Maritime Surveillance Sensor Information Fusion for Improved Decision Making for Sri Lanka Navy

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Abstract— **This paper presents an ongoing research on generic sensor fusion architecture and its applications in maritime surveillance systems. The importance of information fusion in the single sensor type and collectively for different multiple sensor types is also discussed. In sensor data fusion, centralized versus decentralized refers to where the fusion of the data occurs. In centralized fusion, the clients simply forward all the data to a central location and a specific entity at the central location is responsible for correlating and fusing data. Our research intends to correlate multiple maritime sensors such as RADAR (Radio Detection and Ranging), AIS (Automatic Identification System) and other electronic object detection systems. Sri Lanka Navy has a number of surveillance information sources such as AIS, RADAR, SONAR (Sound Navigation And Ranging), MSTT (Maritime Small Target Tracker), HFSWR (High Frequency Surveillance Wave Radar), AVLS (Automatic Vessel Locating System), Radio Communication, Intelligence Data etc. It is clear that information fusion methodology is needed to harness the effectiveness of multiple sensor information. An object identification pipeline is conceptualized in such a way that an unknown object in the maritime domain is detected, reducing the uncertainty of information obtained. The radical new virtual reality application has been developed to visualize the information fused from sensors and discussed in depth. In addition to this, the fusion process is introduced. The technologies used in developing the virtual world and incorporating the real time information into the virtual world are presented in simplified models to ensure that it is better understood. Further design aspects involved and some experimental analysis of research and a developed project conducted at the Sri Lanka Navy are discussed in depth. It is to be noted that these fusion technologies are presented in a real time virtual environment and are currently used by SL Navy.**

1. Introduction

Advances in technology have led to the creation of many sensory information sources, overwhelming the receiver with an information overload. The sheer volume of information available today has given rise to a burgeoning field of computer science known as information fusion. This is needed to reduce the uncertainty associated with each sensor. The objective of the fusion process is to provide the user with an abstract layer of information derived from basic sensors, thus eliminating unnecessary information [1],[2].

To reach the required level of quality in maritime surveillance, it is necessary to use a heterogeneous network of sensors and large scale multi-sensor tracking and fusion architecture capable of processing data. There are various technologies for detection and identification of objects (Radar, Day-night cameras, AIS, etc), but every sensor technology has its own limitations i.e. in range, detection, recognition and coverage. Fusion of data extracted from these different complex scenarios will greatly help overcome this problem and further improve the reliability.

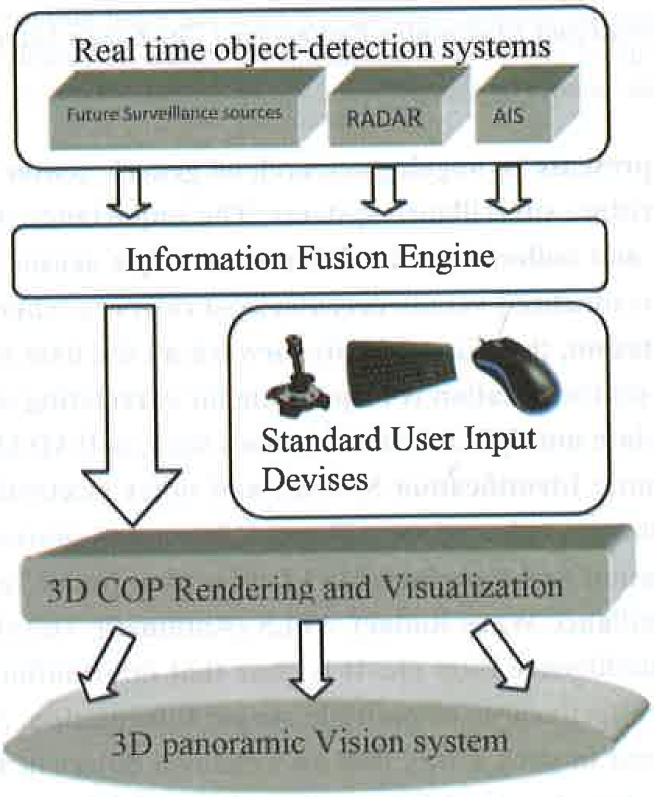

Fig 1. Fusion architecture and output to 3D virtual environment

2. System Architecture

In this section of the paper, a brief description of the system architecture is presented in an abstract view and a few of the sensor types are described.

