Data Fusion for Wide-Area Maritime Surveillance

Fabio Mazzarella, Alfredo Alessandrini, Harm Greidanus, Marlene Alvarez, Pietro Argentieri, Domenico Nappo, Lukasz Ziemba

European Commission – Joint Research Centre (JRC), Ispra - Italy

1 INTRODUCTION

The integration of vessel traffic monitoring systems, from coastal range to satellite based sensors, is vital to fulfill the requirements related to the safety of navigation and to fight maritime pollution, illegal immigration, illegal fishing, piracy and any other security threats. Our presentation is devoted to address the main *data fusion* issues arising from the building of a system able to: *i)* ingest ships' position reports from different sources (terrestrial and satellite AIS, LRIT), *ii)* track the vessels within a certain area of interest both in real-time and off-line, *iii)* provide the final user with a Maritime Situational Picture, and *iv)* associate non-cooperatively detected vessels to positions from cooperative reporting systems, aimed at the signaling of the presence of ships without any reported data from either AIS or LRIT. Finally, our contribution will show the behavior of the JRC's prototype platform for maritime situation assessment on data collected within the PMAR (Piracy, Maritime Awareness and Risks) projects around the Horn of Africa and in the Gulf of Guinea.

2 METHOD

In the maritime domain, surveillance tools may include cooperative vessel reporting systems, such as terrestrial and satellite Automatic Identification System (AIS) [1], Long Range Identification and Tracking (LRIT) [2] or Vessel Monitoring System (VMS) [3]; and non-cooperative systems such as space-borne Synthetic Aperture Radar (SAR) [4], coastal radars or video. A broad range of applications require, for a certain area of interest, the Maritime Situational Picture (MSP): the map of the current ship positions, with additional information on identity, type, destination, etc. [5] [6] [7].

Starting from the incoming data from several reporting systems, the building of the MSP implies the following data fusion issues: (a) the identification and maintenance of separate ship-tracks; (b) the prediction of the ships' positions to a desired reference time; and (c) the fusion -or *correlation*- between the positions of the ships detected in satellite images and the positions from the reporting systems. This work discusses how these aspects are addressed in the "Blue Hub" surveillance platform developed by JRC and how they could be improved in the near future.

2.1 FUSION APPROACH FOR TRACKING

The first step towards the building of the MSP is the discrimination between different ship-tracks. This would seem straightforward as each ship is unambiguously identified in the AIS messages by its MMSI number. Unfortunately, it is not rare that the same MMSI is (improperly) used by more than one vessel. We propose a solution that creates an internal vessel identifier, assigned as a sequential number to each new vessel track discovered, based only on the dynamic information (position, speed, course, rate of turn, etc…). This identifier is subsequently linked to the static information (MMSI, name, IMO number, call sign, destination, etc…) that are extracted from the AIS and LRIT data by a separate process. Using the dynamic data, the recognition and the maintenance of each ship-track has the following stages. (1) *Gating*: a selection of the track candidates is accomplished by using geometric and kinematic considerations. (2) *Data Association*: an association between the incoming message and existing tracks is made through a nearest neighbor approach. (3) *Track Management*: track initiation, confirmation and deletion are implemented [5] [6].

A surveillance system aims at providing the MSP with a constant incremental time. As satellite AIS data become available with a delay of the order of hours, the prediction of the ships' position, speed and heading at the current time of the MSP is essential. The *prediction* step can be accomplished for each initialized track by exploiting the last reported positions and speeds. One way is to make use of a Constant Velocity Model (CVM) to describe the vessel motion [5], yielding a linear track prediction based on either provided or computed ship's position, speed and heading. An alternative way [8] exploits the Rate of Turning (ROT) information contained in the messages coming from reporting systems. A third, more complicated model relies on the idea of using the a priori knowledge of the area under investigation [5] [6]. In particular, we propose an algorithm based on the knowledge of the coastlines and ports locations. The general concept consists of partitioning the area of interest into a grid of cells, conveniently weighted according to the a priori information, and starting with a linear prediction: whenever the predicted position falls in a *land* cell, its heading is modified to avoid the collision with the coastline. On the other hand, if the predicted position falls in a cell containing both a coastline point and a *port* point, it is very likely that the ship is going towards the port, and consequently its heading is not modified. As an example of data fusion for tracking, Figure 1 depicts the MSP provided by the Blue Hub platform, for the area of interest of the Gulf of Guinea, on 7 March 2013 at 09:45 UTC.

2.2 FUSION WITH SAR DETECTIONS

The non-cooperative target detections, that aim to find non-reporting ships in addition to the ones seen in the reporting systems, come from polar orbiting satellites carrying Synthetic Aperture Radar (SAR). To fuse the detections extracted from a satellite image into the MSP, we consider: the reported data acquired over the area of interest; the MSP provided by the tracking procedure; and the SAR acquisition parameters. Only those reported and tracked ship positions close to the image acquisition time and area are considered to provide interpolations of the reporting ships to the time of the SAR image. We have performed both a linear and a cubic spline interpolation by using first the observed data only and then a combination of both the observed data and the estimated (MSP) positions.

The next step aims at correcting the target displacements along the SAR azimuth direction that occur in SAR imaging as a consequence of the target range velocity component [9]. If this position error is not adequately compensated, association errors may occur more frequently.

