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An approach of vessel collision risk assessment based on the D–S evidence theory

Bo Li*, Fu-Wen Pang

College of Information Science and Technology, Dalian Maritime University, Dalian 116026, China

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ABSTRACT

Computing time and decision correctness are the measurable indicators in vessel collision risk (CR) assessment. However, the existing CR assessment approaches, based on fuzzy theory or neural network, have lower accuracy and longer computing times. To overcome these drawbacks and obtain a compromised evaluation, an approach of vessel CR assessment based on the Dempster–Shafer (D–S) evidence theory is proposed in this paper. Considering that CR is associated with the membership functions corresponding to navigation parameters such as the distance to the closest point of approach (DCPA), the time to closest point of approach (TCPA) and the relative distance, we use the multiradar network to achieve them. Afterwards, applying the D–S evidence theory, we successfully assess CR with joint basic probability assignment (JBPA). Finally, the simulation results confirm the validity of the proposed approach.

1. Introduction

Owing to brisk economic growth, marine traffic has been developing rapidly nowadays. Regarding improving shipping efficiency, we are facing challenging issues on account of continuous growth in vessel number and vessel size. When the vessels run into busy waterways and/or linking ports, there is a high potential for collision. Although the collision is often closely related to the navigator's behavior, the ever-changing navigation environment still has irreversible impact on the ship's navigation; see, for example, Zhao and Wang (1999), Zheng and Wu (2000) and the references therein. The study by Shih et al. (2012) reveals that more than 60% of vessel collisions are caused by hostile environments. As powerful impetus, these works in the field of ocean engineering prompted the research on vessel collision avoidance. It is well known that collision avoidance started from assessing collision risk (CR). The concept of vessel domain was first proposed by Fujii and Tanaka (1971) among the several definitions of CR. Currently, the main scope of work done by Wang (2012) relates to the CR assessment method under poor navigation conditions. Since the assessment depends on subjective factors of the navigator and objective factors of the environment, the relevant research has been an oft-discussed maritime issue at home and abroad.

In recent years, several oceanographers have studied these fields with a great deal of success and many papers with respect to vessel CR assessment have been published in some important international journals. Research work conducted by Xu et al. (2009), Su et al. (2012), Ahna et al. (2012) and Bukhari et al. (2013) demonstrate vessel CR assessment in various ways. A fuzzy method for determining the radius of guarding ring for collision avoidance was studied by Shi et al. (2008). Furthermore, Pundlik and Luo (2012) introduced tracked feature points to obtain a set of feature points that most likely represent the potential obstacle based on the threshold step. The assessment by Perera et al. (2012) consists of a fuzzy-theory-based parallel decision-making module whose decisions are formulated into sequential actions by a Bayesian-network-based module. Considering the required ship turning, the fuzzy monitoring system put forward by Su et al. (2012) suggests the optimal rudder steering procedure for the give-way ship to avoid collision. Meanwhile, in the work carried out by Park et al. (2011), the multilayer perception neural network is applied by utilizing the Monte Carlo method. However, the essences of all the aforementioned works are based on the fuzzy theory or the neural network. Owing to some drawbacks of the two algorithms, vessel CR assessment is limited in practical engineering. First, the fuzzy-theory-based CR assessment is considered as a synthesis algorithm using the Boolean operator. In the discourse domain, the vessel with the greatest membership of CR is regarded as the most dangerous target. However, as early as in 2000, Zheng and Wu (2000) pointed out the assessment uncertainty when the target ships have ambiguous membership of CR. In contrast, it is difficult for the neural network to obtain a large number of sample set or to converge in the training stage with multiparameter. Furthermore, the training time significantly

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* Corresponding author. Tel.: +86 13841665178.
E-mail address: bo_li@yeah.net (B. Li).

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increases as the complexity of network structure increases, which leads to the reduction of learning ability (Xu et al., 2003). Compared with the algorithms based on the fuzzy theory or on the neural network, the Dempster–Shafer (D–S) evidence theory – which has a strong theory foundation – can well eliminate the information uncertainty and make full use of the evidence of multisource information to improve assessment accuracy (Surya et al., 2000). Tu and Xu (2001) showed that the hypothesis set that depends on the accumulative evidence on the D–S evidence theory can achieve fast convergence without a priori probability and conditional probability. However, a few works on the D–S evidence theory have been reported to complete vessel CR assessment at the present stage.

In this paper, we propose an approach to vessel CR assessment based on the D–S evidence theory, which can resolve the associated issues of collision avoidance. First we apply the information fusion theory to calculate the membership functions corresponding to the distance to the closest point of approach (DCPA), the time to the closest point of approach (TCPA) and the relative distance r among every ship from the vessel traffic system (VTS) center using a multiradar network. Later, the extracted membership functions are transformed into the joint basic probability assignment (JBPA) and CR is calculated according to the D–S evidence theory. To confirm the performance of the proposed algorithm, we used the required data from a radar processing system to carry out simulation experiment and displayed the degree of CR among all the ships. The remainder of this article has been arranged as follows: Section 2 discusses the calculation of DCPA, TCPA and r. In Section 3, we use the D–S evidence theory to achieve the degree of CR. Section 4 discusses the simulation results about the CR assessment among many vessels. In the last section, we sum up the paper by providing scope for future work.

