Applied Ocean Research 47 (2014) 98–109

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Review

Securing harbor by combining probabilistic approach with event-based approach

Salma Zouaoui-Elloumi*, Valérie Roy, Nadia Maïzi

Center for Applied Mathematics, Rue Claude Daunesse, BP 207, 06904 Sophia Antipolis, France

ARTICLE INFO

Article history:
Received 5 March 2013
Received in revised form 20 December 2013
Accepted 23 December 2013

Keywords:
Hidden Markov Models
Reactive synchronous language
Decision support
Harbor security

ABSTRACT

As a part of SECuring MARitime (SECMAR) project that aimed to improve security at Marseilles harbor, we developed a decision support system that helps port staff to better monitor ship behavior. It consists of two complementary sub-systems. The first system is based on the probabilistic Hidden Markov Model (HMM) approach and deals with nominal (regular and recurrent) behavior of large to medium size of commercial ships. The second system is based on the reactive synchronous language Esterel and concerns aggressive and transgressive behavior of small ships that may navigate freely in the harbor. Real-time evaluations showed that the proposed decision support system efficiently captured and evaluated ship behavior.

1. Introduction

Nowadays, overseas transport, in addition to its touristic aspect, plays a major role in international trade since 90% of raw materials such as oil, gas, iron ore and coal are exchanged over the sea. As a consequence, it is worth paying a particular attention to the maritime space, which can be exposed to significant risks, such as accidents (for example, the recent sinking of the cruise ship Costa Concordia in 2012 in Italy) and terrorist attacks (such as the attack of the American ship USS Cole in 2000). For these reasons, several measures and security systems were introduced by European and American countries:

- The Customs-Trade Partnership Against Terrorism (CTPAT): a government business-program established by the U.S. in 2001 that aims to strengthen the overall supply chain and U.S. border security.
- The Seveso directive of 1996: a European law aimed at identifying and preventing industrial sites with high level of risk (containing dangerous substances).
- The Vigipirate system: a national security alert system created in 1978 by the French government that aims to prevent from threats and terrorism.
- The Automated Identification System (AIS): an automatic tracking system imposed by the International Maritime Organization (IMO) to all the ships of more than 300 tons. The military and small ships do not have this obligation. The AIS is formed by an on-ship transmitter that sends the ship realtime information (type, position, speed, etc.) to a receiver located in the harbor.

However, in spite of the above measures to improve security in the maritime space especially after the events of September 11th, harbors remained unsecure for many reasons:

- First, the AIS, which is considered as the best ship tracking system used by all countries, is unable to track all ships in the sea. In fact, many small size ships such as jet skis or sailboats are not equipped with this system. Moreover, the AIS can be deliberately stopped or its data can be modified.
- Secondly, several aspects of maritime surveillance such as underwater surveillance or video surveillance have hardly ever been established in a harbor.
- Finally, monitoring harbor currently performed by a security guard is a tedious task since the guard must often monitor several vessels at the same time. Besides he needs to have the ability to integrate simultaneously several data sources from the various sensors and from the harbor environment.

In this context, SECMAR project (Fig. 1) aimed at developing a decision support system for the security team of Marseilles' harbor. It comes in three folds:

1. An advanced detection system based on new adjusted *sensors*, namely *radar*, *sonar* and *optronic cameras*. This system is installed on the harbor to avoid any dependency on the ships equipment.
2. A data fusion system that merges all the sensors data to the so called "track system" which is a set of exploitable data such as speed and position.
3. A behavior analysis modulus which is able to transform the track system into a valuable decision support information. This last point is the focus of this current paper.

* Corresponding author.
E-mail addresses: salma.zouaoui@gmail.com (S. Zouaoui-Elloumi)
valerie.roy@mines-paristech.fr (V. Roy) nadia.maizi@mines-paristech.fr (N. Maïzi).

0141-1187/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2013.12.004

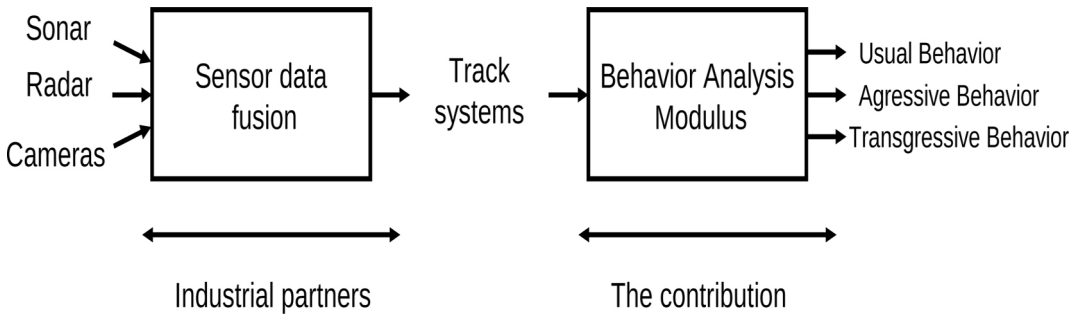

Fig. 1. Steps of SECMAR project.

