vessel activity would have to have the wherewithal to address problems, including the authority to act, perhaps a response vessel to interdict, and command and control protocols. In other words, the value of the information from multiple sensors is low, unless it can be translated into effective response.

As discussed in this and previous sections, the effective use of the information from multiple sensors hinges on seamless fusing of the information to resolve inconsistencies, on providing redundancy, and on delivering a coherent depiction of maritime activity. While these concepts are not new, and in fact there have been tremendous advances in such methods in recent years, small boat detection, tracking, identification, and interpretation present particular challenges. Due to the complexity of these tasks, a natural assumption may be that operators can perform these functions, but, in general, that would present insurmountable difficulties. Instead, increased automation is needed to highlight issues of concern to the operator, who can then focus on and interpret the situation.

To conclude, it appears that improving the capability to monitor small boats in the harbour for aberrant behaviour would be a valuable addition to port security. Should a small boat monitoring system be installed, more detailed human-computer interaction studies should be conducted as part of the system design. Many issues would have to be resolved such as: at what resolution and to what extent to monitor the waters; what types of aberrant behaviour to flag for the operators; how to adjust the warning levels so that there is not too much demand on the operator's ability to deal with the alerts, and yet produce a sufficiently comprehensive picture to have a reasonable likelihood in identifying suspicious activity. Otherwise the investment in a complex sensor system could be squandered.

11 IMPLEMENTATION CONSIDERATIONS AND HURDLES

This study focused on the interaction of deployed sensors. In implementing such interaction, there are a number of implementation considerations and hurdles that need to be accounted for. These considerations will have an impact on the types of sensors utilized for interacting port security systems and where they are placed. The obstacles pertaining to sensor deployment warrants further examination.

While the focus of this paper is on interacting sensors, sensor deployment and selection must be examined on a per sensor basis because the individual deployment considerations (both physical and capability-wise) will have an impact on the nature of sensor interactions as well as the type of port security system that is designed and ultimately placed in-service.

Implementation considerations and hurdles include the following:

Cost. Procuring sensors, deploying them in the field, providing technical support and allocating an operating budget can be financially significant. Fiscal realities often cause users to make hard decisions based on what they would like versus what they can afford.

'Not In My Backyard' (NIMBY). Some stakeholders may take exception to sensors being placed in both urban and rural areas due to unsightliness, health or environmental concerns. A potential offshoot of NIMBYism is vandalism that can be perpetrated by those who harbour strong feelings about the location and purpose of deployed sensors and systems.

Sensor management does not suitably match operator skill sets. For example, radar usage can require a degree of specialized training whereas operating a remote-controlled camera requires minimal training.

Lack of understanding of the technology. All sensors have their limitations, and it is important that users understand what the sensor capabilities actually are, so that their expectations of sensor performance are realistic. An understanding of individual sensor capability is also important so that the correct suite of sensors can be selected in order to interact optimally and address the requirements of the port authority. For example, underwater arrays perform well when deployed in navigational chokepoints, but their effectiveness is reduced when deployed in an open area. It is important that selected sensors are suited for both the physical and threat environments.

Sensor position. It is important to deploy sensors in a manner so that they can perform optimally. For example, if sensors are overly clustered, lack proper lines of sight (e.g., occlusion), or are deployed in a non-overlapping configuration, performance may not be optimized.

Existing Infrastructure. Sensor selection and deployment are subject to line of sight issues, power requirements, data distribution requirements, etc. Consideration must be given to existing infrastructure constraints and assets.

Having someone "own" the system. It is important to have one person who fully understands the functions and capabilities of individual sensors, so that they can understand how individual performance will impact system performance. They will also be able to adjust the system incrementally to meet prevailing security concerns.

12 SUMMARY

12.1 Research Findings

This study has resulted in the following findings:

Layered, overlapping sensors, deployed in an interacting manner, will produce a situational awareness picture that cannot be obtained by utilizing sensors in standalone configurations.

The ASIA camera system was able to detect and identify vessels, although occlusion was a limiting factor.

Radar and underwater acoustic arrays were capable of detecting and tracking vessels. Some classification of ships is certainly possible with these sensors, but identification of individual ships would be a demanding challenge, achievable only with advanced algorithms and databases of specific ship signatures.

The underwater electrode array was only capable of vessel detection. It lacked capability for vessel tracking. Some classification of ships may be possible.

Even with networked, interacting sensors, detecting and tracking small boats still poses a challenge within harbour environments. Factors that impacted the tracking and awareness of vessels in harbour include the detection capabilities of individual sensors, weather, whether or not the sensors are functional at the same time and occlusion.

