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A New Criterion Pose and Shape of Objects for Collision Risk Estimation

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***Abstract*—**As many recent researches being implemented in aviation and maritime aspects, strong doubts have been raised concerning the reliability of the estimation of collision risk. It is shown that using position and velocity of objects can lead to imprecise results. In this paper, therefore, a new approach to the estimation of collision risks using pose and shape of objects is proposed. Simulation results are presented validating the accuracy of the new criterion to adapt to collision risk algorithm based on fuzzy logic.

***Keywords*—**Collision risk, Pose and shape, Fuzzy logic.

I. Introduction

THERE have been occurred a lot of great and small collision accidents such as airplane collision event brought loss of 583 people life in Tenerife Island airport, Hebei Spirit oil spill accident wrought damage $660 million, and satellites impact on Siberia sky in 2009. These greatly impacted the society as well as economy due to result in immeasurable loss of life and serious natural disaster. Therefore, in order to avoid these disaster scholars and researchers have worked on the research regarding collision risk.

In recent years, by using fuzzy logic and probability, a variety of research estimating, collision risks, which are to qualify dangerousness of objects, are actively in progress. These researches are needed to study more in depth for aspects of economy and safety. So far, many researches, for example; the collision risks inference system based on the fuzzy logic, probability, and so on, have been proposed.

Algorithm applied to the fuzzy logic and defined by DCPA (Distance at the Closest Point of Approach), TCPA (Time at the Closets Point of Approach), which are input factors, for calculating collision risks has been proposed by Hasegawa et al. [1]. Many people have presented the improved algorithm based on fuzzy logic to enhance the accuracy. Hara and Hammer [2] enhanced accuracy using relative distance of the other ship which was sensed by human and an angular velocity. Son [3] proposed scheme using model of environmental stress felt by human. Kim [4] suggested algorithm calculating collision risk through VCD (Variation of Compass Degree). Also, in order to improve the uncertainty and the deflection of fuzzy algorithm, Song et al. [5] have studied the experiment on estimation algorithm based on the probabilistic theory for the angle variation of two objects. In the same work, the data from the experiment is combined with prior distribution, using Bayesian model.

Even though the accuracy has been improved by continued effort to suggest various algorithms, some of drawbacks of those studies are only considering the position and velocity of the objects for calculating the risk. However, each object has different directions and size, so that the probabilities of the collision are different depending on situations. Therefore, using these factors for the criteria of collision risk the accuracy will be more improved. This paper presents calculation scheme, MRR (Minimum Required Range), which becomes a criterion for avoiding collision using pose and shape of the objects in order to improve the accuracy of collision risk.

This paper is organized as follows. The basic equation of DCPA and TCPA is described in Section II. In Section II, we explain the MRR for collision prevention. In Section IV the experimental results and an analysis is discussed. Finally, we end with a brief conclusion and future works in Section V.

II. Relationship of Objects

In order to evaluate the degree of collision risk of closing objects, there are several factors to estimate collision risk but TCPA and DCPA are generally used. Thus, we introduce the equations of TCAP and DCPA in this chapter.

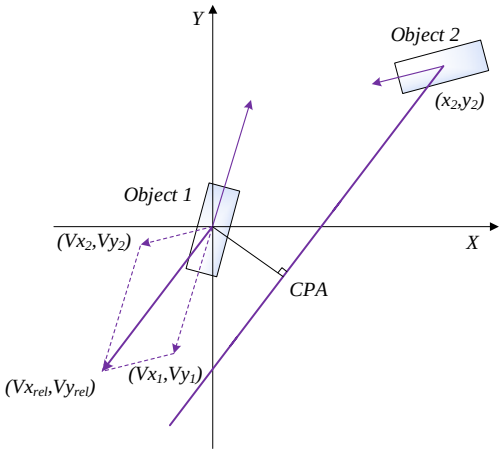

Fig. 1 Object motion configuration

The objects motion configuration is depicted in Fig. 1 where

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the center of objects1 is the same the origin of Cartesian coordinate plane. In Fig. 1, the position and velocity of object 1 are (x_1, y_1), (V_{x_1}, V_{y_1}), respectively. And position and velocity of object 2 are (x_2, y_2), (V_{x_2}, V_{y_2}). The relative velocity is denoted by $(V_{x_{rel}}, V_{y_{rel}})$ in Cartesian coordinate plane. CPA (Closest Point at Approach) refers to the closest point of two objects. A straight-line equation can be defined using the point and slope which are the center of object 2 and the relative velocity as

