Overview of maritime situational awareness research at the Netherlands Organization for Applied Scientific Research TNO

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Abstract

This paper gives an overview of research at TNO in the field of maritime situational awareness (MSA). Our expertise on radar, sonar, electro-optics, electronic support measures and tracking/fusion is typically employed for vessel detection and vessel anomaly detection. Illustrative examples of these applications are presented addressing the detection of small boats, over the horizon detection, spatial resolution enhancement of imagery, emitter localisation and identification, a network centric approach for fusing vessel detections and the modelling of vessel behaviour. Furthermore it is explained how recent activities at TNO include the development of a simulator for 3-D maritime situational awareness.

1 Introduction

Maritime situational awareness (MSA) is of key importance to defence as well as civil authorities. Although much progress has been made to improve MSA, there are many items still open to research. Therefore, MSA has become an important research topic in many programmes such as FP7 of the European Union (EU), MARSUR of the European Defence Agency (EDA), and SCI-211 of NATO.

To successfully deliver awareness of the maritime domain requires detection and identification of all vessels including the non-cooperative vessels and small boats and the fusion of these vessel detections with the final purpose to detect suspect vessels or vessel anomalies. Obviously no single sensor can deliver such awareness. Therefore at TNO, no less than eight departments spread over three business units perform maritime research covering the full field of radar, electro-optics, electronic defence, underwater technology, distributed sensor systems and modelling & simulation.

In this paper an overview is given of the MSA research at TNO. Illustrative examples are presented from national programmes as well as from programmes within the EU, NATO and EDA. Specific subjects that are covered include the detection of small boats, over the horizon detection, spatial resolution enhancement of imagery, emitter localisation and identification, a network centric approach to fuse vessel detections, modelling of vessel behaviour and concept development and experimentation.

2 Detection of small boats with radar

Small floating targets like rubber boats or jet skis pose a potential asymmetric threat against e.g. maritime platforms. Under moderate sea state conditions the reflection of nearly all small targets will be lower than the sea clutter. Therefore with conventional detection methods these targets cannot be detected and more sensitive detection techniques like sea clutter suppression have to be used to improve the target to clutter ratio.

Since the sea surface is highly variable in time, the sea clutter also changes from radar scan to radar scan. However, for operational sea state conditions of typically 2-4, the evolution of the sea clutter can be considered a largely deterministic process that is driven by the space-time evolution of the sea surface. Having the space-time data available as a time series of radar scans, it is thus possible to predict the location of a sea-surface reflection in the radar image from previous scans using the space-time model for sea clutter propagation. Subtracting the predicted clutter from the actual scan results in a residual image. This residual image contains those features that are not predicted by the sea clutter model, i.e. the non-deterministic clutter component and the small target. The procedure is illustrated in figure 1. The middle plot contains a number of small targets, two rubber boats like the one in the left plot and two stationary buoys. These targets have a radar reflection of the same magnitude as the surrounding clutter and therefore are difficult to see. After the clutter filtering, however, the small targets are clearly visible in the right plot. With this radar clutter filter technique, small targets can be detected up to 5 nm [Kleijweg et al., 2007].

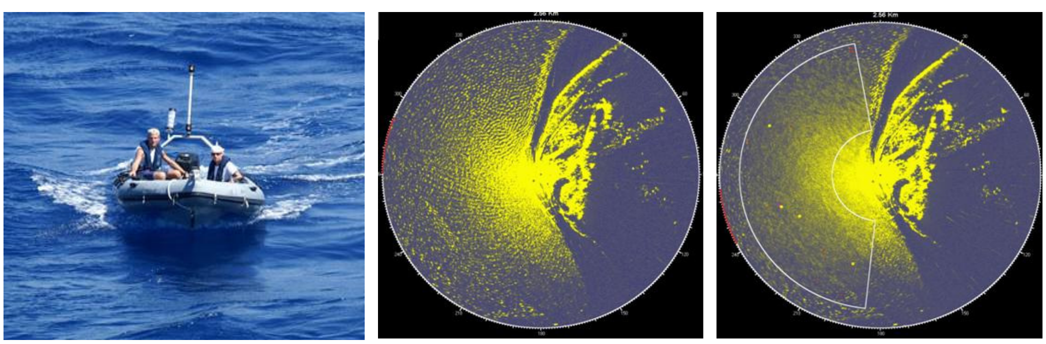

Figure 1: Radar image (middle) with two small boats (left) and two stationary buoys, and radar image after clutter filtering (right).

