International Journal of Navigation and Port Research
Vol.28, No.9 pp. 799~802, 2004 (ISSN-1598-5725)

A Study on the Threshold of Avoidance Sector in the New Evaluation of Collision Risk

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Abstract : *Evaluation of the quantitative risk of collision plays a key role in developing the expert system of navigation and collision avoidance. This study analysed thoroughly how to determine the threshold of avoidance sector as described in the new evaluation of collision risk, and suggested the collision risk obtained by the alteration of course and/or speed in order to pass clear of each danger zone as the threshold of avoidance sector.*

Key words : *collision risk, distance to CPA, alteration of course and/or speed, threshold of avoidance sector, danger zone*

1. Introduction

Evaluating the risk of collision quantitatively plays a key role in developing the expert system of navigation and collision avoidance. There have been several researches into the quantitative assessment of collision risk, which still have a few problems when they are applied to the expert system. For the purpose of solving such problems a new approach to collision risk using *sech* function was introduced(Jeong, 2003a), and the proper method of determining the gradient coefficients shown in this approach was developed(Jeong, 2003b) and the threshold function of avoidance time was analysed and obtained(Jeong, 2003c).

In this paper, of the two thresholds in the new evaluation of collision risk, the threshold of avoidance sector is analysed and obtained. This threshold is applied to several practical situations.

2. Method of obtaining the threshold of avoidance sector

The new evaluation of collision risk using *sech* function is given by(Jeong, 2003a)

$$CR = p \cdot \operatorname{sec}h(a \cdot dcpa) + q \cdot \operatorname{sec}h(b \cdot t_a) + r \cdot \Phi(\theta, \alpha) \quad (1)$$

where CR is the collision risk, $dcpa$ is the closest distance and t_a is the approach time[1]. The five coefficients p, q, r, a and b are to determine the change rate of collision risk properly. The amplitude coefficients p, q and r are to determine the amplitude of *sech* function and the gradient coefficients a and b are to determine the change of *sech* function. $\Phi(\theta, \alpha)$ is a function of determining whether own ship maintains her course and speed or alters her course and/or speed according to the Collision Regulations. It is called the function of own ship's state and expressed by the bearing θ and the aspect α of a target, the magnitude of which is 0 if own ship maintains and 1 if she alters.

2.1 Things to be considered when determining the threshold of avoidance sector

There are two kinds of thresholds in the new evaluation of collision risk as mentioned in the previous paper(Jeong, 2003c). One is to determine when the avoiding action has to be taken if the risk of collision exists. It is called the threshold of avoidance time. The other is to determine which sector will be safe for own ship, which is obtained by own ship's choice, that is, alteration of own ship's course and/or speed. It is called the threshold of avoidance sector.

This paper deals with how to determine the threshold of avoidance sector. The followings are assumed or taken into

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1) An approach time is completely different from TCPA(Time to CPA) and is given by the following equation.

$$t_a = \frac{2 \cdot dcpa}{v_r} \quad \text{if } 045° < \zeta \leq 90°$$
$$= -\frac{2 \cdot dcpa}{v_r} \quad \text{if } 090° < \zeta < 135°$$
$$= \frac{R}{v_r \cos \zeta} \quad \textit{otherwise}$$

consideration.

① The gradient 3and amplitude coefficients in the new evaluation of collision risk depend on danger zone (or safe minimum distance), closest distance and approach time. When we assume here that the closest distance ranges from 0.09 to 1.5 mile, that the approach time ranges between 4.6 minutes and 6.9 minutes, and that the danger zone is 2.12(=$1.5\sqrt{2}$) miles, we can obtain the gradient coefficients $a=0.818$, $b=0.180$(Jeong, 2003b). Meanwhile the amplitude coefficients are assumed $p=1$, $q=1$ and $r=0$.

② Let the range of relative speed be from 0.1 to 1.0 mile per minute. Because the relative speed governs the time elapsed after avoiding action is taken and the collision risk, the size of danger zone should be governed by the relative speed. As shown in Table 1, we here consider that for the target with her relative speed of 0.39 mile per minute and upwards, avoiding action has to be taken to pass outside the danger zone of 2.12 miles, and that for the target with her relative speed of 0.28 mile per minute and more, but less than 0.39 mile per minute, avoiding action has to be taken to pass outside the danger zone of 1.59 miles. We can also assume that for the target with her relative speed of 0.17 mile per minute and more, but less than 0.28 mile per minute, avoiding action has to be taken to pass outside the danger zone of 1.06 miles, and that for the target with her relative speed of less than 0.17 mile per minute, avoiding action has to be taken to pass outside the danger zone of 0.71 mile(Jeong, 2003c).

Table 1 Relative Speed and Danger Zone

Relative Speed (mile/min)	$vr \geq 0.39$	$0.39 > vr \geq 0.28$	$0.28 > vr \geq 0.17$	$vr < 0.17$
Danger Zone (mile)	2.12	1.59	1.06	0.71

③ The threshold of avoidance sector is called the safe range of own ship's behavior such as the alteration of course and/or speed, after the time of avoiding action is determined by the threshold function of avoidance time which was presented in the previous paper(Jeong 2003c).

