ScanMaris : automatic detection of abnormal vessel behaviours

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Automatic Detection of Abnormal Vessel Behaviours

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ABSTRACT

The ScanMaris project is a software workshop designed to develop and evaluate solutions for thread prevention and maritime border monitoring. It relies on enriched tactical picture exploitation tools resulting from the continuous treatment of important volumes of heterogeneous data gathered in real time and differed time. ScanMaris will enable the supervision of the permanent evolving traffic on a global maritime zone in order to follow the flow of transported goods (bulk, containers, energy, chemical….) according to various routes (corridor, coastal traffic…) and to automatically detect criminal traffic of illicit products.

ScanMaris will use data treatment tools to merge ship's kinematic data and other information to establish and maintain a global enriched tactical picture compilation of the traffic, the training methods and the models which exploit the tactical picture. This produces a permanent knowledge of goods flows, improves its follow-up and the rules of investigation organised to detect irregularities like illicit products flows, disasters, regulation violations, etc.

The ScanMaris project will involve functions that improve the effectiveness of a global surveillance of the contraveners. They will contribute to set up optimal answers and intervention means adequately fitting the struggle against illicit activities and maritime violations.

CONTEXT

Maritimes activities, and more generally sea-related issues, are of the utmost importance for the European Union (EU). As a matter of fact, its shoreline is approximately 150,000 km long (even more than that of the United States) and the regulated maritime zones under Member States' jurisdiction are larger than their terrestrial territory. As maritime spaces are more and more exploited and maritime activities move further from the coast, management and surveillance of territorial waters (up to 12 nautical miles) are not sufficient anymore. Member States have now a vital interest in their Exclusive Economic Zones (EEZ) which extends to 200 nautical miles (370 km) from the coast. However, vessel traffic monitoring is currently unable to be extended efficiently to such a range.

This priority can be explained by the fact that over two thirds of EU's borders are coastal and that 90% of the EU foreign trade and 43% of its internal trade are transported by sea. This represents 3.5 billion tons of cargo and 350 millions of passengers per year. The map below (Figure 1) establishes a comparison between trade by road and by sea. A blue line represents, in tons of freight, for the same size, twice as much as a red line, thus revealing the importance of maritime freight transport.

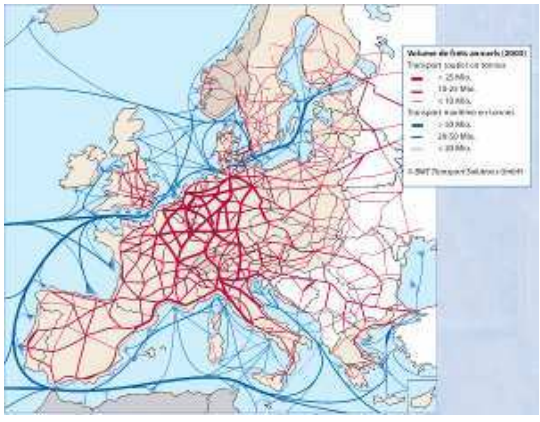

Figure 1: European ocean and short sea shipping routes

OBJECTIVES

Maritime criminal activities become more and more organised. So, future solution should be set up for illicit activities such as clandestine immigration, terrorism and trafficking of drugs, weapons and illicit substances. Indeed, maritime traffic is peculiarly well suited to the development of illicit activities. For example, illegal migrant prefer maritime routes because they can enter through long sea borders where they can hardly be detected. Around 500.000 people enter the EU illegally every year, with few entry points: the Strait of Gibraltar, Italy and Malta islands, etc. The economy based on illegal migrants has generated $10 billions per year, placing it just after weapons and drug traffic.

Moreover, EU has no coordinated security approach on this matter as yet and is not currently able to track and monitor every ship in order to detect abnormal or illicit behaviour. This is why a common surveillance solution allowing Member States to track and fight illicit behaviours on a wide maritime area is imperatively needed.