3 Over the horizon detection of surface targets with sonar

TNO performs research on advanced sonar processing techniques to improve the capability for building an over the horizon operational surface and sub-surface picture.

For the detection, localization and to some extent classification of surface targets, passive low-frequency sonar can bridge the gap left by other sensors when they are ineffective or unusable. Depending on the target's acoustic signature, detection ranges of 50-100 nm can be achieved.

A key component of our research is the development of algorithms that use the increased bandwidth and instantaneous left-right discrimination offered by modern towed array sonars to detect small targets such as go-fasts. These targets could be involved in illegal activities like drugs smuggling. An example is illustrated in figure 2 which shows the detection of a go-fast (left) with a passive towed array (middle). In the right plot, the time and bearing are given on the vertical and horizontal axis, respectively. The broadband spectrum in the middle is caused by the vessel that tows the array. The go-fast can be seen on the right of the broadband spectrum, with a ghost image on the left because of processing imperfections.

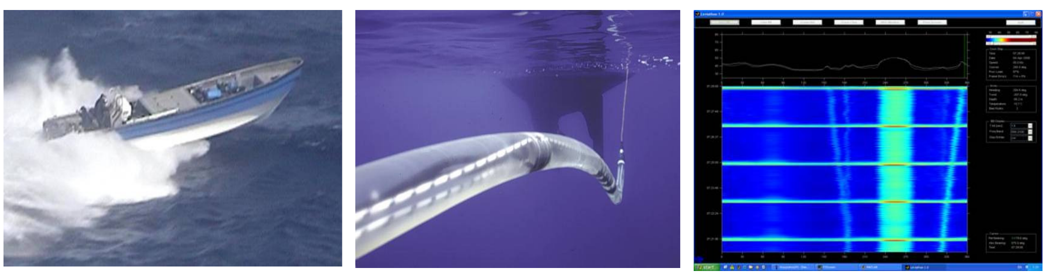

Figure 2: Go-fast (left), towed array (middle) and detection result (right).

4 Identification of vessels with electro-optical systems

Because of their spatial resolution and image contrast, electro-optical (EO) systems like video and infrared cameras are well suited to identify vessels, even at large distance. Still, for security type applications, the resolution or contrast offered by standard cameras may not be sufficient. In such cases, apart from more sophisticated and hence more expensive cameras, advanced processing techniques may offer a more affordable solution. Obviously, because most camera systems have a relatively high frame rate, the success of these image processing techniques relies on a combination of sufficient enhancement and fast processing.

In the two figures below, results are presented of two techniques, one that enhances the resolution and one that enhances the contrast of EO imagery. The dynamic super resolution technique in figure 3 exploits the camera motion relative to the imaged scene induced for instance by the platform or by wind. Because of this relative motion, sub-pixel information is obtained that can be used to interpolate a collected time series of images to a grid of finer resolution. With this technique, typical resolution enhancements of 2-10 can be obtained which in case of figure 3 means that details on the ship's bridge like antennas and other navigation means become visible. Figure 4 shows the result of a contrast enhancement technique that locally stretches the distribution of grey-scale values in an infrared image to obtain a better contrast. The image shows a harbour. In the right plot details of the crane on the left, the old galion in the middle and the cars in the front can be clearly seen.

Figure 3: Result of dynamic super resolution technique in an optical image.

