International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-6, Issue-1, January 2020

Modeling of Collision Risk of Intelligent Ships in Open Waters

Lu-lu ZHANG, Xiao-yuan WANG, Shi-jie Liu, Jun-yan Han

Abstract: **Ship collision risk is a fuzzy concept, which refers to the measurement of the possibility of collision between ships, and is a kind of early warning of possible danger in the future.The existing research on multi-ship collision risk is based on the evaluation method of two-ship collision risk, and the collision risk degree of target ship and each interfering ship is calculated separately, which is used to determine to avoid the ship. This method has a large gap with the actual situation and has certain defects. In open waters with fewer ships, it has certain accuracy, but it cannot accurately represent the degree of danger of the environment in which the target ship is located in busy waters. Lack of an assessment of the overall risk of the target vessel's perceived area. On the basis of the regional analysis of the ship's encounter, this paper analyzes the ship collision risk degree by combining the idea of velocity obstacles. The impact of multiple interfering vessels in the area on the target vessel was considered for the overall collision risk assessment.**

Index Terms—Collision risk ，Ship encounters，Unmanned ship，Velocity obstacles

I INTRODUCTION

With the rapid development of the national economy and the increasing degree of global economic integration, the demand for global trade transportation is increasing year by year. Information shows that the average annual number of maritime traffic accidents more than 200,of which nearly half were caused by collisions, resulting in incalculable economic and ecological losses. The ship collision risk degree is the evaluation index of the ship's risk and the visual reflection parameter of evaluating the ship's safe operation.

On the research of ship encounters, Dong Fang [1] combined with the International Maritime Collision Avoidance Rules to judge and analyze the situation of the two ships, which will help mariners avoid collision according to the situation of the ships. Wu Chunjie [2] put forward the principle of judging the situation of ship encounters, and established a quantitative judgment model of the situation of ship encounters during mutual observation.Su Kaiwen [3] believes that it was not accurate to use the ship's course as the criterion for classifying the encounter situation. Relatively speaking, the relative position between ships can more accurately classify the meeting situation.

On the research of velocity obstacles, Fiorini P [4]-[5] proposes a theoretical framework for the velocity obstacles, which constructs a cone region in the velocity space for each obstacle, which was considered collision when the velocity vector falls into the cone region. Kuwata [6] combines velocity obstacles with collision avoidance rules for the dynamic barrier avoidance of unmanned boats on the surface of the water, and calculates the closest distance between an unmanned boat and the obstacle and the time to reach that point by speed, to determine the likelihood of collision. Huang Yonglong [7] applied the principle of velocity obstacles, designed a dynamic avoidance law that can be used for multi-robot motion coordination, and improved the accuracy of the robot barrier by adjusting the size of the collision area.

Through the analysis of the current research status at home and abroad, domain the current collision risk of the two ships more mature, the calculation method was also diverse, but the multi-ship will encounter less risk research, the main idea was to break down the multi-ship encounter into multiple two-ship encounter analysis, lack of overall thinking. Therefore, the study of multi-ship collision risk is very necessary.

II THE METHODS

A. Regional Analysis of Ship Encounters.

In the busy waters, there are a large number of meeting ships, which greatly increases the complexity and danger of meeting ships. Not every interference ship will cause danger to the target ship. Accurate research of the ship's encounter area can better identify the interference ships around the target ship and increase the identification speed of the ship's collision risk.

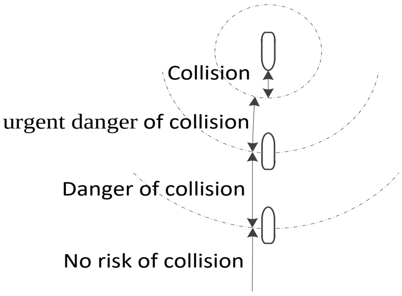

Fig.1 Division of dangerous stages for ships

When the situation around the target ship was analyzed, it was necessary to consider ships around the target ship that were at high risk of collision with the interference ship, the area within 3n mile around the target ship, combined with the " Convention on the Internation Regulations for Preventing Collisions at Sea " on the division of the ship will encounter, the resulting regional division map, convenient after the study of the risk of multi-ship collision.

