A case study using Space AIS for Maritime Surveillance: Experimental performance assessment and integration in a full service chain

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I. INTRODUCTION

The Automatic Identification System (AIS) is a ship born VHF transponder to automatically provide exchange of identification (MMSI), position, speed, course and other information between ships and with coastal stations. Initially designed for collision avoidance, it allows ship-to-ship monitoring and coastal tracking by port authorities or coast guards. But the reception by costal sensors is limited to approximately 50 nm so that traffic on the open ocean disappears into vast blind spots.

AIS signals can propagate much further in the vertical direction; thus it is still possible to implement space-based ship monitoring systems based on constellations of LEO's (Low Earth Orbit) satellites, with the key potential advantage of a worldwide coverage. Space-based AIS reception systems are going to become a reality in the next few years. Several pilot space systems have already been launched; being incomplete constellations, they still are limited in term of revisit frequency but they give a first view of future achievable performances. Full constellations should be available in the next few years, with initiatives announced both by private operators and/or institutional ones.

Spot Infoterra, already engaged in the development and operational delivery of Maritime Surveillance services based on optical and radar satellite imagery, has thus undertaken R&D activities aiming **to integrate space AIS information with information derived from satellite imagery**, and thus leading to **enhanced space-based Maritime Surveillance services**. The main results of this activity will be addressed in this presentation, covering two main aspects.

- An experimental assessment of the performance of current space AIS systems
- The development and experimentation of an integrated service chain for Fusion of space AIS and observation satellite data : **MARISA (MARitime Integrated Situation Awareness)**

II. AN EXPERIMENTAL ASSESSMENT OF THE PERFORMANCE OF CURRENT SPACE AIS SYSTEMS

The AIS protocol ("self-organized" Time Division Multiple Access -SOTDMA) was initially designed for a local reception for ships within a 50NM radius, while the satellite can "listen" at once over a 3000 NM diameter. Therefore reception from a satellite requires dealing with messages collisions, leading to potential loss of information; this results in a **ship detection rate** which is – depending on several factors and in particular ships density in the area - much less than 100%. Other key performance parameters include the **refresh rate** (i.e. ships position data update frequency or sometimes called revisit time defined by the number of satellites and orbit parameters of the AIS constellation), and the **information delivery lead time** (I.e. latency between original message sending time and end user availability, which determines the freshness of the service). Using real space AIS data received during several months from an existing constellation, and other data sources (e.g. coastal AIS, remote sensing data) as a reference for direct or indirect comparison, we have made an experimental assessment of the above performance parameters.

Ship detection rate

We have made several types of experimental analyses in order to evaluate the effective ship detection rate achieved by the space AIS data.

A key difficulty to assess this parameter is the lack of reference data in the areas where the space AIS is the most interesting, i.e. the open sea areas. In order to overcome this difficulty, we took as reference a sample "population" of ships leaving the coast of French Brittany with a known destination, and we measured the percentage of ships which where effectively visible in the space AIS data after having left the area of visibility of the terrestrial AIS.

More precisely, two parameters were measured:

- One-pass detection rate (ODR) : percentage of ships detected by the space-AIS per theoretical observation opportunity (i.e.: per AIS satellite pass over the ship)
- Daily detection rate (DDR) : percentage of ships detected by the space-AIS per day (knowing that with the considered AIS constellation and at the considered latitudes there were in general ten to twelve AIS satellite "fly-over" per day)

The following two pictures show the obtained results in two regions: mid Atlantic Ocean and Atlantic + Mediterranean Sea. In the case of the Mediterranean area, the figures were too low to be considered as statistically accurate, therefore the question marks.