$$V_{y_{rel}}x - V_{x_{rel}}y - V_{y_{rel}}x_2 + V_{x_{rel}}y_2 = 0 \quad (1)$$

DCPA can be obtained by using the point-line distance equation between the origin point and the straight line as

$$DCPA = |\frac{V_{y_{rel}}}{V_{x_{rel}}} \times x_2 + y_2| \Big/ \sqrt{(\frac{V_{y_{rel}}}{V_{x_{rel}}})^2 + (-1)^2} \quad (2)$$

TCPA that the time takes until the object arrives at CPA is given by

$$TCPA = \sqrt{(x_2)^2 - (y_2)^2 - DCPA^2} \Big/ \sqrt{(V_{x_{rel}})^2 + (V_{y_{rel}})^2} \quad (3)$$

III. MRR

It is inaccurate to estimate collision risk only using of the position and velocity of objects. The shapes and poses of objects are different and those of objects are the main factor to determine whether the objects crash or not. Thus, we can improve the accuracy of collision risk considering the shapes and poses of objects. The least avoidable distance between two objects can be determined using the sizes and velocities of the objects. The result is a new criterion called MRR (Minimum Required Range).

A pose is classified two types in accordance with velocities of objects. Accordingly, MRR is also divided into two types. First type is the case that the directions of two objects are parallel each other. Second is that the vectors of two objects cross vertically.

A. Head-On or Parallel Encounter Situation

Fig. 2 shows that the angle between two velocities is 0 degree. However, it is equal that the angle is 180 degree. If the angle is 0, we do not consider the case that the velocity of object1 is less than the one of object2. MRR is expressed by the distance between the center of object1 and the velocity of object2 and given by

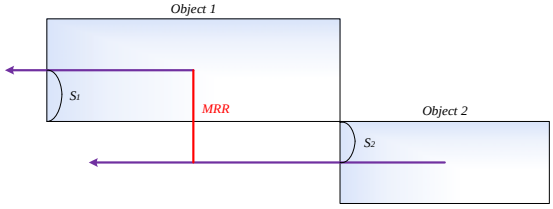

Fig. 2 MRR in Head-on or parallel encounter situation

$$MRR = S_1 + S_2 \quad (4)$$

where L1 and L2 denote the half of width of the object1 and 2.

B. Crossing Encounter Situation

Fig. 3 depicts that the included angle between two velocities is 90 degree. MRR is calculated by the distance of the centers of two objects. It is derived from Pythagoras' theorem as shown in (5):

$$MRR = \sqrt{(L_2 + S_1)^2 + (L_1 + S_2)^2} \quad (5)$$

where S1 and S2 denote the half of height of the object1 and 2.

IV. Simulation Results

To test the validation of proposed estimation criterion, the scenarios of two vessels maneuvering in real maritime environment have been simulated. The performance of the proposed method is compare as per whether the MRR is adapted to membership function of DCPA or not. The membership functions and fuzzy inference tables of the collision risk are quoted from paper [3, 4]. The scenarios are the two cases which are parallel and crossing situation. And each case consists of collision and non-collision situation. We assume that two targets follow a straight-line constant-speed trajectory in two-dimensional space and are a type of rectangular, 200 or 50 meter in each dimension. For the simulations, total simulation time is 200sec and the sampling time T = 3sec.

A. Simulation of the Representative Head-On or Parallel Situation

Fig. 4 presents the simulation for two-vessel collision situation considering different speed and course conditions in the Cartesian coordinate space. Initial positions and velocities of the two vessels are set to be (3000m, -5000m), (20m/s, 0m/s) and (10000m, -4980m), (-20m/s, 0m/s), respectively. The MRR is 50m and DCPA is 20m when two vessels arrive at CPA about 117sec. DCPA is greater than MRR, hence two ships collide each other.