Finally, the correlation process must find the best matching between the SAR detections and the interpolated positions from the reporting ships. Considering the uncertainties in SAR detection and track interpolation, this is not a uniquely solvable problem. The correlation can be thus reformulated as an optimization problem and can be solved by several techniques. In this context, *Simulated Annealing* can be applied [10]. Figure 2 displays the outcomes of the correlation process for the images collected in the Gulf of Aden from 22 Nov to 4 Dec 2011. The blue boxes are the outlines of the images: the dots are ship detections. Green dots are ships that could be correlated with reporting ships. Red dots are non-reporting ships.

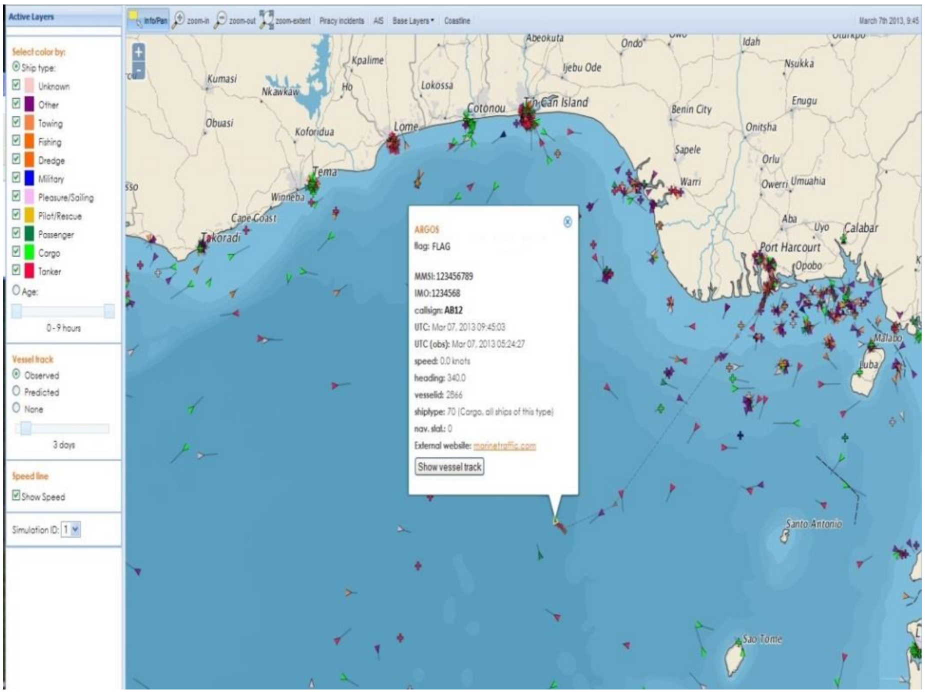

Figure 1. Display of MSP for 07 Mar 2013, 09:45 UTC (Ship details anonymized.)

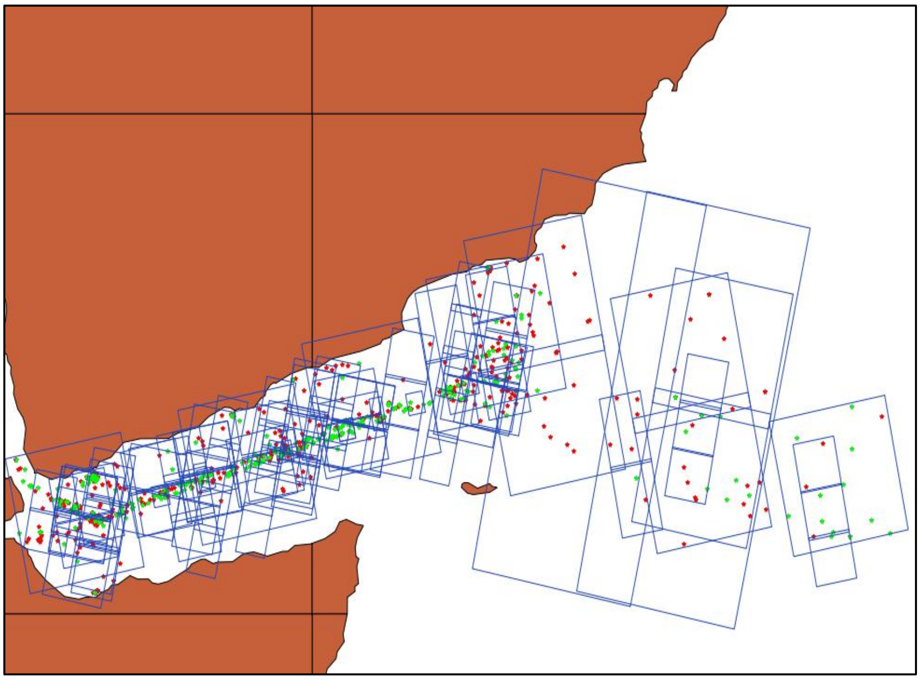

Figure 2. Satellite SAR images with their ship detections taken in the Gulf of Aden from 22 Nov to 4 Dec 2011.

3 CONCLUSIONS

A real-time Maritime Situational Picture can be constructed showing the positions of the reporting ships over a sea basin-wide area, by fusing AIS data from several coastal stations and satellites and LRIT data, compensating for the data delivery delays by predicting the vessel movements. Satellite SAR images can be used to sample the presence of non-reporting ships, however not to track them.

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