Wide Area Integrated Maritime Surveillance: An Updated Architecture with Data Fusion

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Abstract - *An architecture has been proposed for an integrated maritime surveillance (IMS) system to support Canada's defense efforts in a network-centric or information-centric surveillance of the Canadian coasts, where many sensors, for example, HF radar, surface search radar, Automatic Dependent Surveillance (ADS) and imaging radar are used to gather information about the targets of interest. Typically, a realistic IMS system is a distributed one where the information processing is carried out in a number of locations and at different levels (e.g., local IMS, regional IMS or national surveillance center). This paper will discuss IMS, propose an architecture for an IMS system and give some specifications for the proposed IMS system. The paper will describe the implemented data fusion engine. Desirable features are also given in the paper.*

Keywords: IMS, data fusion, high frequency surface wave radar, target tracking, architecture

1. Integrated Maritime Surveillance

Protection of a nation's sovereignty and effective management of the development and exploitation of natural resources within the 200 nautical mile

(nm) Exclusive Economic Zone (EEZ) place new demands on the organizations traditionally tasked with maritime surveillance and enforcement [1, 2, 3]. As a general principle, the level of surveillance that is required at any given time depends on the perceived threat. The ideal surveillance system must be capable of normal, day-to-day operation for the lowest possible cost yet have the resources to respond decisively and economically when required.

The provision of enhanced levels of surveillance will play a key role in the recovery of Canada's East coast fishing industry devastated by over fishing and a 1992 government imposed moratorium banning fishing. Likewise, most other maritime nations face comparable requirements in ensuring that their future economic development and the protection of offshore natural resources are not prejudiced.

The successful management of inshore and offshore fisheries, exploitation of oil and natural gas resources, undersea mining, tourism, and similar ventures, not forgetting environmental protection and disaster management, will ultimately depend on achieving significant improvements in the effectiveness of surveillance infrastructures world wide. Furthermore, such improvements must be achievable without significant increases in

spending profiles as, is the case in many countries, additional funding will be increasingly more difficult to secure.

Surveillance of activity in and beyond the EEZ is but one element in any nation's approach to the enforcement of national security and the management of trade, resource development and transportation. With the increasing availability and deployment of sophisticated information management systems, the trend is towards the implementation of systems to associate information at ever higher levels and produce a common national "big picture" against which all activities will be coordinated and managed.

The advent of shore based High Frequency Surface Wave Radars (HFSWR) permits continuous, cost effective, surveillance to beyond the 200 nm limit [1-6]. Surface wave radar provides the background picture by continuously tracking both surface and low level air targets in the area under surveillance. However, the tracking of targets is only of real value if those targets can be identified. Fusing the HFSWR radar picture with inputs from other existing surveillance systems supports target classification and identification. Existing systems can include mandatory reports from vessels entering and leaving the EEZ, reports from patrol vessels and aircraft, the interpretation of imaging satellite data, coastal radar data, etc. This is the concept called Integrated Maritime Surveillance (IMS).

This paper describes an IMS system based on HFSWR for monitoring surface and low-level air activity within the 200 nm EEZ. The system is designed to help authorities locate and identify such illegal activities as drug trafficking, smuggling, piracy, illegal fishing and illegal immigration. In addition, the system may be used for tracking icebergs, environmental protection, search and rescue, resource protection, sovereignty monitoring and remote sensing of ocean surface currents and winds. Based on an existing HFSWR system, an architecture is proposed to implement an IMS system. Both local IMS (LIMS) and regional IMS (RIMS) will be given. Main specifications for design will be given.

2. An Architecture for an Integrated Maritime Surveillance (IMS)

The ability to continuously track and identify ships and airplanes throughout the EEZ was one of the principal goals in the development of Raytheon's shore based HFSWR. While HFSWR has the capability to track and broadly classify airplanes and ships (small, medium and large), it cannot establish positive identification. Consequently, the development also addressed the requirement to automatically associate radar data with data from a variety of other sensors and systems to resolve this shortcoming. This will lead to the successful implementation of a Multi-Sensor Fusion Processor and ultimately an IMS system, a system built with the following elements:

Long Range Surface Wave Radar: For example, the Raytheon SWR-503 HFSWR will be the primary sensor of the IMS system.