There is already a large amount of information competing for the attention of human operators in security environments. In introducing yet more information, one must be very aware of the potential for operator overload, which reduces effectiveness rather than increasing it. More information is not always better.

Given the risk of overload, sensor interaction involves decisions about what to present to humans and what to hide from them. Cued information, which is presented to operators only when certain events are triggered, can be an effective way to introduce information selectively. For example, cameras could be redirected to areas when tripwire sensors (like the underwater Electrode Array) detect the presence of a vessel. On the other hand, such cueing or alerting necessarily interrupts other tasks and may become a nuisance.

Organizational responsibility for small boat tracking within harbours can be unclear (e.g., is it the responsibility of Transport Canada, DND, CBSA, the RCMP, local police, or port authorities?). Responsibility may be shared across several organizations.

12.2 Lessons Learned and Recommendations

The SISSTAH team has developed the following list of ‘lessons learned’ as a result of the study:

A longer sensor trial is required to properly research the utility of overlapping sensors for small ship detection, tracking and identification. Finding events to analyze that occurred when all (or most) sensors were running concurrently was limited to a two-day period.

A video camera would be a useful sensor to include in future trials as video cameras are common sensors in port environments.

Most of the sensors analyzed in this study were not commercial-grade sensors. Utilizing sensors with well-defined and proven capabilities would result in better data analysis. Much time was spent by the project team determining the capabilities of the sensors used.

It is important that sensor experts serve as embedded team members rather than be employed in a consulting role so that a more in-depth data analysis may be performed.

It is useful to have multiple port authorities serve as embedded team members in order to capture multiple points of view pertaining to security.

More work can be done to quantify the differences between detected tracks of the various sensors.

13 AREAS FOR FURTHER RESEARCH

While this study is fairly comprehensive and investigates a number of matters pertaining to small boat detection and tracking, the project team recognizes that elements of this paper require further research. Namely:

A Human Factors study focused on analyzing the actual data collected through multiple GUI displays that show differing levels of sensor fusion would be useful.

A study on how to interrupt operators most effectively (with alert messages, alarms or other means) that examines not only the manner of the interruption but also determines whether some operator tasks are more interruptible than others. In other words, how should security applications interrupt human operators without becoming a nuisance?

An in-depth sensor capability study would further identify synergies between different sensors that could be used to create new capabilities.

Mapping mandates and capabilities of agencies with a vested interest in small boat detection and tracking would be useful to uncover capability gaps as well as synergies between agencies. This will help improve small boat detection, tracking, and response.

A study could be conducted laying out the entire "decision" process of small boat detection. What/how would boats be detected, identified, characterized by behaviour? How could/should computer algorithms determine anomalies (in general)? How should anomalies be presented to the operators? What could/should operators do with the info (i.e., how should they decide that the situation warrants further action or not? This may be based on a risk assessment.

How can algorithms be used to flag small boat anomalies? If a boat is "behaving" normally, from all outwards appearances, then there is no way it could be flagged as an anomaly through observation anyway (i.e., it would take prior intelligence). If there is something about the pattern that is different (unusual location, speed, movements and/or time-of-day), work is required to figure out what that is. This could be based on the interview information, further expert opinion, and/or a log of "typical" behaviour of small boats (in general or in a specific environment).

14 STRATEGIC ADVISORY NOTE

The following is the Strategic Advisory Note as it pertains to this project. The intent of the Strategic Advisory Note is to propose a strategy for maximizing the success of this study by identifying barriers or enablers and recommendations on measures to be taken to maximize benefits of the study to stakeholders.

14.1 Focus

Determine how overlapping sensors impact small boat detection, tracking and identification.

Examine the effectiveness of sensor combinations in small ship anomaly detection.

Examine how 'Human-in-the-Loop' pertains to sensor interaction and integrated systems.

14.2 Barriers

Some ports were unwilling to provide information on their security practices.

Transport Canada regulations regarding Marine Transportation Security (MTSC) clearance for restricted areas prevented access to HPA facilities.

Internal port authority security policies restricted our ability to observe and solicit the opinions of operators.

Some of the sensors referenced in the trial were not technically ready for or applicable to particular port security applications.

14.3 Enablers

The Halifax Port Authority is actively seeking ways to improve its existing security and surveillance system.

Lack of funding requires port authorities to make trade-offs between cost and performance.

14.4 Recommendations to maximize stakeholder benefit

Present the findings at major port security conference (both Canada and US).

Present a condensed version of the study findings in a recognized port journal.