2. Preliminaries

In 2002, the International Maritime Organization (IMO) adopted new maritime security measures that include amendments to the 1974 Convention of Safety of Life at Sea (SOLAS) as well as a new mandatory International Ships and Port Facilities Security (ISPS) code. The studies by Johansen et al. (2004) and Liu (2006) show that the values of DCPA, TCPA and r from every encounter ship are important navigation parameters, which should be accurately calculated in the VTS center. In this section, we present the representations corresponding to the DCPA, TCPA and r based on the information fusion theory.

2.1. Representations of DCPA, TCPA and r

We suppose that the velocity and the course of the own ship are v_0 and c_0, respectively, with geographic position point (x_0, y_0). Similarly, v_T and c_T denote the velocity and the course, respectively, by indicating (x_T, y_T) as the geographic position point for the target ship (Ahna et al., 2012; Tu and Xu, 2001). To calculate the navigation parameters, we utilized the coordinate system.

Fig. 1 demonstrates their relationships and shows that the relative distance between two ships is

$$r = \sqrt{(x_T - x_0)^2 + (y_T - y_0)^2} \tag{1}$$

Applying the cosine theorem, we obtain the relative velocity in the vector triangle $\Delta v_0 v_T v_R$.

$$v_R = \sqrt{v_0^2 + v_T^2 - 2 v_0 v_T \cos(c_T - c_0 - \pi)} \tag{2}$$

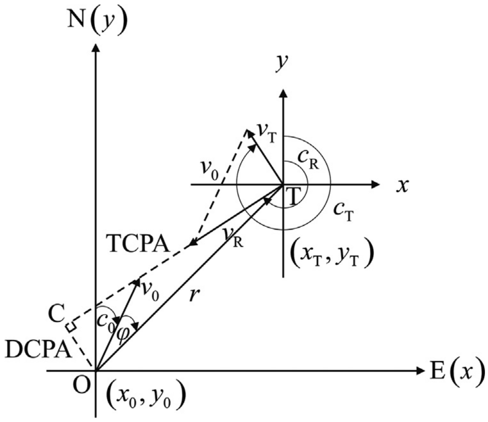

Fig. 1. Important parameters in the coordinate system.

Then the relative course can be calculated as follows:

$$c_R = \begin{cases} c_0 - \arccos\left(\frac{v_R^2 + v_0^2 - v_T^2}{2 v_R v_0}\right), & c_0 < c_T \\ c_0 + \arccos\left(\frac{v_R^2 + v_0^2 - v_T^2}{2 v_R v_0}\right), & c_0 \geq c_T \end{cases} \tag{3}$$

Subsequent to the above parameters, we obtain the DCPA in the collision triangle ΔOCT by applying the sine theorem. As one right side OC, the DCPA is considered as one right side OC, which can be written as

$$\text{DCPA} = r \sin(c_R - c_0 - \varphi - \pi) \tag{4}$$

where φ is the bearing between the own ship and the target ship.

Similarly, we can see that the TCPA is the quotation of the other right side CT and v_R in ΔOCT, i.e.,

$$\text{TCPA} = \frac{r}{v_R} \cos(c_R - c_0 - \varphi - \pi) \tag{5}$$

In Eqs. (4) and (5), it can be seen that DCPA and TCPA are not separated in the analysis of vessel collision; they reflect the collision possibility and the collision degree. Ren et al. (2011) explained that DCPA and TCPA are dependent on the length and speed of the ship, respectively. Since their values are determined by r, the corresponding observation errors should be reduced as much as possible.

2.2. Achieving fusion from multiradar network

As a special sensor, the radar can detect and indicate all the relevant targets on the water surface regardless of any onboard equipment. Because it has the advantage that it can detect small vessels and floating objects, the radar has been widely applied in maritime communications. In the process of multitarget tracking (MTT), the single radar can hardly estimate the number of targets and their states from a sequence of noisy and cluttered measurement sets. In contrast, the multiradar network can improve the tracking accuracy by reducing the randomness of the stochastic oscillator sequence at every moment in overlapping areas (Ling et al., 2000). Therefore, we utilized a multiradar to achieve the navigation parameters by rule and line. In the interest of simplicity, we use the subscript j to denote the DCPA, TCPA and r (j=1, 2, 3).

Suppose k radars can simultaneously observe the same target ship (k=1, 2,…, K), then the jth fusion result at time t can be calculated by using the following equation:

$$F_j(t) = \sum_{k=1}^{K} w_k c_{jk}(t) \tag{6}$$