Automatic Dependent Surveillance (ADS): Vessels and aircraft operating with ADS systems transmit position and identification information on a regular schedule over pre-assigned terrestrial and satellite communications channels.

Other Sensors and Information Sources: RadarSat provides image information. Registration database provides information for all international ships. Microwave radar provides short range surveillance.

Data Fusion Engine: A central data fusion engine automatically correlates target detections or tracks derived from long range radar systems and other complementary real-time sensors.

Data Distribution Server: The Data Distribution Server will provide all required services for authorized clients.

IMS Administration: Provides day-to-day administration like configuration, running or stopping IMS, user accounts and security, managing storage, managing transaction logs, making and restoring backups etc. The display client of the IMS administration provides presentation for customers to view the surveillance picture and to take authorized actions.

Communications Infrastructure of the IMS: Provides communication framework.

Wide Area Surveillance: The system should cover a surveillance area as wide as is needed. For IMS, it means that we should have local IMS (LIMS) systems and regional IMS (RIMS) systems. A local IMS system is a system with a group of HFSWRs and other sensors which

provide overlapped information. Two or more geographically separated LIMS systems form a regional IMS system when a surveillance center is required to coordinate some LIMS systems.

Considering the above elements and the existing components of the IMS system, an architecture for an IMS system can be constructed as follows:

Figure 1: The Proposed IMS Architecture

where HFSWR-CB and HFSWR-CR refer to the two HFSWR at Cape Bonavista and Cape Race. The special clients means clients who need special services, for example, a classified client who needs data through secure data link.

3. Data Fusion Engine

The data fusion engine is the core of the IMS system. By means of fusion, different sources of information are combined to improve the existing surveillance capability. The most obvious illustration of fusion is the use of various sensors typically to detect a target or to build a layered picture.

Fusion is useful for improving several objectives such as detection, identification, tracking, change detection, decision making, etc. Using an

efficient fusion scheme, one may expect significant advantages as:

1. Improved confidence in decisions due to the use of complementary information (e.g. silhouette of objects from visible image, active/non-active status from infrared image, speed and range from radar, etc.)
2. Improved performance against countermeasures (it is very hard to camouflage an object in all possible wave-bands)
3. Improved performance in adverse environmental conditions. Typically smoke or fog cause bad visible contrast and some

weather conditions (rain) cause low thermal contrast, combining both types of sensors should give better overall performance.

Fusion processes are often categorized as low, intermediate or high level fusion depending on the processing stage at which fusion takes place.

Low level fusion combines several sources of raw data to produce output information that is expected to be more informative and synthetic than the inputs. This level of fusion aims at

fusing ‘relevant information’ from the different sensors.

Intermediate level fusion combines various features. Those features may come from several raw data sources (several sensors, different moments, etc.) or from the same raw data.

High level fusion combines decisions coming from several experts. By extension, one speaks of decision fusion even if the experts return a confidence (score) and not a decision.

Figure 2: Two Level Data Fusion Engine

In practical problems, the applied fusion procedure is often a combination of the previously mentioned three levels. In the proposed IMS system, the data fusion will be at low and intermediate levels, with the capability to incorporate a high level component. Some of the related contents can be found in [1, 4, 5, 8-13].

The multi-sensor data fusion engine we proposed and implemented is a two level data fusion. Level one fusion will occur on the radar side. For the High Clutter Tracker (HCT), a small target detection and tracking system for microwave radar, this involves the consolidation

of all the trackers that are receiving data from the same sensor but are possibly processing it

differently due to different system parameters. Similarly, for HFSWR system, the slow, fast, and air trackers will have to be consolidated. Once each system performs level one fusion it will send the consolidated data to the multi sensor fusion engine where second level fusion will take over the multi-sensor track-track fusion.

Figure 2 shows a schematic diagram of the L1 and L2 fusion, involving one HCT and one HFSWR sensor.

The advantage of this scheme is that it will keep the HCT system virtually the same. The only modification will be the addition of a module to send the data to the fusion engine. Also it will keep the HCT and HFSWR systems available for stand alone running.