Distribute bound copies of the final report to port authorities across Canada.

15 CAPABILITY ROAD MAP

To capitalize on the results of the SISSTAH project, the team has identified the following actions to be considered in order to enhance sensor interaction within harbour environments for the purpose of detecting, tracking and identifying small boats.

15.1 Actions

Updating of port threat analyses.

Developing an understanding of how technology can address the vulnerabilities identified in these threat analyses. This will likely vary from port to port, and will likely require a Sensor Survey and Systems Requirements Analysis to map potential technical solutions to vulnerabilities.

Mapping of agency jurisdictions and mandates as well as technical capabilities to track small boats is required. Currently it appears to be unclear who can and who should assume primary responsibility for tracking small boats in harbour.

A study of common 'threat themes' within Canadian port authorities will be useful. This will help establish a baseline suite of sensors that can be integrated nationwide to address common threat scenarios.

A more comprehensive look at fusion of the data from the various sensors contributing to the SICCPA trail should be undertaken.

A longer sensor trial will be required in order to develop a greater sample size using commercialized sensors (TRL 9). This will eliminate some of the ambiguity inherent within the SISSTAH study that was introduced by using some prototype sensors. The larger sample size will lend more credibility to the detection, tracking and identification results.

The Marine Security Contribution Fund will need to be replenished in order to provide funding to ports to upgrade and enhance their security. This study indicates that ports have little internal funding that can be dedicated to security enhancements.

Greater interaction between ports and industry to develop technologies that are focused on enhancing port security. Perhaps a "Port Security Technology Working Group" can be created. This will allow ports to convey to industry what their requirements are and will provide industry an opportunity to convey to ports what technology is out there.

More concentrated Human Factors research is required. Developing multiple Graphical User Interfaces that display different types of sensor information in varying degrees will help determine what is optimal for the end user. These prototypes GUIs should be tested using actual port security operators

15.2 Overarching Themes

Closer interaction between industry, academia and the end-user.

Financial commitment from the Federal Government to enhance port security on an ongoing basis.

Greater consideration of Human factors.

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Annex A Data Analysis Assumptions

The study identified 'events', in order to demonstrate the utility of overlapping and interacting sensors. An 'event' can be described as any occurrence that would be of potential interest to port security operators as they are anomalous or represent unusual behaviour. Examples of 'events' are vessels transiting in close proximity to one other (e.g., shadowing), engaging in close crossing routes or simply being in areas where their vessel type typically do not enter.

A.1 Radar

The following assumptions are made when using the radar data:

The track numbers assigned to the radar tracks are recycled within the same file, so any given track number may be assigned to several, completely unrelated tracks. This is addressed via a track breaking algorithm.

The radar data is time-stamped to local time, while the analysis is done in UTC time. For the trials in October (during daylight savings time), this means that 4 hours was added to all timestamps to bring them to the proper UTC timestamp.

The time stamps for the radar data have an uncertainty of about ±3 minutes. When comparing radar data to other data sets for an event, ensure that the time window chosen for the radar data encompasses the event in the worst-case scenario. The time window can be narrowed if a radar track can be matched to another more reliably time-stamped track to determine a more accurate timestamp offset for the event.

Aligning the radar timestamps is easiest to do visually, matching distinct events across radar and another sensor and comparing the timestamps.

When attempting to align the radar timestamps, it is easiest to choose a track with a distinct shape. Multiple turning points make it easier to align the two tracks and increase the certainty that the tracks chosen are of the same manoeuver by the same vessel.

The SIGMA T seems to have been picked up by radar quite well, and its manoeuvres during the trial contain many, many turns. This makes it very well suited to use as an aligning vessel.

While decent time stamp accuracy can be achieved using static images, the best timestamp alignment technique is to animate the radar track and track from another sensor (often AIS) side by side. This makes matching the turns extremely easy, and allows points where the vessel changes speed to be used for alignment as well.

A.2 Starfish

The following assumptions and considerations were important for processing the starfish data:

The starfish data are time stamped to UTC time, therefore no offset is applied when analyzing the data.

The bearings used are not aligned to true north, they have some degree of offset. For early analyses, an offset of -18.12 degrees (the value of magnetic declination in Halifax Harbour) was applied to each bearing. For later analyses, an experimentally determined offset was applied to each bearing: -17.71° for node 1, -11.41° for node 2 and -15.09° for node 3.

Background noise is approximately 90dB, so a signal strength of 100dB is considered a detection.

A.3 AIS

The following assumptions and considerations are made when using the AIS data:

AIS is time stamped to UTC time, so no time offset is applied.