Then, technical objectives of the ScanMaris project are to provide a new generation of maritime surveillance solution allowing:

- Overall and permanent coverage of the Exclusive Economic Zone (EEZ).
- Continuous collection and fusion of heterogeneous data provided by various types of sensors and external data sources.
- Supervised automatic detection of illicit behaviours.
- Compliance with the relevant national and EU legal requirements (privacy, data storage, proof gathering…).

No equipment deployments and data exploitation systems are currently able to answer all these requirements. However, progress has been made in long range sensors, heterogeneous data fusion and comportmental behaviours that could be usefully merged to build an innovative maritime surveillance solution for security applications.

The ScanMaris project will study, develop and experiment advanced algorithms to learn various vessel compartmental behaviours (Learning Engine) and to automatically extract abnormal behaviours (Rule Engine), such as illicit activities, from a global enriched tactical picture compilation of the vessel traffic over a wide area.

TERRORIST THREATS CONTEXT AND IMPACTS

Context:

Immediately after the devastating September 11th World Trade Centre attacks in New York, governments around the world scrambled to assess their vulnerability to highly organised terrorist groups willing to sacrifice thousands of lives to achieve their aims. The risk of mega terrorism, once a spy novel fantasy, suddenly became very real, and maritime transport system loomed large in eyes of securities agency worldwide as a prime target and/or vehicle for future attacks.

In EU foreign and internal trading, one of the main special concerns is bulk liquid shipment (ranging from crude oil, distilled oil derivatives and liquefied natural gas to molasses and vegetable oil). While the destructive potential of these cargos is great, terrorist attacks could have strong direct effects on critical transport infrastructures such as shipping lanes, vital energy procurement and thus highly disruptive consequences on EU states business.

Policy makers also frequently cite passenger ferries as attractive to terrorist because such attacks are easy to execute, may kill many people, would likely draw significant media attention, and hence, high public awareness and strong psychological impact.

As an example of potential terrorist actions, these previous dangers highlight the combined potential for a bulk liquid shipment to be used as a weapon in a terrorist attack against a ferry just as jet aircrafts were used in 2001 World Trade Centre attacks. These combinations of targets, then, would cause as much as possible loss of life and at the same time would disrupt worldwide national energy procurements by threatening vulnerable trade routes.

As we face the varied threats of terrorism and other lucrative criminal activities, future and innovative solutions shall be set up to permanently track and monitor critical ships and vulnerable trading lanes in order to early detect abnormal or

illicit vessel behaviour. These new generations of maritime surveillance solutions will allow:

- Overall, permanent and all weather coverage of wide maritime areas.
- Continuous collection and fusion of heterogeneous data provided by various types of deployed sensors and external information sources.
- Supervised automatic detection of abnormal vessel behaviours (track and activity).
- Analysis of the nature of suspect event suite of spatial and temporal abnormal behaviours.

No equipment and information system deployments are currently able to answer all these requirements. However, significant technical progress has been made in wide maritime area coverage by different sets of sensors, heterogeneous data processing and fusion, and detection of abnormal behaviours that could be usefully merged together to built an innovative ocean and short shipping routes surveillance solution for efficient security applications in critical transport infrastructure protection.

Impacts:

With this dependency on maritime traffic, the European economy is strongly vulnerable to maritime terrorist attack, and sea transport routes should be assessed a high priority as critical transport infrastructures: they are vital to the EU economy, they are currently highly vulnerable and there is (as will be demonstrated below) a very high potential for improvement in their protection.

Acts of maritime terrorism may have many objectives. They may seek to cause human casualties, economic losses, environmental damage, or other negative impacts, alone or in combination, of minor or major consequence.

If human casualties are the principal objectives, passenger vessels such as cruise ships and ferries, which together account for a few percent of the world commercial fleet, may be more attractive terrorist targets than cargo and other vessels. As an example in the Mediterranean Sea, more than 200 ferries transport about 150.000 passengers daily in total and 50 millions of passengers annually. The following figure (Figure 2) provides the main Mediterranean ferry seaways and destinations.

Figure 2: Main Mediterranean ferry seaways and destinations.