2.2 Way of Determining the Threshold of Avoidance Sector

There can be many ways of determining the threshold of avoidance sector. Here we assume the threshold is one of collision risks when the threshold function of avoidance time determines the time of taking avoiding action. However, the threshold of avoidance sector can not be given as a constant, because the threshold is dependent upon the collision risk of Eq. (1) which is a function of the relative speed and danger zone.

Therefore the threshold of avoidance sector can be thought as either the collision risk obtained by the large alteration of course and/or speed, i.e. the alteration of course of 30°, or that obtained by the alteration of course and/or speed in order to pass clear of each danger zone represented in Table 1.

If avoiding action is taken largely enough, the collision risk of the former is generally less than that of the latter and the safe sector is narrower. Therefore the collision risk of the latter, i.e. the threshold of avoidance sector, is dealt with in the next chapter.

3. Application of the threshold of avoidance sector to a target or more

3.1 Application to a vessel

The application of the threshold of avoidance sector to actual avoiding action is as follows. When each target approaches within the danger zone of 2.12 miles, 1.59 mile, 1.06 mile and 0.71 mile respectively and avoiding action is taken to keep clear of each danger zone, the avoidance time would be determined by the threshold function or minimum approach range represented in the previous paper(Jeong, 2004a;Jeong, 2004b). At the avoidance time the course and/or speed for own ship to pass clear of each danger zone in Table 1 is determined and the collision risk can be obtained by using a new relative speed and approach time. This collision risk would be the threshold of avoidance sector. The range of course and/or speed, collision risk at which is less than the threshold, will be the safe sector of own ship's behavior.

In Table 2 own ship is steering a course of 000° at a speed of 0.4 mile per minute. First of all, let's consider that a target, which is at a distance of 7.0 miles, bearing 355.9°, approaches with a closest distance of 0.5 mile at a relative speed of 0.50 mile per minute. The range corresponding to the avoidance time, at which avoiding action has to be taken so as to make the target keep clear of a danger zone of 2.12 miles, is 4.876 miles. The collision risk at the avoidance time is 1.255, while the threshold of avoidance sector is 0.617. At that time the new course of own ship will be 025°. Fig. 1 shows the threshold of avoidance sector and the collision risk of a target at a relative speed of 0.5 mile per minute with respect to own ship's alteration of course. The range of course, the collision risk at which is

Table 2 Data of Own ship and Each Target

Ownship	Course(°)	000	000	000	000
	Speed(mile/min)	0.4	0.4	0.4	0.4
Tatget	Course(°)	180	311.4	000	345.7
	Speed(mile/min)	0.1	0.257	0.2	0.30
Initial Position	Bearing(°)	355.9	037.7	353.3	033.1
	Range(mile)	7.0	5.0	3.0	3.0
DCPA	before Action	0.5	0.2	0.3	0.1
	after Action	2.12	1.59	1.06	0.71
Threshold	Avoidance Time	1.255	1.231	1.260	1.231
	Avoidance Sector	0.617	0.873	0.955	1.224
New Course of Own Ship(°)		025	028	012	012
Range at Avoidance Time(mile)		4.876	3.476	2.102	1.540
Relative Speed(mile/min)		v_r=0.5	v_r=0.30	v_r=0.20	v_r=0.13

where, gradient coefficients a=0.818 and b=0.180.

less than a given threshold of 0.617, is represented as the safe sector of own ship's behavior. In Fig. 1 the minimum safe course of own ship will be 025°.

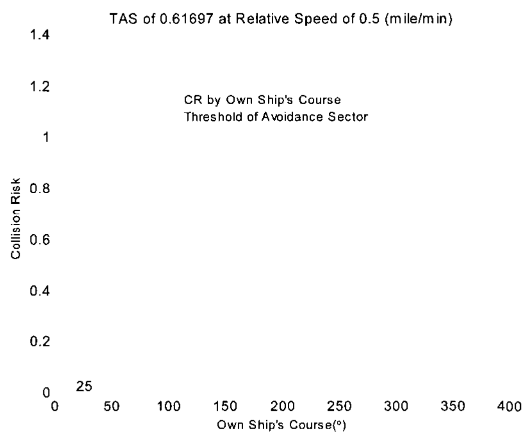

Fig. 1 Threshold of Avoidance Sector at Relative Speed of 0.5 (mile/min)

Likewise, we consider that another target, which is at a distance of 5.0 miles, bearing 037.7°, approaches with a closest distance of 0.2 mile at a relative speed of 0.30 mile per minute. The range corresponding to the avoidance time, at which avoiding action has to be taken so as to make the target pass clear of a danger zone of 1.59 miles, is 3.476 miles. The collision risk at the avoidance time is 1.231, while the threshold of avoidance sector is 0.873. At that time the new course of own ship will be 028°. Fig. 2 shows the threshold of avoidance sector and the collision risk of a target at a relative speed of 0.3 mile per minute with respect to own ship's alteration of course. The range of course, the collision risk at which is less than a given threshold of 0.873, is represented as the safe sector of own ship's behavior. In Fig. 2 the minimum safe course of own ship will be 028°.

