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A Comparison of AIS, X-Band Marine Radar Systems and Camera Surveillance Systems in the Collection of Tracking Data

ZARDOUA Yassir, ASTITO Abdelali, BOULAALA Mohammed

Laboratory of Informatics Systems and Telecommunication; Faculty of Science and Techniques, Tangier, Morocco.

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Abstract

Maritime traffic has increased in recent years, especially in terms of seaborne trade. To ensure safety, security, and protection of the marine environment, several systems have been deployed. To overcome some of their inconveniences, the collected data is typically fused. The fused data is used for various purposes, one of our interest is target tracking. The most relevant systems in that context are AIS and X-band marine radar. Many works consider that visual data provided by camera surveillance systems enable additional advantages. Therefore, many tracking algorithms using visual data (images) have been developed. Yet, there is little emphasis on the reasons making the integration of camera systems important. Thus, our main aim in this paper is to analyze the aforementioned surveillance systems for target tracking and conclude some of the maritime security improvements resulted from the integration of cameras to the overall maritime surveillance system.

Keywords: Marine Radar Systems, Maritime Surveillance, Tracking Data.

1. Introduction

Maritime movement is dense, particularly in straits and some coastal areas. Statistics indicate that maritime traffic is in constant increase (*Review of maritime transport*, 2018), especially in terms of trade activities (Figure 1). Given that, the occurrence of threats is to be expected, which can manifest in multiple aspects.

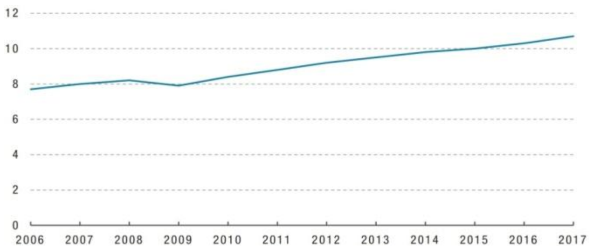

Figure 1
Goods loaded worldwide (Billions of tons) ("Fact sheet number 13," 2018)

To prevent and reduce the impact of maritime threats, well-defined missions must be performed, which are mainly issued from conventions and regulations created by IMO (n.d.). Various centers (e.g. VTS, FMC, MCC, etc) are created by contracting governments to contribute to maritime surveillance on a national and international scope. In maritime surveillance, threats are mainly prevented by detecting anomalies. In the surveillance context, an anomaly is defined as the task of finding unusual patterns in collected data (Chandola, Banerjee, & Kumar, 2009) or uncovering any behavior that is not usually observed.

Correspondence
ZARDOUA Yassir
E.Mail: yassirzardoua@gmail.com

Detection of the aforementioned anomalies can be performed in several ways, one of which is the analysis of data collected from surveillance systems. These systems provide multiple categories of data. In this paper, we focus on the use of tracking data for maritime surveillance. Such data is collected from different surveillance systems. The systems of our interest are AIS (Automatic Identification System), X-band marine Radar system and camera systems. Optical (e.g. Quick Bird and SPOT) and Radar satellite systems (e.g. SAR) are not included in our study for their temporal resolution, which is long enough to make the collection of tracking data impractical.

The rest of the paper is organized as follows: in section 2, we clarify the meaning of tracking data and how it is important in detecting maritime threats. In section 3, we expose the limitations of the AIS and X-band marine radar in the collection of tracking data and the importance of the camera surveillance systems in alleviating these limitations. We conclude by highlighting the maritime security improvements that result from the integration of camera surveillance systems.

2. Role of Tracking Data in Anomaly Detection

2.1 Definition of Tracking Data

Anomalies can be detected through the analysis of multiple types of data and events. Ship's tracking data is relevant for that matter. Tracking a ship mainly involves three major steps: detection; recognition; and identification.