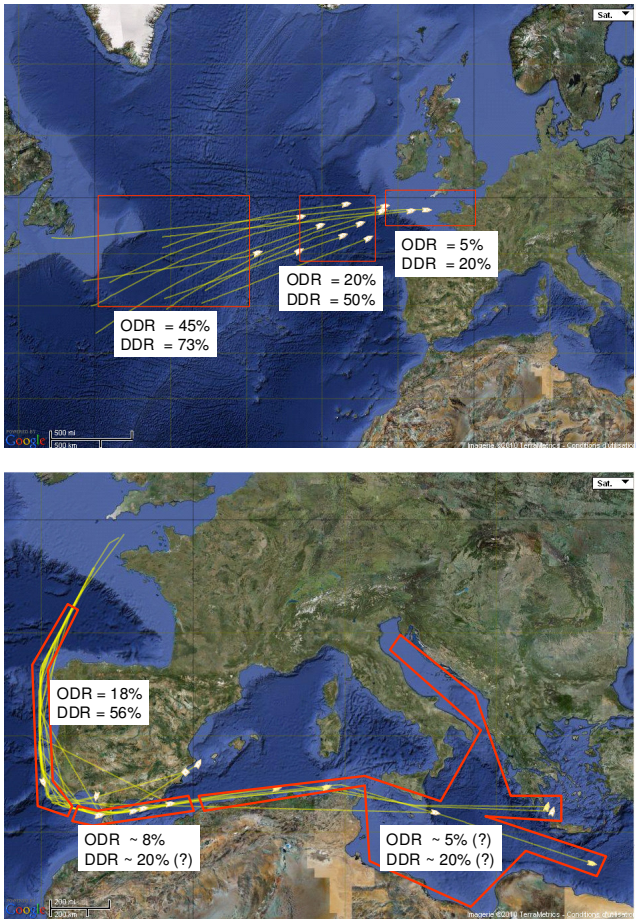

Figure 1: space AIS ship detection rates, as measured through comparison with ground truth data, in two different regions

These results are of course to be taken with some care :

- They are related to one space AIS data provider, and to a current status of its constellation which will evolve in the coming months & years through additional satellites and furtherer developments (eg: data processing)
- They are related to specific geographical areas, which may not be the most "favourable" ones (natural heavy traffic with presence of ground interferers) while other areas like pacific and African coast might be less dense and therefore provide better statistical results

However we think that these results give an indication of the achievable performances with the current space AIS payloads technology , key lessons learnt being:

- Strong geographical variability of the detection rate
- Lowering of detection rate when approaching the coastal areas (probably in relation to traffic density but also "manmade noise" radiated over the ground)
- Even in the favourable cases (i.e.: mid-Atlantic), and cumulated over time, the ship detection rate remains very significantly lower than 100%. Beyond one day, and even in the middle Atlantic, we observed that a significant fraction of the ships (20 to 25%) remained undetected. A denser mesh of satellites on multiple orbits may improve these numbers but the size of the "listening AIS satellite antenna" might always cover some coastal area in addition to "blue water" areas leading to missed collided messages. Another limitation is the physical implementation of the AIS ship-mounted antenna which is good in the horizontal plane to communicate with other boats or coastal towers but could get heavy shadowing of other RF gear from boats in the vertical axis.

Latency

The following histogram shows the data latency (i.e.: time difference between AIS message time stamp and reception time) as observed during one day. Average latency is 12 minutes, 90% of position reports were received within 45 minutes thanks to a comprehensive amount of ground stations. This is of significant interest for live surveillance operations which do not tolerate larger than 2 hours latency.

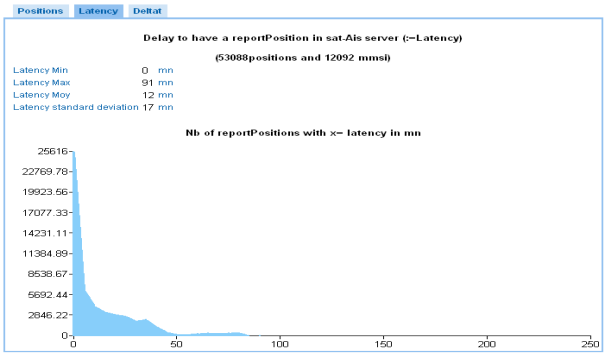

Figure 2: space AIS data latency – histogram of measurements

III. MARISA: AN INTEGRATED SERVICE CHAIN FOR FUSION OF SPACE AIS AND OBSERVATION SATELLITE DATA

Spot Infoterra are already supplying satellite-based Maritime Surveillance services (**OceanWay**), in particular for applications related to illegal activities detection. These services are based on the exploitation of satellite imagery - both optical (Spot4, Spot5 …) and radar (TerraSAR-X, ENVISAT …) – and near real-time delivery of a "Maritime Situation" which characterizes the ships present in the monitored area are detected, and some of their features (ship size, course, speed …).

In order to enrich our service offer, we have developed a service chain, named **MARISA**, which allows to acquire AIS data and perform the fusion between EO-derived information and space AIS information, in order to build a more complete information about "Maritime Situation" common operating picture.