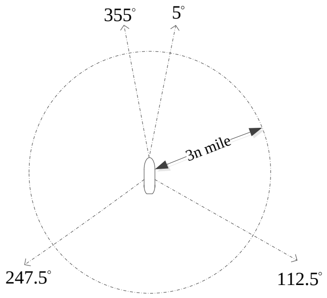

Fig.1 Division map of ship encounters

B. Modeling of ship collision risk based on velocity obstacles.

The velocity obstacles defines a relative speed obstacle area. When the relative speed falls into this area, it is believed that the motion body will collide within a certain period of time, in order to solve the collision, it is necessary to take corresponding collision avoidance operation to avoid the occurrence of collision risk. In this paper, this kind of idea was used to evaluate the collision risk of ships, which provides a good basis for ship collision avoidance decisions. The ship collision risk was analyzed through the idea of the ship encounter area analysis and velocity obstacles, combined with the characteristics of the collision of many ships in the region, and the overall value of the collision risk of the target ship in the area was described.

The collision risk of the encountering ship was studied. The target ship was assumed to be a particle, and the radius of the interference ship was expanded according to the meeting characteristics of the target ship and the interference ship.

When neither ship takes collision avoidance action and keeps the current state of navigation to continue sailing, the two ships are expected to have a collision time t_p :

$$t_p = \frac{\sqrt{(x_b - x_a)^2 + (y_b - y_a)^2}}{\sqrt{(v_b \cdot \sin\varphi_b - v_a \cdot \sin\varphi_a)^2 + (v_b \cdot \cos\varphi_b - v_a \cdot \cos\varphi_a)^2}} \quad (1)$$

The collision factor of distance between two ships is obtained, taking into account the safe distance of approach and the actual distance between the ships.

$$\delta_d = \frac{R_T}{\mathrm{r}_d} \quad (2)$$

Where, r_d is The safe distance of approach is the minimum meeting distance that allows the two ships to pass safely considering the navigation environment and the ship's movement status.

The time collision factor between two ships is obtained by considering parameters such as tcpa and the actual encounter time between ships.

$$\delta_t = \frac{t_p}{\mathrm{tcpa}} \quad (3)$$

The safety radius of the interference ship is determined by reference to the width of the interference ship and the safe distance of approach of the ship.

$$r_m = r_b + r_d \quad (4)$$

Interference ship safety radius is corrected to take into account the collision time and collision distance two factors.

$$r = (\delta_t + \delta_d) r_m \quad (5)$$

$$f(\delta_t) = \begin{cases} 1 & (0 \le \delta_t < 2) \\ 1 - \frac{1}{18}(\delta_t - 2)^2 & (2 \le \delta_t < 5) \\ \frac{1}{18}(\delta_t - 8)^2 & (5 \le \delta_t < 8) \\ 0 & (\delta_t \ge 8) \end{cases} \quad (6)$$

$$f(\delta_d) = \begin{cases} 1 & (0 \le \delta_d < 1) \\ 1 - \frac{1}{20}(\delta_d - 1)^2 & (1 \le \delta_d < 2) \\ \frac{1}{32}(\delta_d - 6)^2 & (2 \le \delta_d < 4) \\ 0 & (\delta_d \ge 4) \end{cases} \quad (7)$$

When $f(\delta_t) + f(\delta_d) > 1.25$, take $f(\delta_t) + f(\delta_d) = 1.25$.

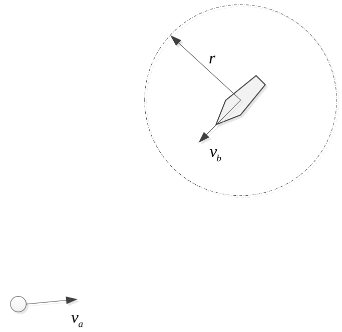

Fig.3 Ship safety radius diagram

As shown in Figure 4, l_{mn} was based on the target ship as the starting point, the target ship relative to the interference ship's relative speed extension line. The angle formed by the line l_{mn} and the center of the two ships was φ, The angle between the tangent line l_{lq} or l_{yq} of the collision area boundary between the target ship and the interference ship and the center of the two ships was Q, The risk of collision between the target ship and the interference ship was as follows:

$$CRI = \frac{\varphi}{Q} \tag{8}$$

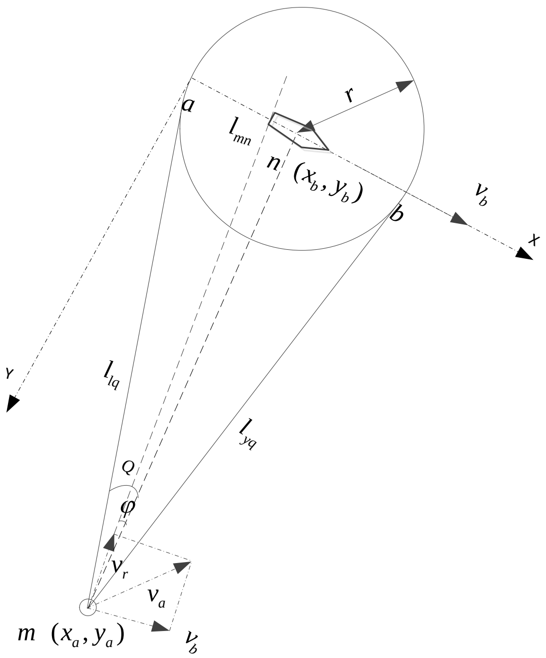

Fig.4 Schematic diagram of ship collision risk

If the relative speed didn't fall into the collision cone, the center of the target ship as the coordinate origin, the speed is the radius, make a circular area, if the speed of the target ship was inside the circle, indicating no collision risk, if the target ship speed exceeds the range of the circle, there was a potential danger.