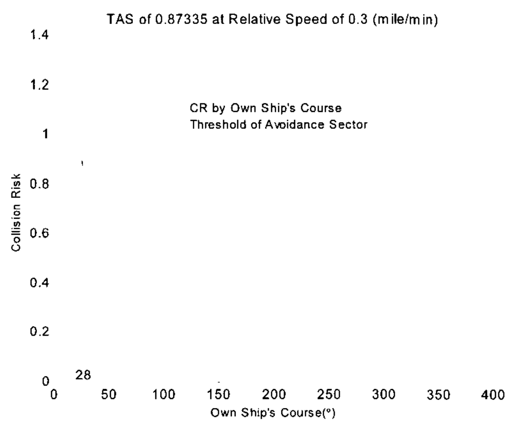

Fig. 2 Threshold of Avoidance Sector at Relative Speed of 0.3 (mile/min)

Meanwhile, we assume that a third target which is at a distance of 3.0 miles, bearing 353.3°, at a relative speed of 0.20 mile per minute approaches with a closest distance of 0.3 mile and a fourth target which is at a distance of 3.0 miles, bearing 033.1°, at a relative speed of 0.13 mile per minute approaches with a closest distance of 0.1 mile. The distances corresponding to the avoidance time, at which avoiding action has to be taken so as to make the targets pass outside the danger zones of 1.06 mile and 0.71 mile, are 2.102 mile and 1.540 mile respectively. The collision risks at the avoidance time is 1.260 and 1.231 respectively, while the thresholds of avoidance sector is 0.955 and 1.224 respectively. At that time the new courses of own ship will be 012° respectively. Fig. 3 and Fig. 4 show the thresholds of avoidance sector and the collision risks of targets at relative speeds of 0.2 and 0.13 mile per minute respectively with respect to own ship's alteration of course. The ranges of course, the collision risks at which are less than the given thresholds of 0.955 and 1.224 respectively, are represented as the safe sectors of own ship's behavior. In Fig. 3 and Fig. 4 both of the minimum safe courses of own ship will be 012°.

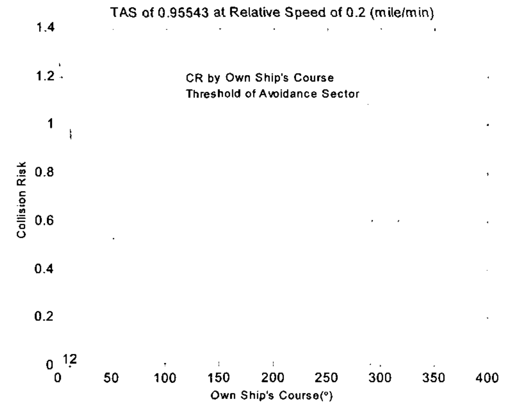

Fig. 3 Threshold of Avoidance Sector at Relative Speed of 0.2 (mile/min)

3.2 Application to many targets

The above threshold of avoidance sector will be applied to many targets approaching own ship as the same method as a single target.

Fig. 5 shows the threshold of avoidance sector and the collision risks of four targets which are simultaneously approaching own ship at different relative speeds with respect to own ship's alteration of course. Meanwhile regarding the target which has the largest collision risk, the threshold of avoidance sector can be obtained. The range of course, the collision risk at which is less than a given threshold, is represented as the safe sector of own ship's behavior. In Fig. 5 the safe sectors are given.

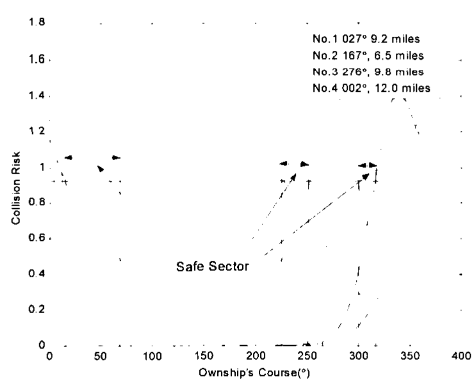

Fig. 5 Threshold of Avoidance Sector and Safe Sectors of Many Targets

4. Conclusion

This paper is to suggest the way of determining the threshold of avoidance sector represented in the new evaluation of collision risk using *sech* function and is to apply such threshold to a target and many targets which are approaching own ship. As a result, it was concluded as follows.

① The threshold of avoidance sector can be given by the collision risk of own ship's alteration to pass clear of the danger zones.

② The range of course, the collision risk at which is less than the threshold of avoidance sector, would be the safe sector of own ship's behavior.

③ The above would be applied to many targets approaching own ship.

Some problems to the new evaluation of collision risk can be solved by using some ways suggested in the studies so far. However, such results should be investigated again through various experiments aboard ships. And, when the amplitude coefficients p and q and the function of own ship's state $\Phi(\theta, \alpha)$ are applied to the collision risk, the thresholds should be corrected. All of these will be dealt with in the future study.

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Received 7 October 2004
Accepted 15 December 2004