If economic loss is the primary objective, terrorists may seek to carry out different type of attacks, with potentially few human casualties but significant impacts to critical transport infrastructure such as important commercial maritime routes (ocean and short sea shipping lanes). The Limburg bombing may have been an attack of this type, threatening to disrupt the global oil trade and causing considerable consternation among tanker operators. Although the bombing killed members of the Limburg's crew, it caused insurance rates among Yemeni shipper to increase by 300% and reduced Yemeni shipping volumes by 50% during months after the attack.

One ship type that is reputed as a lucrative target of maritime terrorism is liquefied natural gas (LNG) tankers. According to a GAO (U.S Government Accountability Office) study, a LNG tanker can be used not only to affect sea commerce (energy), but also to harm people, other vessels and critical infrastructure more than one mile away from the ship. In other word, a LNG "weaponized" near a port or in intense vessel traffic could become a terribly frightening instrument.

As an example in the Mediterranean Sea, more than 600 tankers (oil, chemical and liquefied gas) travel daily servicing 30% of the world oil and LNG trading, and 20% of the transported chemical substances at sea. The following figure 3 gives the main energy routes in the Mediterranean Sea.

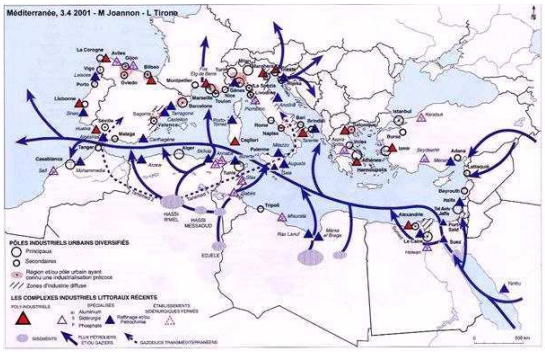

Figure 3: Main energy routes in the Mediterranean Sea

Maritime security analysts have discussed numerous potential tactics for terrorist attack on maritime targets. The following passage from the national Strategy for Maritime Security (Department of Homeland Security and Department Of Defence, USA, September 2005.p.4) summarises many of the tactics most commonly mentioned in maritime security discussion:

> *Terrorists can also develop effective attack capabilities relatively quickly using explosive-laden suicide boats and light aircraft; merchant and cruise ships as kinetic weapons to ram another vessel, warship, port facility, or offshore platform; commercial vessels as launch platforms for missile attacks; underwater swimmers to infiltrate ports; and unmanned underwater explosive delivery vehicles. Terrorists can also take advantage of a vessel's legitimate cargo, such as chemical petroleum, or liquefied natural gas, as the explosive component of an attack.*

So, an accurate assessment of the current nature and scope of the global maritime terrorist threat should be driven by an assessment of what is probable, rather than merely possible. In consequence, it is apparent that probable scenario attack would be based on different combinations of targets and tactics. Considering the adaptability, ingenuity, tenacity and audacity of terrorist community, it seems a clear priority to develop and apply the relevant maritime tactics, techniques and procedures.

Given the dynamic nature of the terrorist threats, and the myriad of forms that they can take, key considerations to be taken into account in assessing the general likelihood of a maritime attack against states, are:

- Ocean and short sea shipping activities are performed over wide maritime areas.
- Sea surveillance capabilities are far less developed than land surveillance capabilities.
- Current overseas intelligence collection is dramatically poor.

A new generation of systems and procedures concerning maritime passenger, goods and energy transport must therefore be developed, addressing these specificities, in order to improve nation's maritime security and to fight varied terrorist threats and other criminal activities

DETECTION OF ABNORMAL BEHAVIOR

The ScanMaris solution is based on the assumption that illicit behaviours are very often hidden behind a law-abiding facade: fishing boats involved in illegal immigration for example. ScanMaris's approach consists in defining official licit objectives, and then applying an Adaptive Multi Agent System (AMAS) method to determine how activities will have to be organised to better answer these objectives (shortest itinerary, safest route, etc.). By deduction, activities that cannot be explained by the will to better achieve an official licit objective will be considered suspicious, and be labelled abnormal by the system.