COMMUNICATION:

The communication between the sensors and the fusion engine is accomplished by using TCP/IP as the transfer protocol and connection oriented socket. TCP/IP is used, as it is a more reliable protocol (as opposed to UDP). In order to minimize the number of open ports on the fusion system a single port is used for each type of sensor (as opposed to using a new port for every sensor). These ports can be defined through the fusion configuration file. The ones that are currently used for testing are as follows:

- HCT port: 60000
HFT port: 60001
ADS port: 60002

At start time, a C++ procedure main() will initialize three threads, one for each type of sensor. All the threads will start with the 'port listen' function, but each will take a different parameter (this parameter will specify the port to listen on). When one of these three threads detects an incoming connection, it spawns another thread that will receive the data and filter it into a structure the fusion engine understands. The new threads that are spawned can start at either of the following three functions, 'recv_HCT_data', 'recv_HFT_data', or 'recv_ADS_data' depending on the port the parent thread is listening on. This new thread

will be passed the master socket, and from it the thread will be able to accept one pending connection. If there are more pending connections the parent thread will span as many threads as necessary in order to accept all the pending connections. This scheme will enable the fusion engine to handle simultaneously sent data, as each data stream will be processed in a new thread.

Currently, the implementation provides support for HCT, HFT, and ADS data. Each of these three systems sends different data to the fusion engine so each requires a different filter. All messages are sent as ASCII strings (ASCII is used so that we don't have to worry about the Big and Little ending data representations of different systems), with comma delimited fields. In most cases, the data block consists of a header followed by one or more track records. Commas are used to separate individual tracks and the header. At the head of the block is an 8 bit (this is a chosen value) string, which is a number, indicating the length of the block. (The length of the block is required for the recv socket function.) The expected data formats are described below.

HCT DATA:

The data sent to the fusion engine from an HCT System is not very detailed; currently it contains only the bare minimum that is required to do fusion. The header contains 10 fields and each track record contains 10 fields.

The header contains repeated data as well as control information for the fusion engine. The header is structured as follows:

Table 1: HCT Data Header

Data	Type	Description	Range
Number of tracks	unsigned int	The number of tracks in the data block	n/a
Year	unsigned int	4 digit year	n/a
Month	unsigned int		1 – 12
Day	unsigned int		1 - 31
Hours	unsigned int		0 – 23
Minutes	unsigned int		0 – 59
Seconds	unsigned int		0 – 59
Radar Source	unsigned int	The radar ID	1 – 4096
Target Type	Char	S (ship)	S

HFSWR Data:

The data sent by the HF system is very detailed. It contains many fields that aren't required by the fusion. The header contains 14 fields and each track record contains 24 fields.

The header contains fusion engine control information and repeated data. The header is structured as follows:

Table 2: HFSWR Data Header

Data	Type	Description	Range
Scan number	unsigned short	The current scan number	1 – 65000
Number of tracks	unsigned short	Number of tracks in block	0 – 35535
Year	unsigned short	4 digit year	n/a
Month	int		1 – 12
Day	int		1 – 31
Hour	int		0 – 23
Minutes	int		0 – 59
Seconds	int		0 – 59
Dwell	float		n/a
Source ID	int	A unique ID for this sensor	0 – 4096
Target type	int	1 → ship target, 2 → air target	1, 2
Range resolution	unsigned short	Measured in meters	1500 – 2000
Azimuth resolution	int	Measured in degrees	5 – 30
Doppler resolution	float	Measure in meters/second	0 – 10

ADS DATA:

The ADS data is special in that it doesn't use a header. A header is not required, as there is no repeated information, and because the fusion engine does not require control information to

process the data. The individual ADS tracks are also very brief. The structure of the individual tracks is shown below.

Table 3: ADS Data

Data	Type	Description	Range
Target ID	unsigned int	The ship ID, can be used to tell the ship type	
Year	unsigned int	4 digit year	n/a
Month	unsigned int		1 – 12
Day	unsigned int		1 – 31
Hour	unsigned int		0 – 23
Minute	unsigned int		0 – 59
Latitude	unsigned int	Latitude format: ddmms - degrees/minutes/seconds	n/a
Longitude	unsigned int	Longitude format: ddmms - degrees/minutes/seconds	n/a
Course	unsigned int	Measured in degrees from true North	0 – 359
Speed	unsigned int	Measure in nautical miles	

In each ADS track the speed and course are multiplied by 10000, so before storing the data divide these two values by 10000 to obtain the actual information. The latitude and longitude must also be converted to a degree representation so that they will be compatible with the HCT and HFSWR data.

