# Knowledge-aided Multi-Sensor Data Processing for Maritime Surveillance


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**Abstract:** Maritime Situational Awareness (MSA) is founded on the collection and processing of information from heterogeneous sources, including radars, Navigation Aids (Vessel Traffic Monitoring and Information Systems, Automatic Identification System, Long Range Identification and Tracking System, etc), air-based and space-based monitoring services (Earth Observation), and recently-conceived passive sensors for maritime surveillance (SIGINT, passive HF/VHF/X band radars). Several strategies for optimally fusing two or more of these information data flows have been proposed for MSA applications. However, the exploitation of context information – i.e. the so-called Knowledge Base – has not yet been thoroughly formulated. This paper provides a preliminary overview of the potential strategies for "knowledge-based" Maritime Multi-Sensor Data Fusion.


## 1 Introduction

The necessity of tracking the elements of a dynamic system usually requires combining information from heterogeneous and complementary data sources in order to overcome the limitations of each sensor. The gathered information might be related to the target status (position, kinematics), its physical features (shape, size, composition) or intentions (route plan, friend/foe, engaged sensor modes, etc). The combination of such heterogeneous information proved to benefit from the availability of *context* information: static and dynamic features of the scenario represent the Knowledge Base (KB) for efficient multi-sensor data processing. Data fusion processing is commonly described by the Joint Directors of Laboratories (JDL) Model ([HM04]) that takes into account the possible architectures (centralized versus autonomous) and the level of inference achieved for the sensed targets (Level 1 to 5). In the MSA frame the exploitation of the *knowledge* is proposed for multi-sensor tracking (JDL Level 1) to multi-sensor data interpretation for target intention prediction (JDL Level 2) and anomaly detection.

For ground moving target tracking (GMTI) applications ([Kl04]), *a-priori* geographic information has been efficiently encapsulated in the tracking process: road information automatically provides constraints to the prediction of target motion by a single sensor or multiple cooperative sensors. Performance is thus significantly enhanced.

Knowledge based techniques are potentially valuable in maritime surveillance applications, as well. Preliminary results are reported in [Ve08] and [BCF06]. Maritime vessel dynamics largely differ from GMTI targets: most maritime targets exhibit slow quasi linear trajectories (bounded to known origin and destination) while only few low-RCS, rapidly moving, bounded-free boats stem out from the "*normal*" scenario (e.g., conventional sea routes). Scenario knowledge is thus to be built up from static and dynamic factors in order to support the multi sensors data processing at different levels.

## 2 Maritime Surveillance Sensors

Maritime traffic monitoring is based on the exploitation of cooperative and non cooperative systems. In compliance with the International Maritime Organization (IMO) regulation [IMO02], ships (300 gross tonnage and upwards in international voyages, 500 and upwards for cargoes not in international waters and passenger vessels) are obliged to be fitted with **Automatic Identification System** (AIS) equipment. AIS will also be required for fishing vessels with a length of more than 15 m and sailing in water under the jurisdiction of Member States of the European Union [EU09]. AIS is based on broadcasting over VHF channels of GNSS-based position reports from cooperative vessels. This system is usually augmented with scenario-sensing sensors (radars, cameras, electro-optical sensors). Radars potentially detect all vessels in the covered area, such as incoherent X/S-band coastal radars – adopted in the frame of **Vessel Traffic Services** (VTS) implementation. The traffic picture provided jointly by AIS and VTS radars covers the territorial waters (up to 12 NM) for law enforcement.

Recently, the spreading of transnational and illegal activities led to the investigation of wide area surveillance means in order to increment early warning capabilities ([IMO06]). Systems such as **Long Range Identification and Tracking** (LRIT), **Satellite based AIS** (Sat-AIS), Satellite based **Earth Observation** and **Airborne Remote Sensing** spread in the latest years and are currently operated by national and international maritime authorities. Finally, the idea of fusing active sensing outputs with the information collected by **passive sensors** has been proposed. It is clear that one of the major achievements to be sought for in future MSA systems is the effective integration of all data sources. However, the heterogeneity of the available data sources poses stringent requirements on data fusion algorithms. Ancillary information or higher level of abstraction are to be used in order to combine information "bits" with common origin but different in nature, time and/or space. In this perspective the Base of Knowledge has a significant role.

## 3 Maritime Knowledge Based Data Fusion & Tracking

JDL Level 1 (Object Refinement) for maritime data fusion has been widely addressed from theoretical and implementation points of view, ([DL06], [VSB08]). Addressed data sources are mostly coastal radars, AIS and satellite-based earth observation, while the extension to all the above-described sources is still under investigation.

So far, decentralized or autonomous data fusion architectures have been considered, due to the operational constraints and unavailability of raw datasets at central level. Theoretical advantages of centralized approaches – used in multi-sensor tracking – are still to be demonstrated for MSA, to the Authors knowledge. Moreover, hybrid data fusion architectures have been developed in [CC10], where the *track-break-fuse* solution exploits both measurements and track information in a multiple hypotheses frame.

Several "un-sensed" elements have influence on the evolution of the maritime traffic; these represent sources of *a-priori* information that can be used in target inference. This information can be collected either statically (once before the observation period) or dynamically (before each traffic picture update). Examples of a-priori information are road maps along which moving targets are bounded. This knowledge is effectively used in GMTI applications ([UK06]). Following the considerations reported by the Authors in [Ve08], the sources of a-priori information for MSA could be ports, the coastline, sea corridors, Aid to Navigation and declared/preferred routes. Also target dimensions, target behavioural models and available maritime target signatures could contribute to the base of knowledge. Different degrees of inference might exploit different KBs.

KB exploitation for enhanced tracking has been formulated mainly for ground moving targets. Few examples do exist for maritime surveillance. In [DL06], littoral target tracking is aided by the knowledge on geographical maps in order to reduce false tracks and speed up true track confirmation. In [Ve08], the Authors propose an innovative approach: a-priori information dynamically concurs in creating spatial maps of "potential"._Vector forces affect locally the target motion as in a force field (Navigation Field). In this research work the navigation field-based approach is encapsulated in the mathematical models presented in [UK06] and [SC02], where knowledge based and constrained tracking filters for moving targets are described. A set of "atomic" maritime scenarios will be presented: the performance improvement for Knowledge-based Level 1 data fusion is under evaluation. The heterogeneity of the presented scenarios clearly stresses the potential added value offered by KB processing. Similar considerations can be drawn for Level 2 to Level 5 processing.

## 4 Conclusions

This paper introduces the framework for enhanced multi-sensor data processing for MSA applications. The data fusion problem is presented with reference to state-of-the-art data models and sensors features. Knowledge-based algorithms are then assessed in the frame of common data fusion architectures and MSA reference scenarios. Results of the KB exploitation on simulated scenarios will be further shown.

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