a. System Description

The system consists of a remote sensing network distributed over a large area covering a major economical busy maritime domain. It consists of information fusion engine, data disseminating interface, 3D panoramic display, 2D display, mobile platform and a human computer interface. A secured wide area network is used to connect the sensors distributed over the large maritime area such as AIS, RADAR and other distant object detection systems. In addition to that, informal means of data gathering such as SMS can be used. Internet sources are also planned to be incorporated. The intended system is an abstract layer for intelligence information and response guidance.

b. Automatic Identification System (AIS)

The Automatic Identification System is an automatic tracking system used by ships and vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and AIS base stations. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. The following diagram illustrates the AIS object detection system's overview as seen by the developer. Every ship sailing in commercial maritime waters should carry an AIS transponder enouncing its static and dynamic data. The AIS base station at the harbor picks up the AIS signal and registers the ship in the database. The ship then acts as a sensor of its own, transmitting dynamic data such as GPS coordinates, COG, SOG etc [4].

Fig. 2 is the abstract view of the AIS systems as seen from the fusion engine. AIS base stations are connected through a wide area network to a centralized fusion centre.

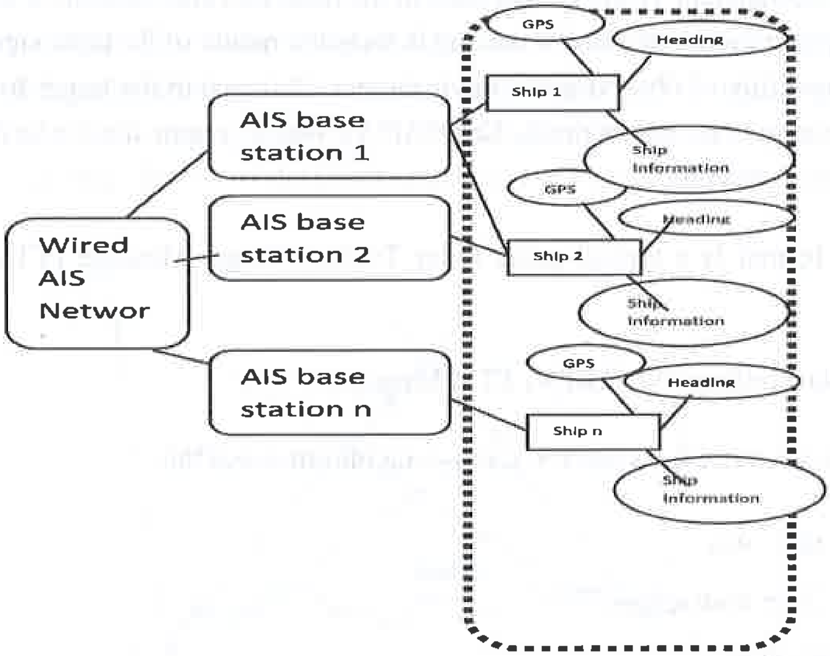

Fig 2. AIS object detection system

The following is a format of a sample sentence of an AIS output interface statement.

!aaccc, x1, x2, x3, c—c, x4*hh<CR><LF>

Among the sentence, "c—c" is a data field of "6 bit" binary encapsulated data and the example of the interface statement is shown as follows.

