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Reprint Series NURC-PR-2007-006

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October 2007

Originally published in:

UDT Europe, Undersea Defence Technology Europe, Naples, Italy,
5-7 June 2007.

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Multi-Sensor Data Acquisition, Tracking, Fusion and Intelligent Decision Aids in the NATO Maritime Situational Awareness Initiative

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Abstract

The objective of the NATO Maritime Situational Awareness initiative is to effectively understand anything that could affect the security, safety, economy or environment of the Alliance in the global maritime environment and to provide a more effective contribution to the maritime picture. Information delivered by airborne and spaceborne sensors, coastal and maritime radars and Automatic Identification System (AIS) transponders is collected and analyzed. Ships can be automatically detected in open sea areas from Synthetic Aperture Radar (SAR) pictures of commercial satellites provided in near real time. In some conditions, ship speed and heading can be obtained and ship pre-classification achieved. Statistical analysis of AIS messages and radar/SAR tracking coupled with AIS fusion provide the appropriate input to further automated anomaly detection tools. Intelligent decision aids further reduce the false alarm rate, contribute to a better maritime picture and support the decision making process for following investigation or action.

Introduction

In recent years, Defence Against Terrorism has become a priority for NATO Nations around the world. Maritime surveillance, from open sea to shore, and port protection are playing an increasingly important role in naval activities. In a context of limited resources, efficient methods of detecting and classifying vessels and identifying those that are suspect have been developed, increasing the security of NATO nations. The NURC, a NATO Research Centre, has been working on key technical issues and is contributing innovative solutions, based on a long tradition in data acquisition, multi-sensor tracking and fusion techniques, automatic pattern recognition, information processing, detection theory and systems. Experimentation and validation of new concepts based on spaceborne sensors, radars and Automated Identification Systems (AIS) have opened the way for long and medium range maritime surveillance.

Problem Statement

The Automatic Identification System is required on board vessels larger than 300 tons. The initial exploitation of these AIS messages has provided a better knowledge of coastal and high seas maritime activities [1]. There are however some limitations to the use of this system for surveillance operations. Because the AIS system is based on cooperation, it can easily be turned off or misused in a number of ways and it is likely that vessels conducting illegal activities will switch off their systems if and when necessary. Currently one can expect to detect suspicious activity if the AIS system is permanently turned off. Over time, it is likely that these vessels will hide in the mass of regular shipping and will exhibit normal behaviour, keeping their AIS transponder turned on most of the time, switching it off only for a short period of time. Detection of such transient threats requires persistent surveillance, multiple sensors and advanced techniques for multi sensor data acquisition, tracking and fusion.
The first key issue is to optimize sensor coverage in space and time, given the limited amount of resources available for this kind of activity. Traditional assets are military vessels and maritime patrol aircrafts and there is a clear need for automated platforms to provide additional capabilities. Preferred potential candidates for

conducting these operations are Unmanned Aerial Vehicles and commercial satellites. Although these systems provide valuable information at long range and in open seas, they still have a problem of cost, autonomy (UAVs) or persistence (satellites). The challenge is to globally optimize the use of all these assets and sensors to maximize the effectiveness of the surveillance operation.

A second key issue is to increase the efficiency of data analysis. Because of the large volume of information available today, particularly for AIS data, automatic data processing, tracking, fusion, analysis and anomaly detection is required to avoid overwhelm operators. The target is smart and agile and automated systems have to be efficient and adaptive. The problem is to keep the false alarm rate at a low level while maximizing the probability of detecting anomalous behaviour.

The NURC is working on these issues to provide reliable technical solutions through research and experimentation.

Commercial satellite imagery

Satellite sensors are a very obvious source of information when there is a need to collect data in open seas. However there are technical challenges to address in order to apply this new capability in maritime surveillance.

NURC has been involved in remote sensing to collect information for meteorology predictions, oceanographic models and experimentations with its satellite ground station. Techniques and algorithms that include commercial satellite radar imagery as a source of information for long range maritime surveillance have been developed. An experiment was successfully conducted in 2006 to validate the technique [2].

Fig. 1 The NURC ground station

Multi sensor tracking and fusion

Data fusion and target tracking are critical components of a multi-sensor surveillance capability. Contact-level data, particularly in multi-sensor settings, provides far too much information to a human operator. Rather, the output of an effective multi-sensor tracker provides a unified surveillance picture with a relatively small number of confirmed tracks and improved target localization.