The industrial partner of SECMAR project, Thales Underwater System, has developed an innovative algorithm to merge sensor data recorded by radar, sonar and cameras in order to obtain the track systems. A track system is a single information about every vessel in the harbor at each time step. It is composed of the following information: position in longitude and attitude, speed, heading, time and type (small or commercial ship). To conceive the behavior analysis modulus (BAM), ships' positions (meter), speeds (m/s), times (seconds) and types are used as input of the system. We have started by observing the ships trajectories (Fig. 2 represents some ships trajectories in Marseilles harbor) reconstructed from the track systems and their motion through the well-marked areas established by the legislation (for example area A, area B, area Mooring N in Fig. 2). Thus, we have established two kinds of ship behavior:

- Commercial ships such as oil tankers or container ships displayed regular, recurrent behavior. They have a well-established route that they have to follow to reach their corresponding platform (Fig. 2(a)).
- Small boats, like sailboats and jet skis moved freely in the harbor without any restriction (Fig. 2(b)).

In this paper, we propose a behavior analysis modulus (BAM) formed by two parallel and complementary sub-systems (Fig. 3) that tackle this duality of the observed ships:

- The first system is based on the probabilistic Hidden Markov Model (HMM) approach and deals with nominal behavior of commercial ships showing regular and recurrent behavior.
- The second system is based on an event-based approach with the Esterel synchronous reactive language and concerns mainly the aggressive and transgressive behavior of small ships.

We will start, in the next section, by presenting some related works in the field of behavior recognition. We introduce in Section 3 an overview of the proposed approach. The used approaches for the BAM conception are presented in Section 4: the HMM is presented in Section 4.1, then the synchronous reactive approach and the Esterel language are introduced in Section 4.2. We describe in Section 5 the behavior analysis modulus for ship behavior recognition. This system is formed by two systems: the probabilistic modulus that we introduce at first in Section 5.1 and the reactive modulus that we present thereafter in Section 5.2. The parallelism and the complementary of both systems are illustrated in Section 5.3 through the description of two examples of ship behavior: a nominal and a dangerous one. Finally, Section 6 ends with a comparison and analysis of both systems.

2. Related works on behavior recognition and analysis

Behavior recognition is an important field of artificial intelligence (AI). Techniques such as statistical or logical methods were widely used to conceive autonomous systems used for security or for decision support. We can classify works on behavior recognition and analysis into two categories: works based on probabilistic approaches and works based on event-based approaches. In this section, we will focus briefly and separately on both of them.

2.1. A probabilistic-based approach for behavior recognition

In robotics and according to [1] , the conception of an autonomous robot goes through modeling its interaction with its indoor or outdoor environment. For example, authors proposed in [2] to use the probabilistic approach Hidden Markov Models (HMM) to learn many human skills that were transferred to a space station robot system for teleoperation control. In the same manner, authors in [3] used HMM approach in order to develop many autonomous robots playing soccer. The behavior recognition was also used in order to integrate intelligent systems in vehicles to driver support. In [4], the HMM approach was used in order to learn driver's behavior that through a model of "intention-action". Seeing that human behavior is based on unknown intentions, we were able to infer them from the driver actions. In this case, human behavior is well described by an HMM where model's variables were constructed from the hidden states (intentions) and the observations (actions). In [5] and [6], authors also used HMM in order to model many drivers' behavior since each driver has its own manner of driving. This idea proved to be a very good method in preventing against vehicle theft.

2.2. An event-based approach for behavior recognition

The event-based approach is a logical and a deterministic method. For example, in robotics, modeling robot's interaction with its environment goes through programs based on geometric terms, analytical expression and symbols [1]. In this context, authors in [7] used logical methods, programming languages and automaton theory in order to resolve plan and control problems associated to robots. Authors also proposed in [8] to model ants' behavior by robots programmed in an imperative language (Esterel).

The next section justifies the use of the two previsouly described approach for the conception of our framework.

3. Overview of the proposed approach

We propose a complete framework for recognizing usual and unusual ship behavior by combining a probabilistic HMM approach and a reactive synchronous system developed in Esterel language. By analyzing ships' behavior in the harbor from a previously recorded track systems, we noted that commercial ships' trajectories are recurrent and regular since they are respecting maritime rules. Thus, the systems can constitute a set of data that can be handled in a statistical way. We have chosen to use the track systems as well as the well-marked areas to construct and learn, in a probabilistic manner, the set of all models of usual ship behavior in the harbor. This set of models