Reliability Engineering and System Safety 155 (2016) 179–195

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

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

A novel approach of collision assessment for coastal radar surveillance

Feng Ma [a,b,d], Yu-wang Chen [b], Zi-chao Huang [a,c], Xin-ping Yan [a,c,*], Jin Wang [d]

[a] Intelligent Transport System Research Center, Wuhan University of Technology, PR China
[b] Decision and Cognitive Sciences Research Centre, the University of Manchester, Manchester M15 6PB, UK
[c] National Engineering Research Centre of Water Transportation Safety (WTS), PR China
[d] Liverpool Logistics, Offshore and Marine (LOOM) Research Institute, Liverpool John Moores University, L3 3AF, UK

ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
7 May 2016
Accepted 9 July 2016
Available online 15 July 2016

Keywords:
Collision probability
Bayesian Network
Artificial Potential Field
Marine radar
Nonlinear optimisation
Dempster's rule

ABSTRACT

For coastal radar surveillance, this paper proposes a data-driven approach to estimate a blip's collision probability preliminarily based on two factors: the probability of it being a moving vessel and the collision potential of its position. The first factor is determined by a Directed Acyclic Graph (DAG), whose nodes represent the blip's characteristics, including the velocity, direction and size. Additionally, the structure and conditional probability tables of the DAG can be learned from verified samples. Subsequently, obstacles in a waterway can be described as collision potential fields using an Artificial Potential Field model, and the corresponding coefficients can be trained in accordance with the historical vessel distribution. Then, the other factor, the positional collision potential of any position is obtained through overlapping all the collision potential fields. For simplicity, only static obstacles have been considered. Eventually, the two factors are characterised as evidence, and the collision probability of a blip is estimated by combining them with Dempster's rule. Through ranking blips on collision probabilities, those that pose high threat to safety can be picked up in advance to remind radar operators. Particularly, a good agreement between the proposed approach and the manual operation was found in a preliminary test.

1. Introduction

Marine radar is an active detection tool of coastal surveillance, which does not require replies from supervised vessels. As well as that, it is capable of detecting waterfronts, buoys, and other obstacles. Through marine radar, all the vessels and obstacles are represented as blips on screen with corresponding characteristics, including shapes, velocities, directions and trajectories. In daily managements, these characteristics are used for target extraction and identification. Presently, several other maritime tracking systems have been invented, including the Automatic Identification System (AIS) and maritime satellites. However, the reporting frequency of AIS is too low for real-time tracking [20]; not many vessels possess satellite transmitters. Therefore, marine radar is still the kernel of a maritime detecting system.

In fact, a considerable proportion of radar blips or objects are caused by noises or stationary objects. In inland waterways or ports, such false or stationary objects are even more than real moving vessels [23]. Therefore, radar operators have to identify moving vessels from a plethora of blips manually. However, even if a blip is confirmed to be a real moving vessel, it might not need much attention. For instance, a vessel that is far away from piers, rocks, obstacles, and other vessels is usually safe; in daily management, it does not need much attention. In fact, only a blip that is probably a real moving vessel and is posing a threat to safety needs close inspection [20]. Particularly, the threat to safety here generally means a potential collision, as the collision avoidance is the main objective of radar surveillance.

Most of radar systems have integrated an Automatic Radar Plotting Aid (ARPA) function to track moving objects. However, the authenticities or collision potentials of targets cannot be obtained by an ARPA function directly. For instance, a late-model coastal surveillance radar system is capable of tracking a 0.5 m^2 target at a distance of 5 miles. However, its ARPA function is not capable of determining whether this 0.5 m^2 target is a real moving vessel, or just a trivial object floating on the water. Presently, the authenticity or collision probability of a target can only be inferred by experienced radar operators. Such manual operation might be impractical when there are too many objects in observation. For instance, there are about 20,000 vessels passing through Nantong waterway, Yangtze River, China in one day. Obviously, it is impossible to inspect them one-by-one manually. On the basis of the procedures of manual operation, this research aims to develop a data-driven method that helps radar operators identify targets preliminarily so as to enhance their supervision and management efficiency.

* Corresponding author at: Intelligent Transport System Research Center, Wuhan University of Technology, PR China.
E-mail address: xinping_yan@126.com (X.-p. Yan).

http://dx.doi.org/10.1016/j.ress.2016.07.013
0951-8320/

It is worth emphasizing that the collision probability in radar surveillance is different from the usual sense. In conventional research, a collision probability is determined by the speed, rotation rate, course, encountered vessels, and environmental factors [9]. However, the course and speed measured by radar are not completely credible [11,12]. False alarms might be triggered easily when using them in collision estimation [22]. Nevertheless, the positions of targets obtained from radar are comparatively reliable. Therefore, radar operators always take the position as an important factor in the estimation of a blip's collision probability. For example, when a blip or object is located in a dangerous zone, it should attract much attention without regard to whether it is a noise or not. On contrary, if an object is located in open water outside the main channel, which poses limited threat to safety, it might be ignored by radar operators. Particularly, the collision potential of a position is actually determined by surrounding obstacles and environments, including waterfronts, berths, water depths, piers, buoys, shoals and encountered vessels. Apparently, these factors are varying all the time. As a result, to estimate the collision potentials of different positions requires radar operators' experience.