Fused data acquired from deployed sensors over a large maritime zone (conventional coastal radar, AIS, HF long range radar, etc.) are combined with auxiliary information coming from on line databases (TRAFFIC 2000, LLOYDS, EQUASIS, SATI, etc.) or intelligence, to built an enriched traffic picture where track for each detected vessel are associated to auxiliary information (name, flag, type, operator, owner, tonnage characteristics, etc.).

Then, both the Learning Engine built on the AMAS (Adaptive Multi Agent System) theory and a Rule Engine access these data. The Learning Engine will process these data and assess the behaviour of each ship indicating three states: licit behaviour, abnormal behaviour and unknown. A trust value

can also be associated to these assessments. The Rule Engine uses both this assessment and the direct result of the data fusion process and analyses them using defined rules established to detect abnormal behaviour. For example these rules allow defining transhipping, coupling, shifting of speed/course, etc. Also, systematic coherence tests on all the acquired data are undertaken by the Rule Engine, for example, AIS code discrepancy with similar information in the LOOYDS data base, etc. The Rule Engine issues alerts to the Man Machine Interface. The operator manages each alert, provides a feedback to the Learning Engine, and specifies if the behaviour having triggered an alert is ultimately to be defined as "licit", "illicit" or "unknown", possibly after enquiry with experts.

HIGH FREQUENCY SURFACE WAVE RADARE

Current systems are based on a non permanent multi-sensor coverage, encompassing networked coastal radars that cover 50 to 70 km, mobile radars or IR cameras on surveillance boats or aircrafts, etc. The EEZ is neither entirely nor permanently observed, and the zones that are partly covered necessitate a costly deployment of numerous mobiles sensor platforms (boats & aircrafts). The ScanMaris project intends to experiment cost-efficient sensor coverage, introducing set of complementary sensors with improved ranges. The goal is not to replace the entire sensor cover currently in use: that would be an unnecessary and unrealistic financial waste. But the ScanMaris project aims at proposing add-on sensors, that serve to improve detection range and release currently monopolised mobile sensor capacities that could be better used elsewhere or otherwise (surveillance aircrafts are better suited to specifically targeted recognition missions for example).

ONERA deployed during the first quarter 2007 a promising long range High Frequency Surface Wave Radar in the Bay of Biscay. The HFSWR radar is composed of an omni-directional transmitting antenna and an array of 16 passive receiving antennas. The transmission and the reception system are entirely numerical. The design allows focusing the reception beam in several directions within an azimuth sector of +/- 45 degrees.

Figure 5: ONERA HFSW radar

During the project, the HFSWR of the Bay of Biscay will be run to realise various trials in order to obtain data usable for the multi sensor (HFSWR and conventional radars, AIS, etc.) data fusion process to built representative traffic pictures over wide maritime areas.

SCANMARIS ARCHITECTURE

The ScanMaris system is structured in three data processing layers. Each of them elaborates added value traffic pictures for the detection of abnormal behaviour.

Figure 4 provides the ScanMaris layers (3 & 4) in a global system architecture.

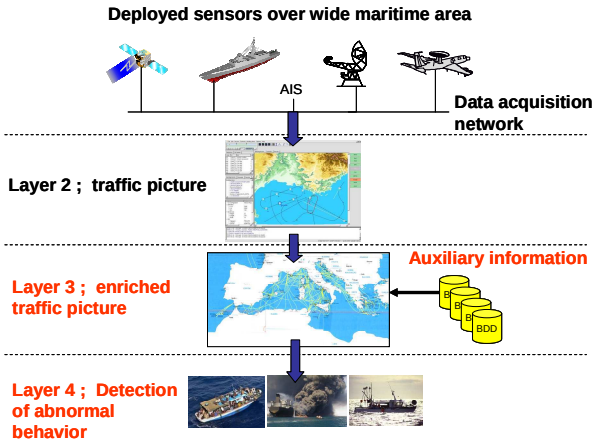

Figure 4: ScanMaris architecture

The ScanMaris solution is made up from data treatment tools to cross and amalgamate the measured ships' kinematics data in a global traffic picture, and auxiliary information in order to establish and to maintain a global enriched tactical picture compilation of the sea traffic, the training methods and the models which exploit these pictures. This is organized in order to acquire a better permanent knowledge of the flows of transported goods, with an aim to improving its

follow-up, and the rules of investigation to detect irregularities like the flows of illicit products, disasters, violations of regulation, etc.