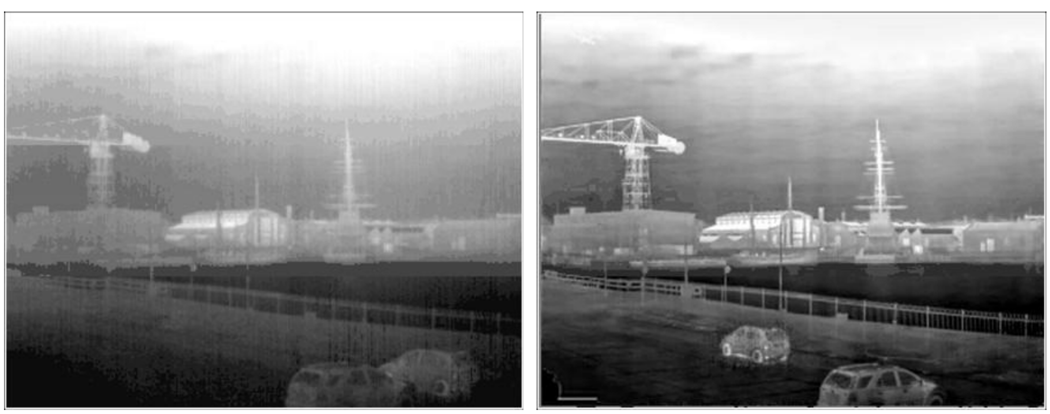

Figure 4: Result of contrast enhancement technique in an infrared image.

5 Emitter localisation and identification with electronic support measures

Electronic support measures (ESM) passively detect electromagnetic emissions of interest to locate, characterise and possibly identify the transmitting source. For the purpose of maritime surveillance, these emissions could result from Automatic Identification System (AIS) transponders or navigation radars.

In figure 5 an example is shown of emitter localisation with a direction finder (left plot) of vessels transmitting AIS. Basically, with this technique, the location of the AIS source is determined with the direction finder and compared with the position in the transmitted AIS message. Position discrepancies then indicate suspect vessels. As can be seen in the right plot, in most cases, the true vessel positions (horizontal axis) as determined with the direction finder coincide with the transmitted positions in the AIS messages (vertical axis). However, position discrepancies are also noted which are assumed to be caused by e.g. malfunctioning AIS transponders. It should be mentioned that in the experiment, only the front part of the direction finder was used which explains the ambiguity in the right plot of figure 5, i.e. two position solutions are found with the direction finder.

To identify radar emitters, we look for characteristic features in the pulse emitted by the vessel's navigation radar such as pulse duration, the shape of the pulse or more complex characteristics derived from the pulse shape. Because these features are derived from the radar pulse, the method is called intrapulse identification.

In an experiment of about one week, an X-band antenna for receiving radar pulses was deployed at TNO. With that antenna, radar pulses of specific ferries and cargo vessels in a patch of sea (red lines in left plot of figure 6) including the portway to the harbour of Rotterdam were collected. In figure 6, the blue lines are the vessel tracks of the ferries and cargo vessels of which there were a total of seven in the depicted analysis series. Because these vessels carry AIS, their radar pulses could be uniquely coupled to the vessel identities. The right plot in figure 6 shows as an example the radar pulses of three different vessels. Using these pulses in an algorithm based on a principal components analysis to reveal unique differences, the seven vessels could be identified and separated from each other.

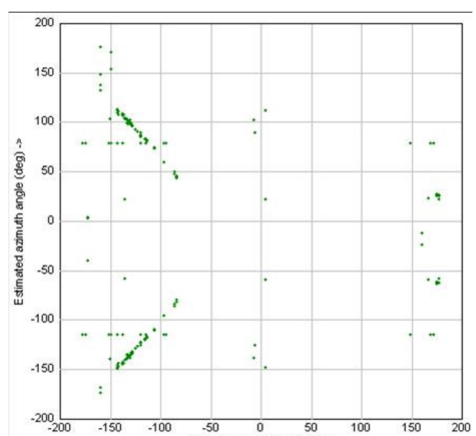

Figure 5: Verification of vessel locations in AIS messages (right) with vessel locations determined with a direction finder (left).