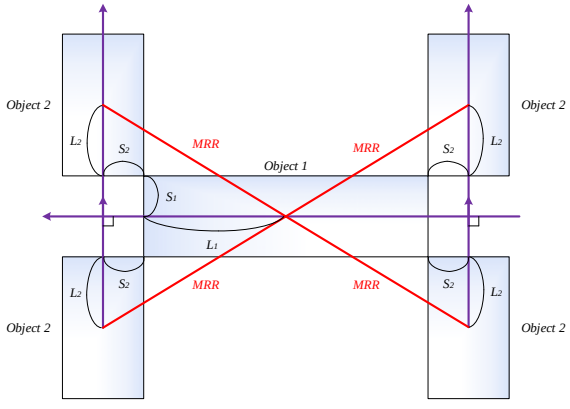

Fig. 3 MRR in crossing encounter situation

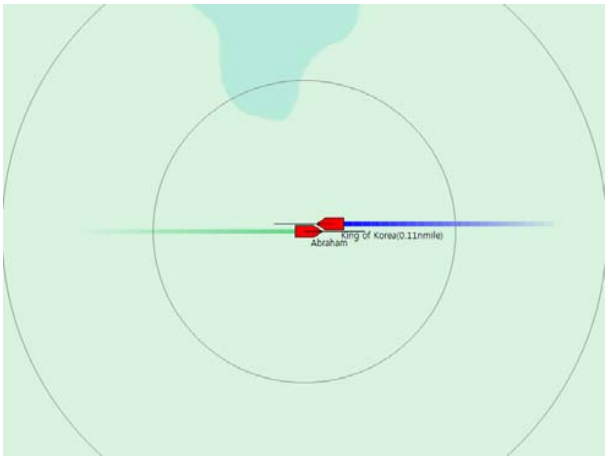

Fig. 4 Ship position in XY plan – collision situation

Fig. 5 shows the result of the scenario of Fig. 4 considering MRR and the distance between two vessels. The distance of two vessels decreases in every hour, so that the distance is the least about 177 sec and after that, it increases.

With two vessels moving at a constant velocity, DCPA is identical but TCPA decreases in every hour. Considering these factors, the collision risk rise gradually. In the case of colliding two vessels, the outcome of the collision risk is the same both with and without applying MRR.

Fig. 6 shows the scenario for two-vessel non-collision situation in the Cartesian coordinate space. Initial positions and velocities of the two vessels are set to be (3000m, -5000m), (20m/s, 0m/s) and (10000m, -4930m), (-20m/s, 0m/s), respectively. The MRR is 50m and DCPA is 70m when two vessels arrive at CPA about 117sec. Two ships do not collide because DCPA is less than MRR.

Fig. 7 depicts the collision risk with and without applying the MRR, and the distance of two vessels. As shown in the Fig. 5, the distance of two vessels decreases in every hour and the distance is the least about 177 sec. Above it mentioned, DCPA is always constant and the TCPA calculated as time passes decreases. As a result, it shows that the collision risk with applying the MRR is less than the one without applying the MRR because two ships do not collide.