Once data from a sensor is available, it has to be filtered and stored into a common data structure. The data structure has enough fields to store all the data sent in each HFSWR track.

The below table describes some of the key variables that are used for fusion.

Table 4: Description of Some Variables

Variable	Description
sensorID	This is a dynamic array of integers. At input time it should be allocated to size 1, and initialized with a sensor ID that will be assigned by the fusion engine when 'getSensorID(...)' is called. The id range is 0 to MAX_NUMBER_OF_SESNORS-1.
targetID	This is a dynamic array of integers. At input time this array should be allocated with size 1, and initialized with the ID of the track that was sent to the fusion engine. The ID is not assigned by the fusion engine but by each individual sensor (NOTE: the IDs from different sensor might not be unique).
numIDs	This is an integer, which will indicate the size of the sensorID and targetID arrays.
fusedID	This is a unique ID assigned by the fusion engine to each track. The 'fused_do_ids' function will associate a new ID to each track based on the previous ID associations.
latitude	A coordinate representing the location of the target in the North South direction. This value is measured in degrees ranging from -90 to 90.
longitude	A coordinate representing the location of the target in the East West direction. This value is measured in degrees ranging from -180 to 180.
speed	The speed of the target in knots. It is only the magnitude.
course	Measured from the true North. Values range from 0 to 360 degrees.
hours	Time of target detection.
minutes	
seconds	

4. Features of the IMS Architecture

- **An Open System**

The design of the proposed architecture incorporates the so-called wide-area surveillance

concept, i.e., both local IMS and regional IMS are considered. The advantage is that the

Figure 3: The Proposed IMS Hierarchy

architecture could be easily configured for a LIMS system or a RIMS system . As a result, we

propose the above IMS hierarchy where the LIMS system is structured as follows:

Figure 4: Local IMS

A regional IMS system can be built to coordinate several LIMS systems:

Figure 5: Regional IMS

- **A Network-Centric System**

The network-centric features enable collaborative sensing networks such as:

1. Application layer self-organization
2. Automatic acquisition of context
3. Recruiting and matching sensors to targets
4. Sensor and network resource management
5. Interoperability and transparent access

- **A 3-tier System**

The proposed architecture will be a 3-tier system. A general three-tier system will be implemented in the LIMS or RIMS systems. The three-tiers are presentation tier (client), service tier (server) and data tier (database). The separation of the three tiers makes the system easier to maintain, more robust to avoid system crash and securer for the system logic and data.

- **A Re-configurable System**

1. The system can be re-configured to use different processing schemes.
2. The system can accept command profiles.
3. The system should be adaptive to environment conditions as well.

- **A System with Intelligent Agents Feature**

Intelligent Agents is a flexible infrastructure applicable in many computing environments. Agents are excellent in both interacting with humans and in modeling human behavior, and they offer large advantages of productivity, comprehensibility and reliability in the development of complex, distributed and real time software systems.

In the proposed architecture for IMS system, an intelligent agent can be launched when a special mission is required. For example an agent tracker can be launched for ice-burg tracking in a specific area.

- **A System with Recovery, Debugging and Playback Facilities**

Disaster recover, debugging and playback of the system are required. These facilities will be helpful for the development and later-on operation after deployed.

- **A system with Diagnosis and Prognosis**

1. The system will provide different log files for status diagnosis and prognosis.
2. The system will provide visualized diagnosis and prognosis information.

5. Conclusion

Based on Raytheon Canada's existing HFSWR system, we proposed an architecture for an integrated maritime surveillance (IMS) system to support different needs. Specifically, we discussed the features needed for the proposed architecture. Both LIMS and RIMS are presented for wide-area surveillance. The proposed architecture and its implementation will enhance the capability of the existing system with HF radars on the Canadian east coast and provide flexible integrated maritime surveillance systems for coasts of different countries.

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