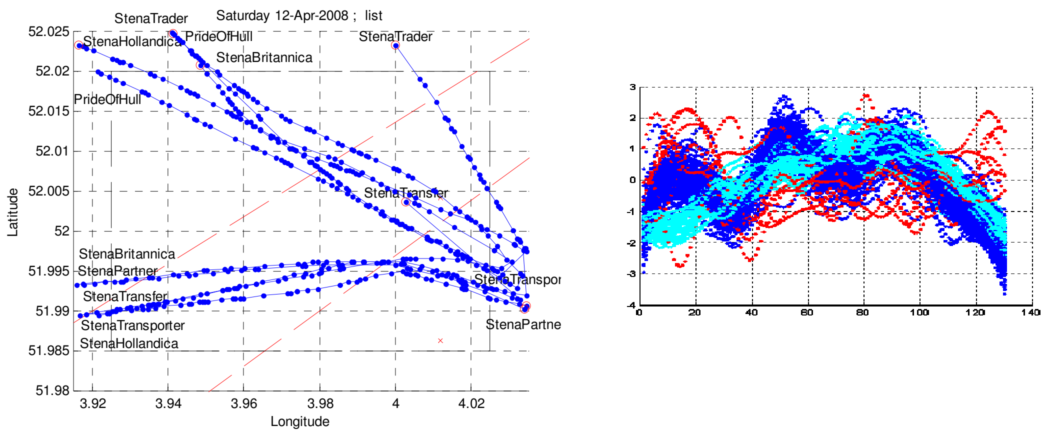

Figure 6: Identification of navigation radars with intrapulse method. The left plot shows a number of seven vessels passing through the test area (red lines). The right plot shows the radar pulses of three of these vessels.

6 Fusion of vessel detections

One of the problems with maritime operations in coastal waters compared to the high seas is the increase in the complexity of the maritime picture formation for situation awareness. Nowadays the image formation is platform centric, i.e. using active and passive sensors a common picture is built up separately on each platform and only when it is more or less complete it will be exchanged through classical data links such as Link 11 or 16 in the form of tracks. Considerable improvement of the quality of the common picture can be achieved through a (multi-platform) network centric approach in which the data from the sensors on different platforms can be exchanged e.g. as plots and combined in an early stage [van Iersel et al., 2008]. The most important advantages of this approach are an increased probability of detection and a higher accuracy and better continuity of the track.

To illustrate this approach we have coupled our multi-hypothesis tracker/fusion engine M6T to our recently developed NAIHS (Networked Adaptive Interactive Hybrid Systems) model [Kester, 2006] to handle the track information requests of different platforms. As depicted in the left plot of figure 7, a naval scenario was specified in a simulator environment in which three friendly vessels (yellow circles) detect an enemy fighter (green circles). As shown in the right plot, three different methods to track the enemy fighter (red line gives the fighter's trajectory) were tested: (1) no contacts were exchanged and only tracking is performed (blue track shows result obtained by one of the vessels), (2) all contacts are exchanged and only tracking is performed (black track), (3) contacts are evaluated by association and only those contacts which can be associated to a track (information request handled by NAIHS) are exchanged (yellow track). By comparing the tracks with the enemy fighter trajectory it was found that the network centric approach with information request (method 3) gave the best detection results and track accuracy/continuity, followed by the network centric approach without information request (method 2) and the platform centric approach (method 1).