Target detection involves the indication of an object's presence as well as an estimate of its location. Then, it is necessary to recognize it as a marine vehicle. The recognition of a target aims to classify the detected target as a ship, then identify its type (e.g. fishing boat, bulk ship, cruise ship, etc). Since many ships can be detected at the same time, tracking a specific target requires labeling each ship by a unique identifier. Ideally, ships are identified by the IMO number, which is a unique permanent reference of a ship. In many cases, the IMO number is unknown by the tracking system. In fact, the vessel may not even have an IMO number. In that case, a unique identifier that can be recognized by the surveillance system is used. With that said, the tracking data includes the type or the class of the vessel, an identifier to differentiate it from other vessels of the same type and a track, which is a history of all its previous positions.

2.2 Usage of Tracking Data in Anomaly Detection

Tracking data is used by comparing it to a set of patterns or rules. We will explain why both of these methods can uncover anomalies. The first method is used because a ship of a given type has a track characterized by a set of patterns, which are mainly imposed by its type or nature its activities (Lane, Nevell, Hayward, & Beaney, 2010). For example, ships involved in international cargo transportation, such as bulks, tend to make the most efficient track from departure to arrival point. Collecting regular detections of an identified ship of a given type is used to generate a track. Multiple tracks of ships involved in similar activities are used to create a normalcy model, which is a representation of normal tracks. A ship that deviates from that normal track is thus suspected to be a threat.

The second method is relatively easier and faster in detecting anomalies. It consists of establishing rules for safety, whose violation is an anomaly. An example is zone entry anomaly, which consists of checking whether a ship of a given type has entered a defined zone (Lane et al., 2010). For example, far coast regions are usually frequented by medium and big size vessels. Detection of a small boat there is unusual, therefore this is a zone entry anomaly and it can potentially be related to illegal drug trafficking or immigration.

Safety rules can be more detailed, such as the ones defined in COLREGs (*COLREG*, 2003) convention, which aims to achieve efficient traffic, reduce risks of collisions and illegal boarding. The rules it defines are manly about safe speed, allowed maneuverability, passage priority, overtaking conditions, etc. Other rules include estimating risks of collision or boarding based on speed and heading of surrounding ships as well as actions to take if the collision alert is triggered. The nature of these rules indicates that tracking data are of primary importance in executing them.

3. Collection of Tracking Data: Comparison of the Main Systems

In this section, we will compare the usage of AIS, Radars, and camera surveillance systems in the collection of tracking data. In that comparison, we show the limitations of the AIS systems and how Radars, can to some extent, alleviate them. Camera systems are introduced as a complement to AIS and Radars. The resulted improvements of using camera systems are eventually illustrated.

3.1 AIS (Automatic Identification System)

AIS is the main system used in maritime surveillance. It provides tracking data of ships as well as other information, which is divided into 4 main categories; static information such as vessel's class, name, flag, image, IMO and MMSI number, GT (Gross Tonnage) and dimensions; dynamic information which includes position, speed, acceleration, and track; voyage related information that are mainly the type of cargo, number of passengers, destination, ETA (Estimated Time of Arrival) and route plan; short safety-related messages such as information on tides, weather in specific areas and warnings (e.g. suspected piracy or terrorist activities). AIS information is gathered from different sources, which include weather stations, ship's sensors such as GPS or manual log by the ship's officers. Sharing and getting access to AIS information is done through VHF coast stations.

3.1.2 AIS Limitations

There are many limitations to AIS in collecting tracking data. According to SOLAS (*SOLAS, consolidated edition 2014*, 2018) regulations, not all ships are required to transmit AIS signal. AIS system is mandated only on passenger ships, vessels over 300 GT on international voyages and vessels over 500 GT not on international voyages with the exclusion of naval vessels. Also, nothing guarantees that vessels mandated to transmit the AIS signal will collaborate since the AIS device can be switched off. Additionally, AIS information may have a slow information update and some positional errors. These limitations manifest in the target tracking into 3 inconveniences: important inaccuracies in detecting fast vessels; non-detection of non-mandated AIS boats, especially the small boats; non-detection of ships having switched off the AIS. We will see in the next section 3.2 that these problems can be reduced using Radars.