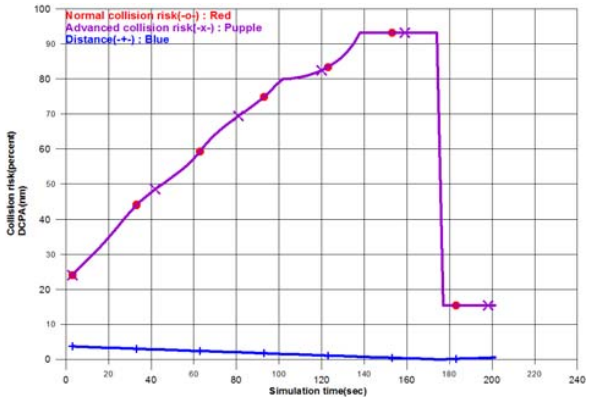

Fig. 5 The collision risk and distance – collision situation

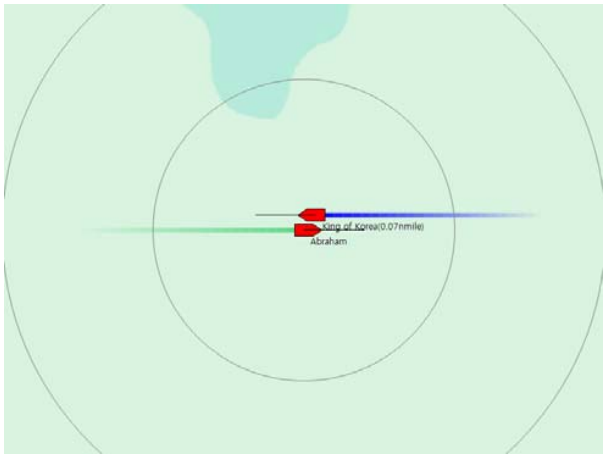

Fig. 6 Ship position in XY plan – non-collision situation

B. Simulation of the Representative Crossing Situation

The representative crossing situations are simulated again as shown in Figs. 8 and 10. The figures present collision and non-collision situation in the Cartesian coordinate space. It is shown that the scenario for two-vessel collision situations in Fig. 8. Initial positions and velocities of the two vessels are set to be (3000m, -5000m), (20m/s, 0m/s) and (6000m, -8000m), (0m/s, 20m/s), respectively. Two vessels arrive at CPA about 114sec and the MRR is 177m. DCPA is less than MRR, consequently, two ships crash.

Fig. 9 illustrates the result of the Fig. 8 scenario. It is presented the collision risk with and without applying the MRR, and the distance of two vessels. DCPA is the same and the distance of the two vessels is minimum at around 144 sec because the vessels move in a constant velocity motion. Since TCPA is decreasing in every sampling time, the collision risk increases until around 120 sec and from 120 sec to just before the collision shows the greatest collision risk. In the case of collision of two vessels, the collision risk is same in both with and without applying MRR.