NURC has a long experience in multisensor tracking and fusion systems in undersea warfare. Historically, prototype or scientific sonars with passive and active capabilities, deployable underwater surveillance systems with multiple sources/multiple receivers that require advanced tracking and fusion techniques have been designed and developed at NURC [3, 4, 5]. In the under-water world, most of the data are provided by a number of individual hydrophones (e.g. sonobuoys) or acoustic arrays and the problem is to detect the useful signal buried in noise or reverberation and provide a contact and a track by means of signal processing, multi sensor fusion and tracking. In the maritime surveillance field, the main sensors are AIS, maritime and coastal radars and SAR imagery detections. Not unlike the underwater situation, these sensors have different performance, range of operation, accuracy and noise characteristics. They also present similar features such as potential data corruption (additional mechanical or transmission noise in acoustic systems, manually input errors or wrong settings in AIS messages) (Fig.2). Those similarities have been exploited to adapt the NURC Distributed Multi-Hypothesis Tracking (DMHT) technology to maritime surveillance with a minimal effort [4]. The main upgrades that have been applied to the DMHT tracker for maritime surveillance application are:

- *Positional measurement data*. Rather than (time, bearing) contact data, here we have (x, y) measurement data, and, correspondingly, simpler recursive filtering (linear Kalman filtering);

- *Track-breakage functionality*. Network AIS track data contains anomalies that result from erroneous use of the technology, e.g. improperly entering ship identification information in the AIS unit. In almost all cases, these are unintentional errors that nonetheless lead to erratic track data. AIS tracks fed through the DMHT module will be essentially unaltered, except that track updates that fall outside a validation gate lead to track breakage.

- *Target-specific coordinate system*. Each target has its own coordinate system centered on the current positional estimate for the target, and tangent to a spherical earth model. As the target moves, its coordinate system slowly translates and rotates. The modification allows for consolidated global tracking.

Future required upgrades include the following:

- *Advanced filtering algorithms*. Information on coastal constraints and traffic flow patterns should be exploited in the prediction stage of recursive filtering computations.

- *Data registration*. There is a need for automated alignment of imagery-based detections for subsequent fusion with coastal-radar and AIS tracks.

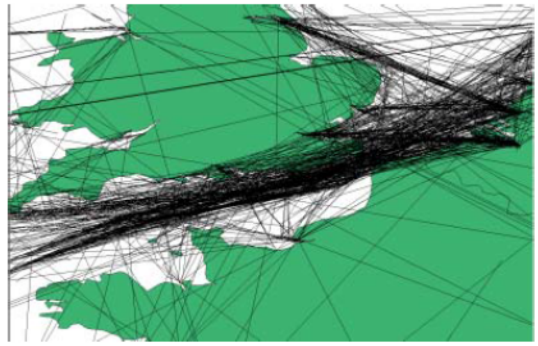

Fig. 2 Corrupted AIS data

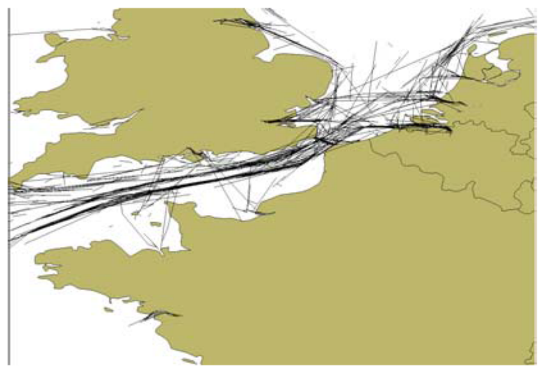

Fig. 3. Processed AIS data

A key requirement for the global fusion and tracking module is the capability to maximize the efficiency of multi-sensor track association with heterogeneous sensor data and limited overlap in area coverage. The following scenario simulation illustrates the problem: the area of AIS coverage and AIS tracks are presented in red and two areas of radar coverage and radar tracks in blue in Fig.4. Twenty ship tracks are present in the figure. Two of these tracks exhibit anomalous behaviour, one with AIS turned off and the other with AIS temporarily off to coincide with target maneuvers. With AIS or radar data only, none of the anomalies can be detected whereas the fused picture in Fig. 5 clearly shows the problem.