The concept of this service is shown in the figure below:
- In figure 3a, we see the type of observation which can be extracted from satellite imagery alone: ship size, course, qualitative speed (slow, medium, high).
- In figure 3b, we see the information which can be extracted using, in addition, satellite AIS. The detected ships (when cooperative and when effectively detected by AIS satellites), are identified with additional level of parameters (precise course, speed, dimensions, name of ship, ETA, final destination, type of ship, eventually a picture…)

In order to obtain this result, it is necessary to perform the fusion (or matching) of EO-based and AIS-based information. The main issue for this is that both information sources are discontinuous and not synchronized; thus the satellite image in which ships are detected and the AIS acquisitions may show a time difference of several hours, up to 12 hours or more (limited by imagery and AIS satellite constellations)

The MARISA platform allows to perform this fusion in a supervised way (i.e.: semi-automatic). This approach has been used in several live operational service campaigns in the Caribbean and Mediterranean areas, with very successful results.

IV. CONCLUSIONS AND PERSPECTIVES

Space-based AIS is only at the beginning of its development, and still shows significant performance limitations, in particular in terms of ships detection rate – as shown in this paper. But these performances will improve with the completion of the AIS constellations and the improvement of key technologies ; furthermore the benefit f spaceborne AIS, allowing ships tracking in open sea areas out of reach of any coastal systems, is such that it will without any doubt develop in the future years.

In this paper, we have shown how space AIS information can be combined with satellite observation – based services, in order to provide an enriched "Maritime Situation" in which:

- all ships – cooperative or not – are detected thanks to the use of satellite imagery
- cooperative ships, carrying an AIS device, are in addition fully identified

This combination of information has an obvious interest for Maritime Surveillance applications such as the detection of illegal activities.
The Spot Infoterra strategy is to continue the enhancement of space-based maritime surveillance services, building on top of our existing OceanWay service, and enriching it by taking benefit of all additional data sources.

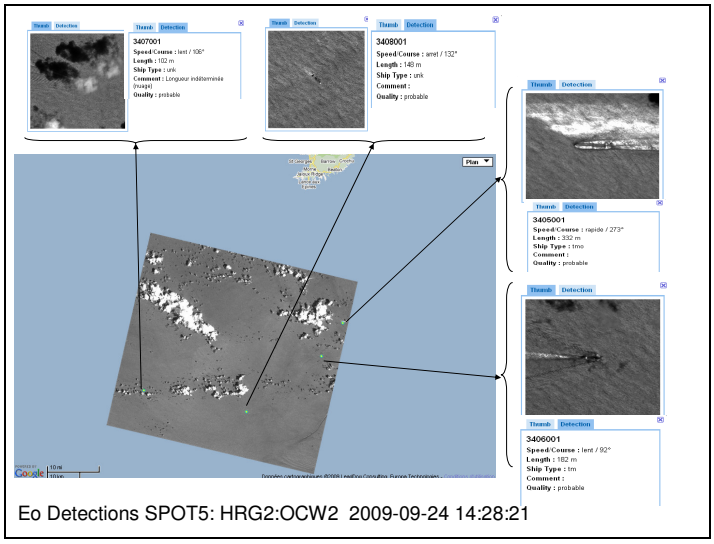

Figure 3a: observed properties on ship detections using satellite imagery alone

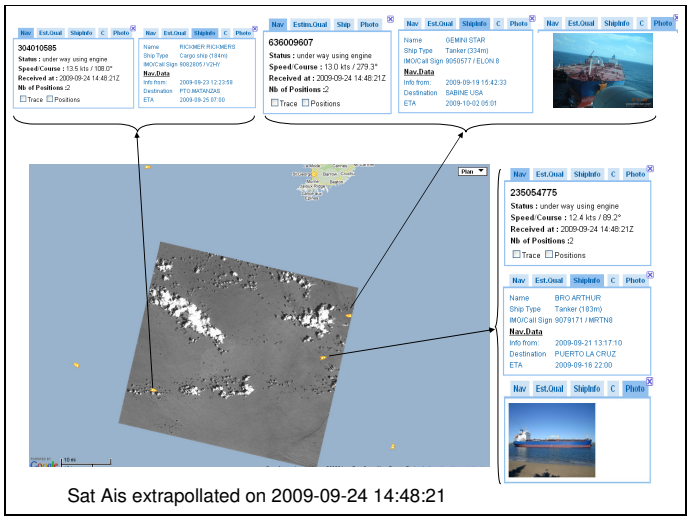

Figure 3b: enhanced Maritime Picture using satellite AIS in combination with EO detections