AIS is usually considered to be a ground-truth sensor, in other words, it is assumed that the positions given by the sensor are more or less accurate, and are not spoofed for the purposes of analysis.

The timestamps given under the "time of fix" column are generally the ones being used for plotting tracks or positions at a given time, not "time received".

A.4 ASIA

The following assumptions and considerations are made when using the ASIA data:

ASIA records the predicted location of the ship at the time of the photo.

There is a small delay between receiving ASIA data and the system taking a picture, so it is assumed that some empty pictures are due to a sudden change in ship speed or direction that the system cannot predict.

The ASIA camera is time stamped in UTC time, so no time offset is applied.

A.5 GPS

The following assumptions and considerations are made when using the GPS data:

GPS data is time stamped in Unix seconds according to UTC time, so no offset is applied during processing.

The GPS data is assumed to be very accurate. The sensors were on our ground truth boats, so we know that no spoofing was involved.

The cleaned data files have been carefully processed, and are usually considered the most accurate files.

A.6 Swedish Electrode Array

The following assumptions and considerations are made when using the Swedish Electrode data:

The data was time stamped in Unix seconds, as calculated by the SIGMA T and NORTHCOM's GPS. Since these sensors are aligned to UTC, no offset was applied to the data.

The peaks seen in the data are assumed to be the result of the closest ship to the sensor at the time of the peak.

The location of the sensor has been approximated visually from the maps produced in the Swedish data report.

A.7 Swedish Acoustic Array

The following assumptions and considerations are made when using the Swedish Acoustic data:

The data was time stamped in Unix seconds, as calculated by the SIGMA T and NORTHCOM's GPS. Since these sensors are aligned to UTC, no offset was applied to the data.

For any work done on the acoustic sensor early in the project, dark red was assumed to represent the strongest signal. This assumption has since been confirmed.

List of symbols/abbreviations/acronyms/initialisms

AIS	Automated Identification System
ASIA	Automated Ship Image Acquisition
C2DB	Command and Control Database
CBSA	Canadian Border Services Agency
CCTV	Closed Circuit Television
CFB	Canadian Forces Base
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EM	Electro- Magnetic
FOI	Swedish Defence Lab
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human Computer Interface
HITL	Human In The Loop
HPA	Halifax Port Authority
IMO	International Maritime Organization
ISPS	International Ship and Port Facility Security
MARIN	Maritime Activity and Risk Investigation Network
MCTS	Marine Communications and Traffic Services
MOE	Measures of Effectiveness
MOP	Measures of Performance
MSCP	Marine Security Contribution Program

MTSA	Maritime Transportation Security Act
OPI	Office of Primary Interest
PTZ	Pan, Tilt, Zoom
QHM	Queen's Harbour Master
RCMP	Royal Canadian Mounted Police
SA	Situational Awareness
SAR	Synthetic Aperture Radar
SICCPA	Sensor Interaction for Close Coastal and Port Awareness
SISSTAH	Sensor Interaction for Small Ship Tracking and Awareness in Harbour
SVSS	Small Vessel Security Summit
Ultra	Ultra Electronics Maritime Systems
UTC	Coordinated Universal Time
UUV	Unmanned Underwater Vehicle
VTS	Vessel Traffic Service

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This study examined the benefits derived by using interacting sensors for small ship tracking and awareness in harbour, so that port authorities could better understand the implications of deploying integrated security systems. The role of human operators in maintaining vigilance against threats arising from small craft was also examined. The study employed techniques from operations research, data analyses from a relevant scientific trial in the approaches to Halifax harbour, and interviews. These techniques resulted in the following findings:

Layered, overlapping sensors, deployed in an interacting manner, will produce a situational awareness picture that cannot be obtained by utilizing sensors in standalone configurations.

Despite using networked, interacting sensors, detecting and tracking small boats still poses a challenge within harbour environments.

There is still a reliance on human operators within port security regimes.

Cameras are an important sensor because they can validate what type of vessel has been detected and tracked.

In some Canadian harbours, there may be a lack of overlap between those organizations with the capability to monitor small craft activity and those with the mandate or responsibility to respond to small craft incidents.

These findings suggest that there is value in deploying overlapping sensors because multiple, networked sensors creates a situational awareness picture that cannot be achieved otherwise. Perhaps more importantly still, there is a need to ensure that those organizations with the best sensors for monitoring vessel activity and the people to monitor those sensors do more to share their information with the organizations responsible for incident response.

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Sensor Interaction, Human In The Loop, Tracking, Detection, Port Security

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