!AIVDM,1,1,B,**F0WDBv22N2P3D73EB6>6bT20000**, 0*76

!AIVDM,2,2,3,B,1@0000000000000,2*55

Every ship emits these sentences periodically with static ship related information Eg; the name of the ship, MMSI (Maritime Mobile Service Identity), IMO (International Maritime Organisation) code etc. and voyage related data such as latitude, longitude, heading etc.

Whenever a ship is registered by the AIS data, the database will be updated with its information with the primary key of the MMSI number which is unique to each ship. Then as long as the ship is in the vicinity, the database will keep its records updated in real time. Once the ship leaves the range of the AIS, a record is kept for future references with its path in the interested maritime domain.

Protocol decoding is discussed in depth in reference [3],[4]. Briefly, the above payload is converted from 6 bit binary strings to 8 - bit binary strings and pre-specified sections are identified from the specific pattern.

c. Radio Detection and Ranging (RADAR)

Radar is an electromagnetic (EM) system used in the detection and location of objects. It operates by transmitting a pulse-modulated EM wave and detects the nature of the echo signal. Radar is used to extend one's capability of observing the environment. Distance to the target from the Radar and the bearing of the target can be obtained. The RADAR has a system similar to that of AIS, when messaging target information.

The following format is a typical pulse radar Tracked Target Message (TTM) signature of a tracked target.

Automatic Radar Plotting Aid (ARPA) TTM Message:-

$--TTM,xx,x.x,x.x,a,x.x,x.x,a,x.x,x.x,a,c--c,a,a,hhmmss.ss,a*hh

1=Target number, (00 - 99)

2=Target distance from own ship

3=Bearing from own ship

4=Target bearing is T / R (True / Relative)

5=Target speed

6=Target course

7= Target course is T / R (True / Relative)

8= Distance of closest point of approach)

and so on ...

Radar with the ARPA capability can create tracks using radar contacts. The system is capable of calculating the course, speed and closest point of approach (CPA), of the tracked target, thereby revealing if there is a danger of collision. TTM data extracted from the RADAR are fed to the information fusion engine. This information is fed to the 3D /2D virtual environment creating a real time environment virtually.

For the fusion process, the target information which is given in range and bearing, is then converted to latitude and longitude using the following equation written in Java programming language.

Equation to find Latitude:

Latitude = Math.asin [Math.sin(lat1) * Math.cos(linDistance/6371) + Math.cos(lat1) * Math.sin(linDistance/6371) * Math.cos(bearing)]

Equation to find Longitude:

Longitude = Lon1 + Math.atan2{ [Math.sin(bearing) * Math.sin(linDistance/6371) * Math.cos(lat1)]* [Math.cos(linDistance/6371)]}

When multiple RADARs are connected, a separate fusion algorithm has to be developed. When the ARPA data are received through the WAN in NMEA 1083 standard, data is interpreted to get the target movements and positions from range and bearing.

Further research is underway to derive a new algorithm to introduce any future sensor addition to the system. If an object is tracked by multiple radars as shown in the Figure 3, a fusion algorithm has to be utilised. When a single target is detected from multiple radars they are viewed as two different targets. Thus the algorithm has to be designed to fuse these two targets information and produce a single target.

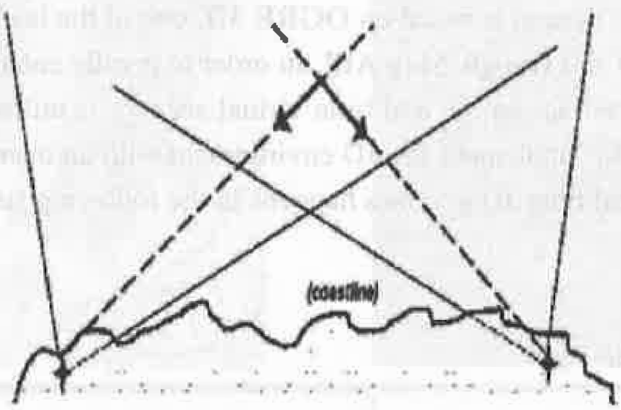

Fig 3. Single target from multiple RADARs

d. CCD cameras or Thermal Images

A possible addition to the fusion platform information is a video stream. Most IP cameras are equipped with built-in direction notification mechanisms. When the position and direction of the camera are known, then the information from the camera can be accurately incorporated to the fusion algorithm.