This system and transverse approach of the maritime safeguard at the borders (Homeland Safety and Protection against actions of the malevolent type) calls upon multi-field competences which are capitalized in a grouping of complementary partners. The partners are industrialists (DCNS SIS, SOFRESUD, and Private cnie, ECOMER), academics (IRIT, ENMP, ONERA, Centre of Maritime Law and Transport) as well as operational actors of the maritime safeguard (Prescriber and Operators of the Maritime Businesses Direction of the Ministry for Transport).

For the enriched traffic picture compilation, the heterogeneous data treated, crossed and amalgamated are:

- The geo referenced observations performed in real time by deployed sensors (coastal radar, long range radar, AIS, satellite imagery, etc.).
- The information extracted in differed time from the on line data bases as TF2000, LLOYDS, EQUASIS, TROCS, SATI, etc
- The zoning of maritime space (territorial water, contiguous, economic exclusive, ecological protection, surface of seasonal fishing, opens sea, etc.).
- The weather conditions (visibility, nebulosity, wind, etc.) and the oceanographic parameters (wave height and direction, sea surface temperature, surface current, etc).

TESTING SCENARIO (TERRORIST THREAT)

To illustrate the future ScanMaris outputs, a fictive terrorism threat scenario is presented. The goals are to demonstrate that fused data from different sources contribute to detection and expertise of abnormal behaviours.

The maritime zone is the Aegean Sea where numerous ferries and tankers are navigating. The figure 4 provides the possible deployment of the conventional coastal and high frequency surface wave radars to observe the entire area.

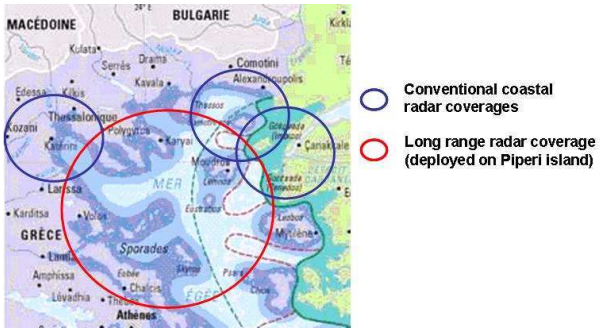

Figure 6: Radar coverages of Aegean Sea

The successive abnormal behaviours detected are:

- N°1; Southern mouth of the Bosporus; tanker boarding by a fast boat (after the return of the pilot boat).
- N° 2; 5 hours later significant change of course of the tanker in open sea.
- N°3; 2 hours later another significant change of course in open sea.
- N°4; 3 hours later tanker stops at the limit between the open sea and Greek territorial water.
- N°5; 1 hour later tanker shifting of speed and course while entering into Greek territorial water.

The chart below gives the tanker's route history, including localisation of the anomalies and the ferry's itinerary.

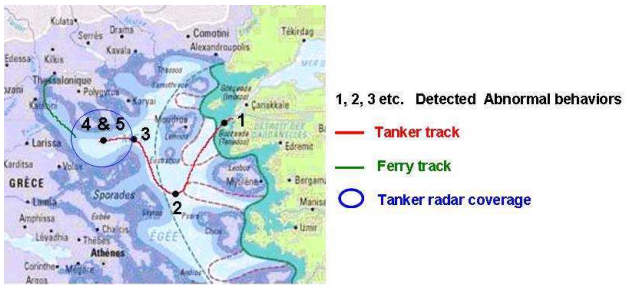

Figure 6: Tanker track and anomalies

In the timeline of the events, data are acquired to provide auxiliary information in order to expertise the encountered anomalies and upgrade the alert level until decision for intervention. These information are:

- The Ataköy marina (650 harbour berths), destination of the fast boat, is located near the Atatürk international airport.