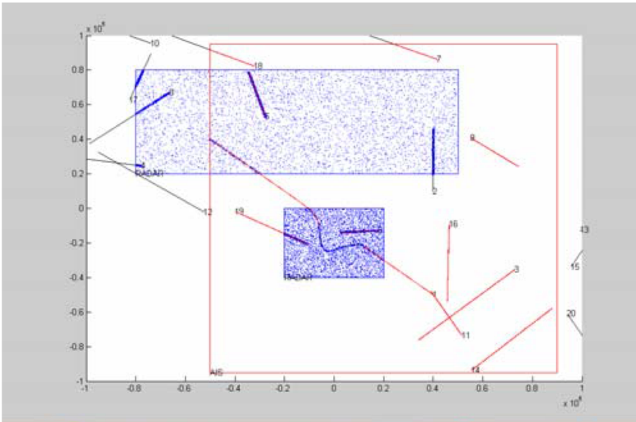

Fig. 4. The input to the DMHT: radar contacts and AIS tracks

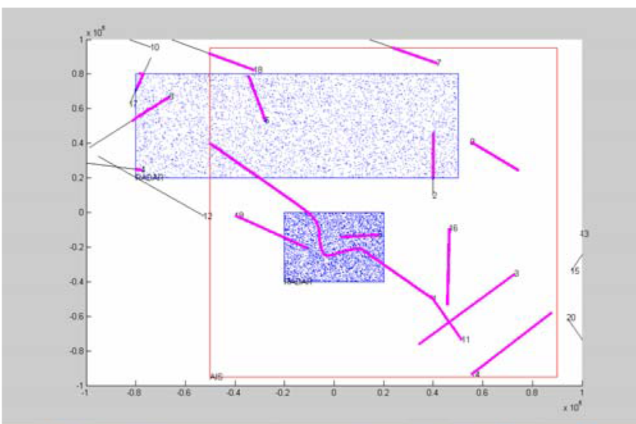

Fig. 5. Fused tracks

Anomaly detection

The first activity in anomaly detection is to characterize the traffic, which can be seen as the background "noise" of a detection problem. Efforts have been made through statistical analysis of AIS messages to describe this background noise. The first four statistic orders are calculated for a number of AIS parameters and provide useful information on statistical ship behavior. Fig. 6 presents the standard deviation of ship speed in the Straits of Gibraltar. The main technical challenge is that AIS information is non-gaussian, non-ergodic and non-stationary. Analysis tools have been developed and are used to look for invariants in time, space and situations where data can be assumed to be locally stationary.

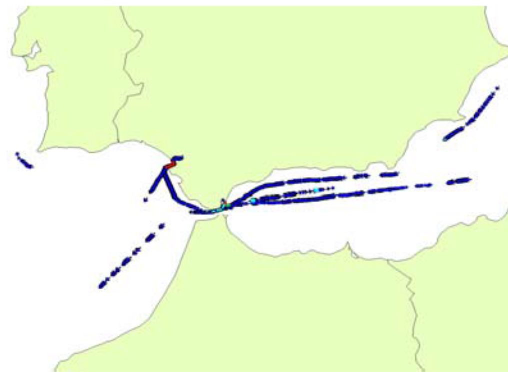

Fig.6 Standard deviation of ship speed

Anomaly detection is then achieved by additional analysis. Competing techniques, such as supervised machine learning and other adaptive techniques are under investigation to maximize the probability of correctly detecting anomalies while keeping false positive detections at a low level. In this field, NURC is leveraging previous efforts conducted in-house on intelligent agents and target behaviour modelling for tactical decision aids in underwater warfare. Neural networks and artificial intelligence techniques have the potential for providing flexible, adaptive solutions [6] but this capability has to be balanced with rule-based algorithms that usually provide more robust and more predictable solutions.

One of the technical issues in maritime surveillance is the abundance of AIS data with few cases of identified and recognized anomalies. This asymmetry creates a problem for training a neural network for instance. A mix of real and simulated data has to be used to develop the adaptive methods and algorithms that are required to effectively detect anomalies.

Experimentation with RV Alliance

Additional data from radar and AIS receiver of the NATO Research Vessel Alliance will be collected and analysed during the next sea trials in the May – June 2007 timeframe and will provide ground truth information. SAR satellite imagery will be collected at the same time through the NURC ground station along with coastal radar data and will augment the dataset for future analysis, development and test of intelligent decision aids.

Conclusions

This paper presents some aspects of the research conducted at NURC on maritime surveillance and how it leverages previous efforts conducted in underwater warfare.
Efforts have been made on data acquisition, with AIS, maritime and coastal radars and satellite imagery providing the information required for maritime surveillance. The challenge is to globally optimize the use of assets and sensors to maximize the effectiveness of the operation.
Multi Sensor fusion and tracking is a key component of the system, providing a simple, comprehensive and more effective maritime picture, essential to anomaly detection modules and optimal asset management.
The development of anomaly detection algorithms is a long term effort. Initial work has been done on the characterization of the maritime traffic in coastal and open waters through statistical analysis of AIS messages and ship tracks. Current efforts aim at developing robust yet adaptive and flexible solutions to provide operators with a high probability of detecting an anomaly while keeping the level of false positives as low as possible.

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Document Data Sheet

Security Classification		Project No.
Document Serial No. NURC-PR-2007-006	**Date of Issue** October 2007	**Total Pages** 5 pp.

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Grignan, P., Coraluppi, S., Carthel, C.

Title

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Abstract

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Keywords

Issuing Organization

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