3. OBJECT IDENTIFICATION PIPELINE

When an object is detected by the RADAR, it is first fused with AIS information to identify the target. When the target is identified, more information available an internet data sources about the same is extracted.

If not, other information sources such as intelligence information, Naval Automatic Vessel Locating System (AVLS) and transponder data etc. could be cross-matched to improve accuracy.

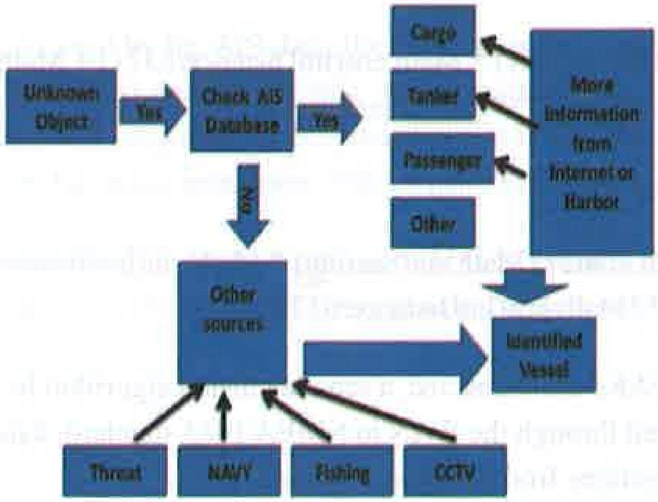

Fig 4. Identification Pipeline

4. REAL TIME RENDERING OF VIRTUAL WORLD

The entire visualization system is based on **OGRE 3D**, one of the leading free and open-source graphics rendering engine and **Google Map API**. In order to greatly enhance user perception, multiple-tiled displays extended across the real time virtual scenery is utilised. [6], [8]. Additionally, Google Map API is used to supplement the 3D environment with an overall picture and additional information. Rendering real time 3D graphics happens in the following steps.

a. Real world in 3D Modeling

3D models are created using precise high resolution photographs and modeling using **3D studio Max** with a low polygon count. Real world objects such as ships, boats, other marine vessels, buoys, harbors, lighthouses and other coastal structures with significant importance are modeled. The models of the vessels are updated according to a hierarchy. Any moving object detected and tracked by the RADAR is modeled as an unknown object with a higher uncertainty. AIS and other information sources such as CCTV cameras, AVLS, intelligence means will have lower uncertainty and will display the real object with lesser uncertainty. Generic models of cargo vessels, passenger vessels, tankers, boats, and naval vessels are modeled and presented in the real time virtual environment with the identical model extracted from a database.

Fig 5. Sample modelled harbour area

b. Achieving the precision of the virtual world

Precision is achieved by modeling the actual environment appearance on top of Google maps. Further all the interested maritime landmarks are modeled in 3D and are placed on the Google maps image using 3D studio max. **OgreMax Scene Exporter** is used to export the modeled environment from **3D studio max** to **Ogre 3D**. The **OgreMax Scene Exporter** is a **3D Studio Max** plug-in that exports **3D Studio Max scenes** to **OgreMax scene files**.[5]

Lon/Lat (Ln, Lt)	Virtual position (x, y)
[Ln_1, Lt_1] → (79.847423, 6.941968)	[X_1, Y_1] → (106000, 36000)
[Ln_2, Lt_2] → (79.849883, 6.942490)	[X_2, Y_2] → (112090, -37380)