3.2 X-band Marine RADARs

Marine radar is an instrument that operates in X band frequencies (8.0 12.0 GHz).To detect and track targets, a rotating flat antenna constantly sweeps a narrow beam of microwaves in all horizontal directions. The reflected waves are detected by the same antenna, hence surrounding obstacles and marine vehicles can be detected and displayed on a screen.

Unlike the AIS, Radar systems do not require equipping its targets with any special device. This allows the detection of ships not transmitting the AIS signal. Also, radars have a high detection update (around 1 second) as compared with the AIS signal, which addresses the problem of fast vessel tracking.

3.2.1 RADARs Limitations

Despite the mentioned advantages of RADAR systems as compared to the AIS, it still has its inconveniences. Radar systems have been blamed in several accidents involving small boats for their limitation in detecting small targets (Branch, n.d.). Another study suggests through analysis of SAR actions taken in the Adriatic Sea that small boat accidents represent the highest percentage of the total number of accidents (Komorčec & Matika, 2016). Another limitation is their poor ability to recognize the detected target, which is important information as explained in the section 2.2. This can be overcome if the target is transmitting the AIS signal, as it contains information about the type and the activity of the vessel. Yet, the problem persists as this information can be faked or the vessel may not even fit an AIS device.

3.2.2 Causes of Marine Radars Limitations in Detecting Small Targets

Radar Cross Section (RCS) is a measure of the electromagnetic signal reflectivity of an object. It depends mainly on the object's size, material, and shape. An object with a low RCS has a weak reflection of the signal. Sea-clutter from another hand is any undesirable reflected signal caused by the nature of the sea. Capillary waves and gravity waves are mainly caused by winds and are considered as the major cause of sea clutter for X-band radars (Raynal & Doerry, 2010).

Detection of small targets is difficult due to the low SNR (Signal to Noise Ratio) caused by the sea-clutter and the low RCS value associated with small targets. Radar techniques based on Doppler-effect have been found useful in detecting small targets in sea clutter (Herselman, Baker, & De Wind, 2008). Doppler-effect takes place when the distance between the radar transmitter and the target is changing. This change causes a shift in the received frequencies, called the Doppler frequency shift, which is governed by the radial velocity of the target (Chen, 2019). When the Doppler frequency shift of sea clutter and small targets have non intersecting bands, small object detection is possible as shown in figure 2.

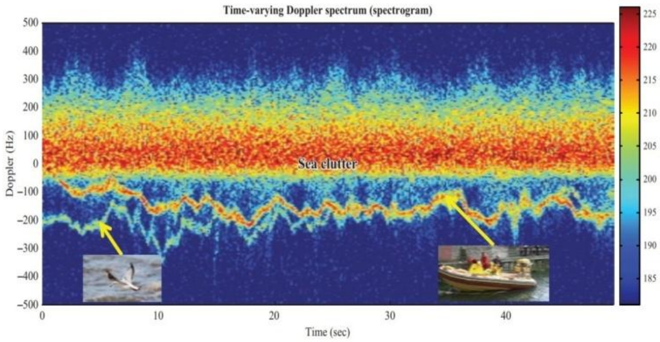

Figure 2
The time-varying Doppler frequency shift of the small boat, sea clutter and flying birds (Chen, Tahmoush, & Miceli, 2014)

Doppler shift of some targets may have intersecting bands such as the RIB (Rigid Inflatable Boat) and the seagull after the instant t= 30 sec (Figure 2), which makes a distinction between targets difficult. Such an intersection can also appear between sea-clutter and targets of interest (Raynal & Doerry, 2010) and bury the small vessel's Doppler shift (Chen et al., 2014) making its detection impractical.

3.3 Camera Systems

3.3.1 Cameras as a Complimenting Sensor

We have seen how AIS combined with radar systems, has limitations, mainly in collecting the tracking data of ships not fitting AIS as well as of small targets. Some works suggest that cameras are good candidates to complement existing surveillance systems (Almeida et al., 2009; Komorčec & Matika, 2016; Ponsford, Sevgi, & Chan, 2001).