Overall, referring to manual operation, there are two major underlying factors in the preliminary identification of a blip that has a high collision probability. The first one is the probability of the blip being a real moving vessel; the other is the corresponding collision potential of its position.

The first factor can be inferred from its characteristics. For instance, a blip that is moving at a usual velocity is likely to be a moving vessel. This inference process is based on the speed of the blip and the experience of the operators. In fact, such experience can be considered as prior information accumulated from a long-time observation. In this light, a probabilistic model might be appropriate in this research [32]. Among different types of probabilistic models, Bayesian Network (BN) is considered to be efficient and rigorous. Particularly, it is capable of learning structures and the associated coefficients with verified samples under uncertainties [38].

The other factor, or the collision potential of a position, is more complicated. Generally, the term "collision risk" discussed in maritime research is usually considered as the product of a collision probability and the impact of the collision [36]. However, the impact involves much detailed information of vessels [9], such as the rudder angle, types of cargo, and the number of people on board the ship. This information is difficult to obtain for radar surveillance. In fact, the primary objective of VTS operator is to avoid all the possible collisions without regarding or weighing the collision consequences. Hence, only the collision probability is investigated in this research.

In relevant research findings, the estimation of the collision probability is generally based on macro perspectives or ship handling. These macro perspectives include waterway design, port engineering and policy-making [8]. The relevant methods are not capable of describing the successive variation of collision probabilities in microscopic adjacent positions [7]. For instance, these methods can be used to estimate the overall collision probability of a bridge zone for setting a speed limit; however, they are not capable of describing the collision probability differences between two points that are 50 m apart from each other in the bridge zone. In radar surveillance, such a microscopic estimation is essential. Another conventional research perspective of studying the collision probability is for ship handling, which also requires much manoeuvring information of the vessels [26]. As described, such information is mostly unknowable for radar surveillance. Therefore, the conventional collision probability estimation methods might not be very suitable for the perspective discussed in this research.

Referring to the research conducted in the robot area, the problem can be addressed with an Artificial Potential Field (APF) model, which does not need detailed information of obstacles, and describes the collision probabilities as a continuous function [34]. For decades, the APF model has been widely used in robot route planning and manipulation, and it is believed to be efficient and concise.

In summary, this paper aims to propose an intelligent approach to estimate the collision probabilities of radar blips preliminarily using BN and the APF model. It is organised as follows. Section 2 dedicates to introducing the characteristics of blips and conventional research of collision probability. Section 3 proposes a novel approach to estimate the collision probabilities of blips. In Section 4, a case study is conducted. Section 5 concludes this paper.

2. Literature review

2.1. The uncertainties of marine radar blips

By detecting echo signals which bounce off the surroundings, the coastal surveillance radar can be used to determine the distance, speed, and direction of each moving object in a specific area. The echo signals can be represented as frequency spectrums or blips on a screen. Generally, the blip form is more accessible, which is shown as a radar image. The satellite image and the grey-scale radar image shown in Fig. 1 were captured at the same location and surroundings of Yangtze River, Wuhan, China. In the radar image, waterfronts, vessels, buoys, and bridges have been represented as blips at the very beginning of target extraction. The speed, course, and position of targets can be quantified in accordance with the inter-frame differences of corresponding blips. However, radar images or blips are actually not stable. The graphs of blips will be affected by the observation angle and radar resolution notably. Moreover, blips often overlap and connect to each other. Therefore, the direction and speed measured by radar blips are not completely credible [11,12]. In practice, stationary or noise blips might drift like moving vessels; moving vessels approaching to berths might move too slowly, and they look like stationary or noise objects. It is worth noting that each object's speed can be measured with the Doppler velocities too. However, most marine radar systems work on a low Repetition Pulse Frequency (RPF) mode, and the Doppler velocities are ambiguous. Hence, the radar images are used as the major evidence for further identification.

To address the problem of uncertainties described above, radar performance appraisals and improvements have attracted much attention in recent decades [13,18] Many researchers were dedicated to developing a generic filtering algorithm to obtain more accurate trajectories of radar objects [37]. However, it may be argued that all these filtering algorithms incorporate some assumptions regarding objects' states, which are only applicable in specific conditions.

It is shown in Fig. 1 that the marine radar also captured many useless and noise blips, and operators might take them for moving vessels easily. Hence, some intelligent methods have been introduced to distinguish moving vessels from false or stationary objects. For marine radar, Ma et al. [22] proposed a fuzzy k-means (FCM) based classification method to identify the false targets among ARPA targets, and reported the accuracy of 91.0%. Zhou et al. [41] invented a radar target-recognition method based on fuzzy optimal transformation using high-resolution range profiles. Although the existing algorithms are shown to be effective for specific case studies in radar research, they do not constitute a rigorous probabilistic inference process, nor are they proven to be effective in principle or in general. As such, they are of an *ad hoc* nature and might not be as robust as required for real life applications or implementation. In addition to the identification of a blip, operators of radar also need to know the exact probabilities about the blip's states for making appropriate decisions.