Fig 6. Geo referencing

Finally, the virtually created environment is compared with the real environment. To incorporate ships and important landmarks into the **Ogre3D** virtual world, latitude and longitude data received from fusion engine are then converted to matching coordinates with the virtual world and real world. To exactly map the 3D virtual environment with the real world, the objects are placed in **Ogre3D** environment with calculated coordinates. Using the **Ogre3D** library, the coordinates of the position of the target are extracted according to the pivot point of the 3D model. Then the corresponding latitude and longitude is obtained from **Google maps**. Then, using following simulations equations, constants of 'C1', 'C2', 'P' and 'Q' are extracted.

$$(long_1)P + C_1 = X_1$$

$$(long_2)P + C_1 = X_2$$

$$(lat_1)Q + C_2 = Y_1$$

$$(lat_2)Q + C_2 = Y_2$$

Solving the above simulations equations in real time **Ogre3D** determines the coordinates using real world latitudes and longitudes.

$$P = (X_1 - X_2)/(long_1 - long_2)$$

$$C_1 = X_1 - (long_1)P$$

$$Q = (Y_1 - Y_2)/(lat_1 - lat_2)$$

$$C_2 = Y_1 - (lat_1)Q$$

5. PANORAMIC VISUALIZATION

Panoramic images and videos are regularly used in virtual reality applications such as virtual walkthroughs, flight simulators, tele-pretence, etc. In this project, the panoramic visualization technique is adopted to enhance user perception of real time environment.

The visualization technique is based on a maritime navigation simulator [5]. Client-server architecture is used in sending synchronized information to the visualization computers. In each client computer, the same virtual environment is loaded and position, orientation values are received by a parental node.

6. EXPERIMENTAL OBSERVATIONS

Currently, the AIS network of Sri Lanka Navy has been integrated with a 2D map type display. The technology used is Google Maps API [6],[8], which is a reliable internet - based GIS tool with customizable and user - friendly API. The low cost and accelerated implementation were made possible because of the web application provided by Google. The major drawback of the system is its reliance on internet connectivity when downloading satellite images.

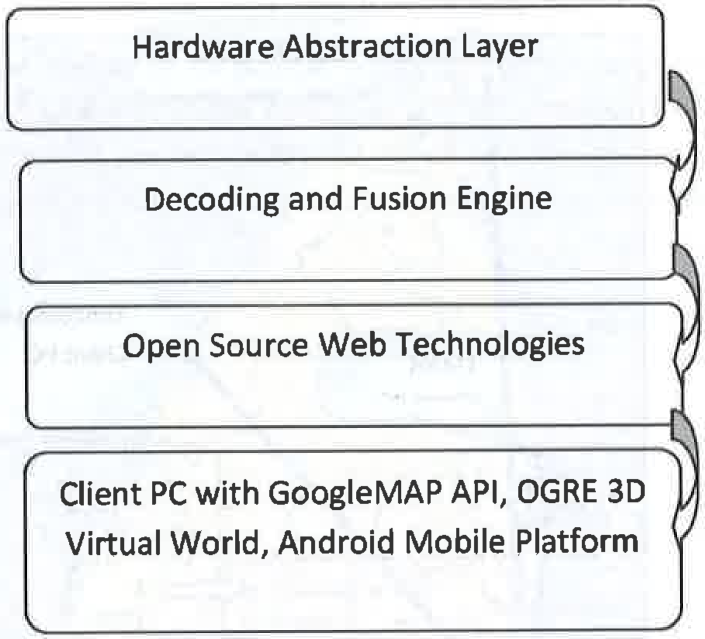

Fig 7. Simplified software model

Fig 8 illustrates the simplified architecture of the technologies used in the fusion system. This is currently deployed in Navy Ops rooms around the island as indicated in Fig. 9.

Fig 8. Client user interface of AIS target display

This is an effective method of distributing fused information while making use of web technology.