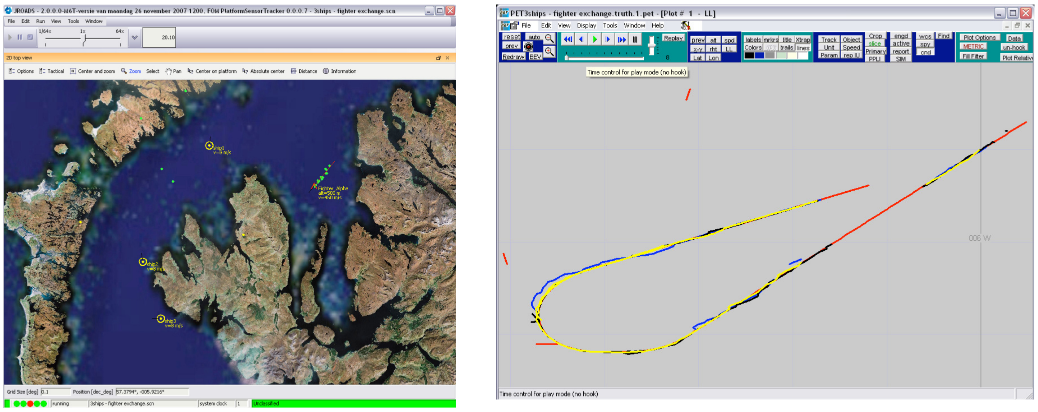

Figure 7: Configuration of three vessels to track an enemy fighter (left) and tracking result (right). See the text for an explanation of the track colours in the right plot.

7 Modelling of vessel behaviour

Apart from instantaneous detection of vessel anomalies with sensors or sensor networks, research at TNO has begun to look at anomaly detection as derived from vessel behaviour. To detect suspect vessels, a vessel's behaviour has to be described by a number of indicators. The indicator values are compared with statistics that describe normal behaviour where a practical way to define normal behaviour is to compute the mean of the indicators over a long time series. A large enough deviation from the normal behaviour then indicates a suspect vessel.

One year of coastal AIS data has been collected with an AIS receiver deployed at TNO to learn about normal vessel behaviour along the Dutch coast. Vessel behaviour is described by four basic indicators: (1) speed over ground, (2) direction over ground, (3) vessel length, and (4) time of day. Direction over ground equals the vessel's course over ground with 180º ambiguity. Time of day is computed as the absolute value of the hour of day relative to noon. In this way, AIS timings at noon are assigned a time of day around 0 hours, timings around dawn and dusk are assigned a value of 6 hours, while timings early in the morning and late at night are assigned a time of day of about 12 hours. Vessels were grouped into four classes using the vessel type field in AIS: (A) fishing vessels, (B) passenger ships, (C) tankers, and (D) cargo vessels. For each class, normal behaviour has been derived from the AIS data by averaging the speed over ground, direction over ground, vessel length, and time of day, in the received AIS messages over a grid of about 5 km cell size.

As an illustration, figure 8 shows normal behaviour of the passenger ships. These ships have an average length of 150-200 m and their travels are confined to shipping lanes connecting Rotterdam and Amsterdam with other ports. The average speed of the passenger ships is about 15 knots and significant variations in the time of day are observed. Note that further inside the Rotterdam port area, the vessel length decreases to 50-100 m. Typically, such smaller ships provide transport to passengers between these ports and other Dutch cities.

For all indicators the variations with respect to the mean were computed. These variations were of the order of 10% or less. These results show that the behaviour of passenger ships is systematic in place and time which means that suspect vessel behaviour such as excursions out of the shipping lanes or a reduction in vessel speed are easily detected. It should be mentioned that the other vessel classes behave less systematically wherefore suspect fishing vessels, cargo vessels and tankers are more difficult to detect [Smith et al., 2008].