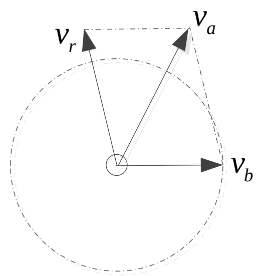

Fig.5 Potential hazard determination diagram

The risk of collision when a ship was sailing in busy waters was assessed taking into account the impact of multiple ship in the area on the target ship. The collision risk of all ships in the area to the target ship was calculated as follows:

$$CR=\sum_{i=1}^{n} CRI_i \alpha_i \vec{d} \qquad i=1,2,3,\ldots,n \tag{9}$$

Where, CR is the collision risk of the meeting area; CRI_i represents collision risk calculation for interference ship i; $\vec{d}$ is the direction vector between ships whose size is equal to the distance between the two ships and whose direction is from the interference ship to the target ship; α_i is the reduction coefficient, the expression is $\alpha_i = 1/i$; n is the total number of interference ship; i is the serial number of the interference ship , the interference ship with the highest collision risk is 1, and the interference ship with the lowest collision risk is n .

III Discussion

The modeling and evaluation of ship collision risk based on the velocity obstacles is a new method for the assessment of the degree of danger of multi-ship collision, and a prerequisite for the ship to guarantee the safety of navigation in complex navigational environment. The effect of the target ship's real-time assessment of the surrounding navigation environment provides a strong reference for the intelligent navigation system of the unmanned ship.

References

[1] Dong Fang, Xu Jianhong, Su Kaiwen.Judgement of the situation of ships [J] .Navigation Technology, 2007 (01): 2-5.

[2] Wu Chunjie. The construction of quantitative judgment model of the situation in which the ship will encounter each other[C]Professional Committee of Inland River Ship Navigation, Chinese Navigation Society. Proceedings of Ship Navigation Safety and Management in Bridge Region (1). Society, 2010: 74-76 + 79.

[3] Su Kaiwen. Research on Ship Collision Avoidance Expert System [D]. Dalian Maritime University, 2007.

[4] Fiorini P , Shiller Z.Motion planning in dynamic environments using the relative velocity paradigm[C]//IEEE International Conference on Robotics and Automation.Piscataway , NJ , USA ：IEEE，1993：560-565.

[5] Fiorini P , Shiller Z.Motion planning in dynamic environments using velocity obstacles[J].International Journal of Robotics Research，1998， 17：760-772.

[6] Kuwata Y,Wolf M T,Zarzhitsky D,et al.Safe maritime navigation with COLREGS using velocity obstacles[C]//2011 IEEE/RSJ International Conference on Intelligeng Robots and Systems,2011:4728-4734.

[7] Huang Yonglong, Zhong Xunyu. Multi-robot collision avoidance planning algorithm based on improved speed obstacle method [J]. CEA, 2012, 48 (32): 47-51.

AUTHOR PROFILE

**Lulu Zhang**, She was born on January 1993 in Heilongjiang Province, China. She is a graduate student at the Shandong University of Technology, and major in Transportation Engineering. Her research direction is the Unmanned ship intelligent collision avoidance.

**Xiaoyuan Wang,** He was born in Shandong Province, China. He is a professor at Qingdao University of Science and Technology. His research interest covers transportation planning and management, tra ffi c information engineering and control, traffic behavior and security, tra ffi c flow theory, traffic simulation, and controlling and cooperative intelligence of human-vehicle-environment.

**Shijie Liu,** He was born on June 1996 in Shandong Province, China. He is a graduate student at the Shandong University of Technology, and major in Transportation Engineering. His research interests include driving behavior analysis, affective computing, controlling and cooperative intelligence of human-vehicle-environment.

**Junyan Han,** He was born on August 1995 in Shandong Province, China. He is a graduate student at the Shandong University of Technology, and major in Transportation Engineering. His research interests include driving behavior analysis, affective computing, controlling and cooperative intelligence of human-vehicle-environment.