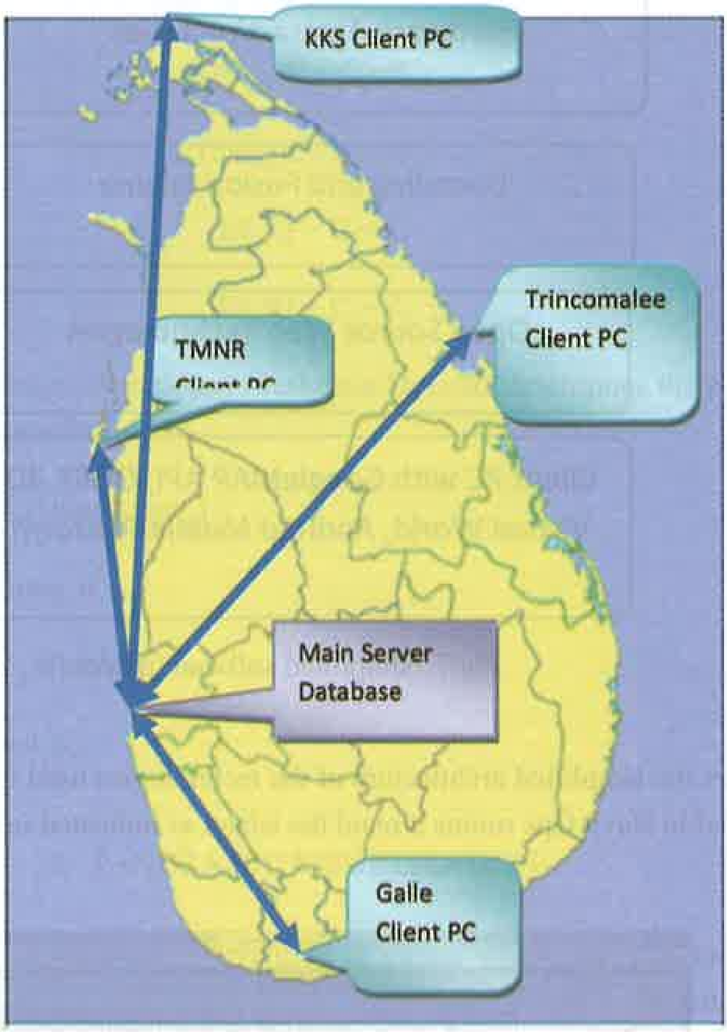

Fig 9. Deployments around the country

Fig 10 is an image from the 3D client interface. The 3D virtual system requires higher level computers with dedicated or GPUs.

Fig 10. 3D sky view

7. FUTURE RESEARCH

Future research will focus on generic sensor description procedure of the sensor input which will facilitate the fusion of information from any given sensor. Further, improvements on the visualization of sensor information on the 3D virtual environment are yet to be implemented. Fusion of data from a greater number of various sensors is incorporated to reduce the uncertainty of received data.

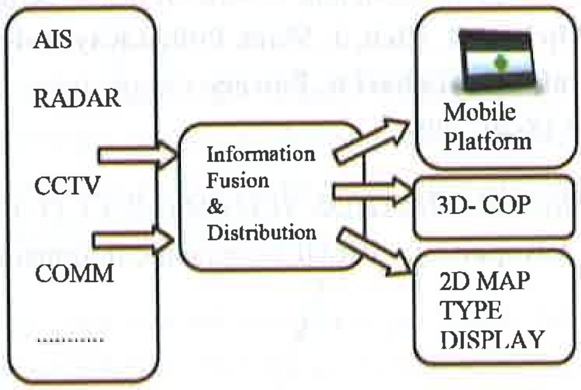

Fig 11. In and out of information

This will fuse the data fusion engine as a black box, to sensor inputs and outputs, enabling the required information to be distributed to each selected platform as shown in figure 11.

Future research can even go beyond a mere tactical picture to a complete surveillance decision – making a model with reasoning capability for military applications. [7]

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