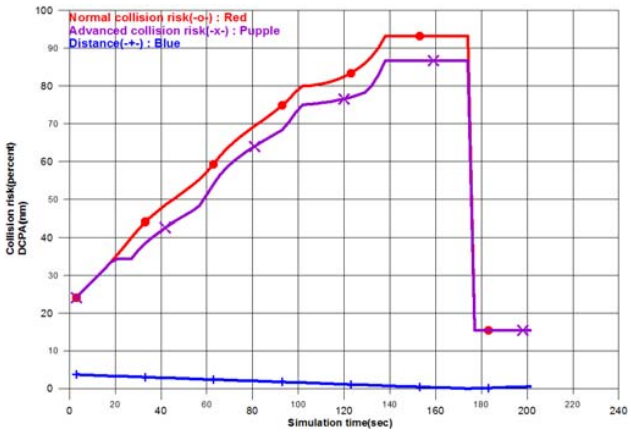

Fig. 7 The collision risk and distance – non-collision situation

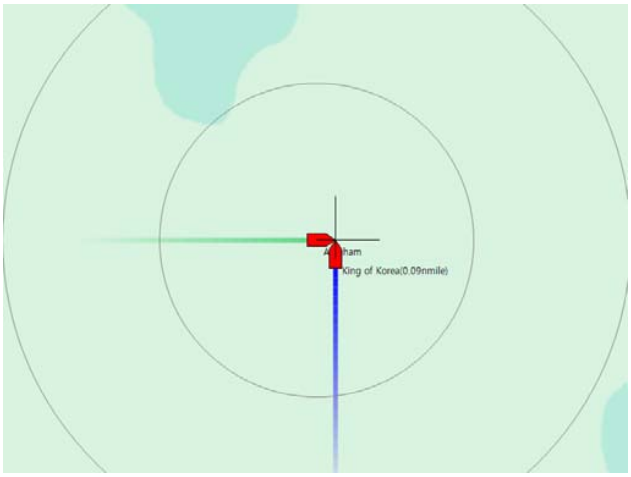

Fig. 8 Ship position in XY plan – collision situation

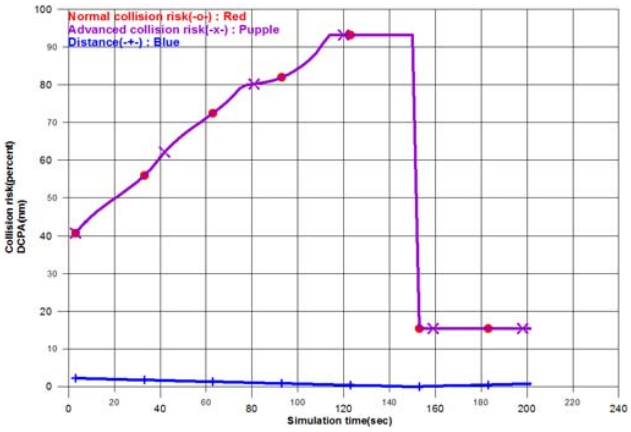

Fig. 9 The collision risk and distance – collision situation

Fig. 10 presents the scenario non-collision situation when two vessels are crossing. Initial positions and velocities of the two vessels are set to be (3000m, -5000m), (20m/s, 0m/s) and (6000m, -7700m), (0m/s, 20m/s), respectively. Two vessels arrive at CPA about 114sec. The MRR is about 177m and DCPA is about 211m. As the DCPA is greater than MRR, two ships do not collide to each other.

As shown in the Fig. 11, since DCPA is the same but the velocity of ship is constant, the degree of collision risk increases from 0sec to 120sec. TCPA is less than minimum threshold of member function between 120sec and 177sec, so that the collision risk is shown constant. There is lower collision risk with applying MRR than without applying MRR as the two vessels cross but not collide.

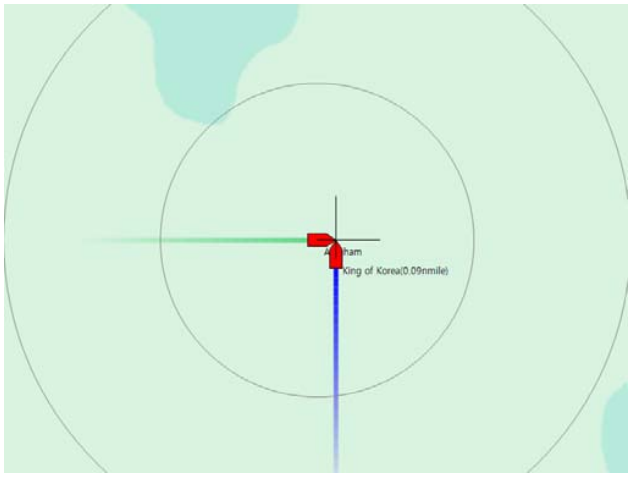

Fig. 10 Ship position in XY plan – non-collision situation

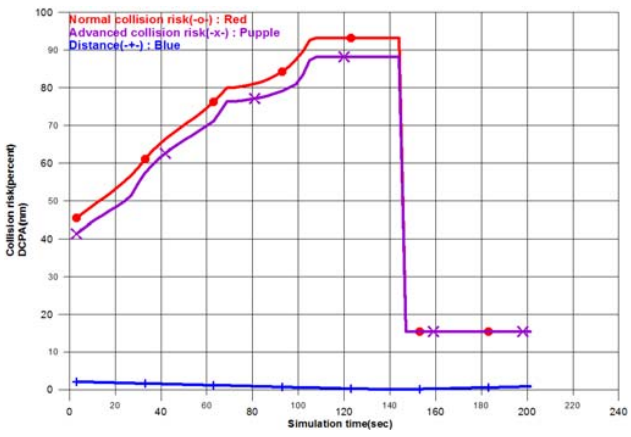

Fig. 11 The collision risk and distance –non-collision situation

V. Conclusions

Recently, by increasing exportation and importation through globalization, seaborne trade is becoming actively. For this reason, the safety of maritime transportation is vitally important. Thus, we discussed the scheme improving the accuracy of collision risk. In this paper, we presented a new formulation referred to MRR depending on the pose and shape of objects and the performance is verified by simulation. As a result, when two objects do not collide, the collision risk applied MRR is lower than one not applied MRR. It is shown that the imprecision of existing method was improved. From this, by using the scheme presented, it is possible to reduce the warning error in actual traffic control. Future work will utilize an experimental test environment to confirm another collision risks and to investigate others.

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