Figure 7: Ataköy marina

- From the LLOYDS on line data base is downloaded the tanker file

General Information

Name	: XX
IMO	: 65348703
Flag	: Bahamas
Type	: Combination
Subtype	: Bulk/Oil Carrier
MMSI	: 308954333
Callsign	: C6SH4
Operator	: XX
Owner	: XX
Manager	: XX

Tonnage Characteristics

Deadweight tonnage	: 80394
Gross tonnage	: 100232

Engine Characteristics

Engine type	: Motor Diesel
Engine number: 2	
Service Speed	: 18/25

Structure Characteristics

Length overall/Draft	: 243/17.62
Beam/Depth	: 32.25/20.10
Sea way	: Odessa to Arzew

Liquid Capacities

Liquid	: 86345
Tanks	: 11

Figure 7: Tanker descriptive file

- The ship-owner of the tanker is contacted and gave the information stating that the oil tank is empty. The last report communicated by the captain, nothing to declare, is date one day before.
- The sailing conditions in the vicinity of the Gulf of Thermaikos are goods with a maximum wave height of 1.5 meter.

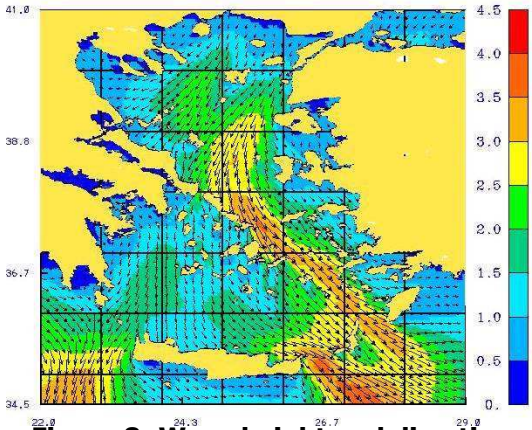

Figure 8: Wave height and direction

- Port of Thessaloniki is contacted and informs that the ferry has onboard 1350 passengers and 238 vehicles.

As soon as the second anomaly had been noticed, the Hellenic Merchant Navy Ministry and the Turkish Ministry for Transport have been informed to activate their terrorism reaction plans.

The chronology and the nature of the detected abnormal behaviours of the tanker present the following profile:

- Boarding of the tanker by pirates/terrorists at the Southern mouth of the Bosporus.
- Diversion of the tanker in open sea.
- Threat of collision, attack/destruction by night, while approaching the Gulf of Thermaikos (Greek territorial water) of the ferry and its 1350 passengers while ensuring the regular night connection; Thessaloniki to Spokelos.

After the detected fifth anomaly the alert is granted top level, then, recommendations formulated by the decisional authorities are:

- Combined immediate action recognition and air intervention.
- Support by the navy and installation of backup facilities at sea for passengers in distress.
- The tanker is empty and the environment risks (pollution by oil) are very limited.

CONCLUSION

The ScanMaris project is the result of a thorough analysis of the needs and requirements of EU member States in terms of maritime security pursued by the partners consortium on the basis of various publicly available pieces of information, such as for example the EU Green Paper or the ESRAB Report. Following this analysis, the consortium has come to the conclusion that an efficient solution in the field of surveillance of wide maritime area would have to encompass the following features:

- New sensors capabilities provided by long range high frequency radar (HTSWR) in order to permanently monitor vessel traffic over wide area.
- Innovative data fusion tools to generate continuously enriched operational traffic picture.
- Innovative comportmental behaviour learning and detection of anomaly based on Adaptive Multi Agent System (AMAS).

Then, the technical components studied, developed and evaluated within the ScanMaris project will enable to improve the effectiveness of an overall monitoring and detection of the contraveners in the frame of increasing and complex vessel traffic. They will thus contribute to set up optimal solutions, well adapted to the struggle against disasters, illicit activities and violations to the regulations.

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