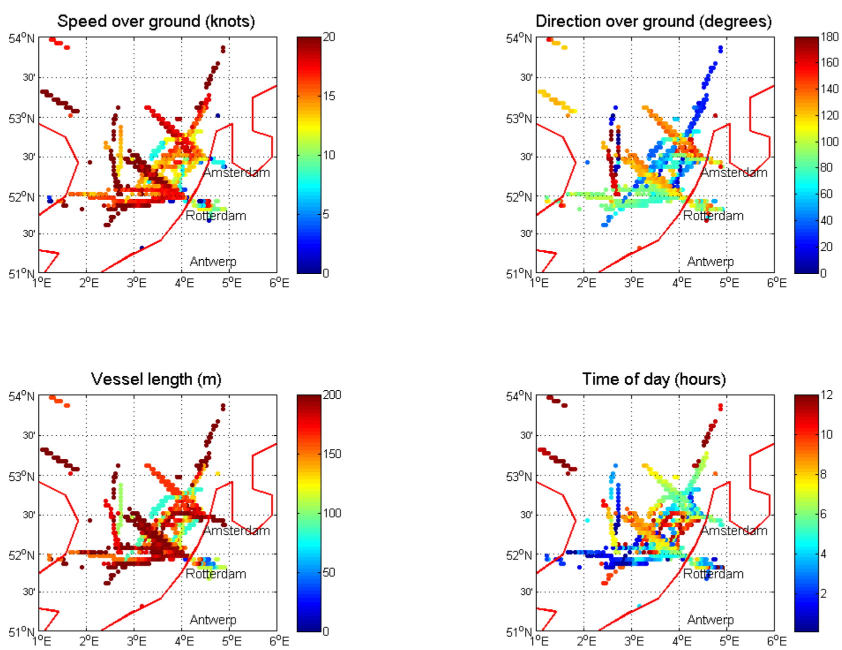

Figure 8: Indicators for passenger ships. Shown are: speed over ground in knots (top left), direction over ground in degrees (top right), vessel length in meters (bottom left), and time of day in hours (bottom right).

8 Simulation environment

J-ROADS is TNO's modular simulation environment for concept development and experimentation, originally developed for simulation of joint theatre air and missile defence. It is a very diverse and flexible simulation model, usable for real-time air defence exercises and wargames, for analysis on extended air defence and as a test bed for analysis of specific (sub)systems or capabilities. As such JROADS contains detailed models for sensor and weapon systems, track management, and communications whereas simulated threat types include fighters, cruise missiles and tactical ballistic missiles. Environmental factors such as terrain and weather conditions and their effect on the sensor performance are also incorporated into J-ROADS.

Because of its generic structure, J-ROADS allows easy creation and incorporation of new systems and capabilities. Therefore, a recent development at TNO is to use this simulator for the implementation of various maritime surveillance sensor models. Currently, J-ROADS includes sophisticated models for radar, AIS, and ESM as well as the M6T multi hypothesis tracking/fusion engine. With this configuration we are currently implementing the baseline network of the Netherlands Coastguard and investigate possible surveillance improvements. As an illustration and without going into details, figure 9 shows the complexity of the surveillance network.

In the near future J-ROADS will be augmented with satellite AIS, camera systems, and sonar, working towards integration of the most commonly used above and underwater sensors of which the result will be a complete 3-D maritime situational awareness.

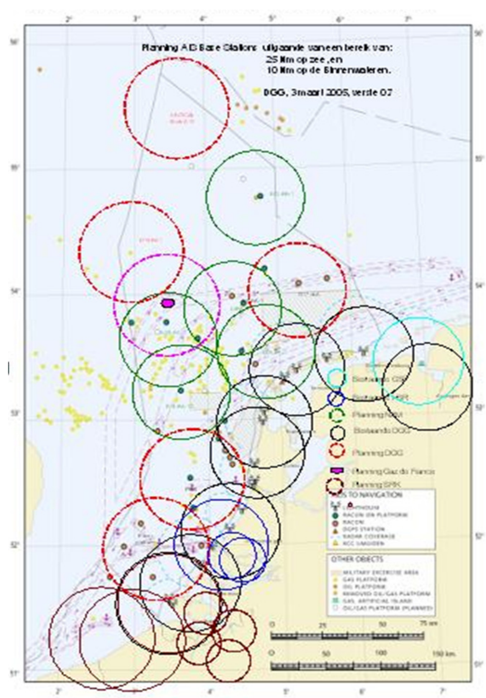

Figure 9: Surveillance network of the Netherlands Coastguard consisting of radar, AIS and ESM stations.

9 Conclusions

This paper gives an overview of research at TNO in the field of maritime situational awareness. Expertise on radar, sonar, electro-optics, electronic support measures and tracking and fusion is employed for vessel detection and vessel anomaly detection. Most recently, the activities at TNO include investigations into the detection of suspect vessel behaviour and the development of a simulator for 3-D maritime situational awareness.

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