The development of imaging technology in the last few years makes cameras good candidates to integrate with other technologies. These developments include the high resolution of images, the availability of flexible lens to focus on different fields of view as well as the possibility of getting visual data from multiple light frequencies such as infrared spectrum, which is particularly useful in night vision.

The data collected from vision sensors are also amenable to automatic processing, which is useful in overcoming problems related to (i) human errors due to fatigue and information overload and (ii) the resources needed in terms of the watch-standers number required to monitor different CCTV screens as well as their training. In the context of target tracking, camera systems provide 2 advantages as compared to the AIS and the radar system combined: the first is increasing the probability of detecting small targets, as these clearly appear on the image; the second is the recognition of vessels type. In the section 3.3.2, we illustrate how these advantages can improve the security of the maritime environment.

3.3.2 Deployments of Camera-Based Surveillance Systems and the Resulted Security Improvements

Given the advantages offered by vision sensors in terms of target tracking, many systems integrating cameras as a complementing sensor have been developed to increase the detection of maritime threats (Bloisi & Iocchi, 2009; Gupta, Aha, Hartley, & Moore, 2009; Pires, Guinet, & Dusch, 2010; Rhodes et al., 2007; Wei et al., 2009). To show the resulted security improvements, we need to consider different deployments of the camera-based surveillance systems. We consider 3 types of deployments: ground-based; buoys-based; and ship-based video surveillance.

Ground-Based Video Surveillance

In subsection 2.2, we've explained that detecting anomalies with tracking data is mainly done by comparing them with a set of patterns and rules. Automatic video surveillance may currently be impractical to be used in collecting data on a wide coverage area, such as tracking a bulk on an international voyage. However, they can be deployed for the data collection on a short coverage area (e.g. 5km to 10km) (Auslander, Gupta, & Aha, 2011), such as ports, harbors, and rivers. This enables the collection of tracks of small targets and the recognition of a vessel's type. This improves the ability to threat prediction, as this task requires the tracks and type of marine vehicles (See section 2.2).

Buoys-based video surveillance

Buoys-based video surveillance consists of a network of buoys equipped with a camera, processor to perform image processing tasks and bi-directional communication unit to transfer the collected information to surveillance centers (Fefilatyev, Goldgof, Shreve, & Lembke, 2012; Zhang, Li, & Zang, 2017). With proper processing algorithms, these systems can be used in open-ocean to detect and recognize small boats, which are often associated with illegal immigration and drug trafficking. Another improvement is the prevention of poaching, especially if the VMS device of the ship is turned off. This can be done through the recognition of the vessel as a fishing ship in a fishing restricted area.

Ship Based Video Surveillance

As small boats do not carry AIS and are unlikely to be detected by marine radars, cameras can be a good complement for navigation equipment of a ship. Such integration is useful in avoiding collisions and preventing maritime threats in the open ocean such as piracy and terrorist attacks, which are, based on several incidents, mainly carried out by small boats. Other improvements include the search and rescue of people in distress, especially if the used camera operates in the infrared spectrum, which provides a good contrast of the human body (Pires et al., 2010) and makes its detection easy.

4. Conclusion

In this paper, we compared the ability of 3 systems in the collection tracking data. We explained the different target tracking limitations of the AIS, how some of these limitations are alleviated by the X-band marine radar system. Then, we exposed the ability of the camera surveillance systems to overcome the limitations of the AIS and Radar system combined. Afterward, we listed a number of maritime security improvements that result from the integration of camera surveillance systems for 3 types of deployments. These improvements are mainly: enhancement of threat prediction on a short coverage area; the detection of illegal activities, which are illegal immigration, drug trafficking, and poaching; collision avoidance; and piracy attacks prevention.

Abbreviations

IMO = International Maritime Organization
COLREGs = COLlision REGulations
VTS = Vessel Traffic Service
FMC = Fishery Monitoring Center
MCC = Mission Control Center
CCTV = Closed Circuit TeleVision
VMS = Vessel Monitoring System

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