

RESEARCH ON INTELLIGENT AVOIDANCE METHOD OF SHIPWRECK BASED ON BIGDATA ANALYSIS

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ABSTRACT

In order to solve the problem that current avoidance method of shipwreck has the problem of low success rate of avoidance, this paper proposes a method of intelligent avoidance of shipwreck based on big data analysis. Firstly, our method used big data analysis to calculate the safe distance of approach of ship under the head-on situation, the crossing situation and the overtaking situation. On this basis, by calculating the risk-degree of collision of ships, our research determined the degree of immediate danger of ships. Finally, we calculated the three kinds of evaluation function of ship navigation, and used genetic algorithm to realize the intelligent avoidance of shipwreck. Experimental result shows that compared the proposed method with the traditional method in two in a recent meeting when the distance to closest point of approach between two ships is 0.13nmile, they can effectively evade. The success rate of avoidance is high.

Keywords: Big data analysis, Shipwreck, Intelligent avoidance, Genetic algorithm

INTRODUCTION

Ships at sea will encounter. Many factors such as the bad weather or the low visibility, the ship driver's dereliction of duty without using the safety speed, the risk judgment errors, or the improper avoidance operation[1-2] can cause the ship into the close quarters situation, even forming urgent danger[3-4]. More than 80% of the maritime accidents are owing to human factors[5-6]. Most of them are caused by violating International Regulations for Preventing Collisions at Sea and the driver's carelessness[7-8]. In order to alleviate the human error factors in the process of ship avoidance and fundamentally reduce the shipwreck caused by human decision-making errors, we need to research the intelligent avoidance methods for ship shipwreck[9]. The reference[10-12] proposes the method for avoiding maritime accidents based on big data for scientific decision. Through the cluster analysis

of sailing factors of ship accident and association rules mining for all kinds of accident factors, we can realize the intelligent avoidance of shipwreck, but this method has a series of problems that the recognition accuracy of ship collision avoidance is low, the probability of successful avoidance is low, and the feasibility of avoidance decision is poor. Therefore, a method of intelligent avoidance of ship collision based on big data analysis is proposed [13-17].

CALCULATION OF DISTANCE TO SAFE POINT OF APPROACH OF SHIP BASED ON BIGDATA ANALYSIS

Using the big data analysis to calculate the ship safe distance of approach under the head-on situation, the crossing

situation, the overtaking situation. The specific process is as follows:

The ship safe distance of approach (SDA) is mainly determined by the radius of the collision region (SDA_{min}), the room for manipulation of the ship and the encountering characteristics of ship. Because the radius of ship collision region (SDA_{min}) is centered on this ship, the size of two ships, the circular area of the ship encountered situation will be considered, and the collision will occur when two ships enter the area. The radius of ship collision zone is calculated by big data analysis. Its formula is:

$$SDA \min = \frac{1}{2}L_0 + \frac{1}{2}L_t + 2P \quad (1)$$

Among them, L_0 and L_t respectively indicate the length of our ship and the target ship; P indicates GPS positioning accuracy of the ship [18].

Considering the intersection relation between position of ship and our ship, different distance of the safe point of approach (SDA) models of ships are obtained, and the formula is as follows:

$$SDA = \begin{cases} R_f & (1) \\ R_f - Adm & (2) \\ R_f - v_t \cdot t & (3) \\ R_f - Trm & (4) \end{cases} \quad (2)$$

In the formula, Adm and Trm respectively represent the longitudinal distance of ship gyration and the horizontal distance of the ship gyration. t represents the time required that the small rudder angle of this ship changes to the new heading distance; v_t represents the real speed of the target ship sailing. According to the formula (2), when the target ship is overtaken by our ship, formula (3) holds; when the target ship is the overtaking ship or it is placed in (122.5°, 247.5°) relative to navigational position b , the formula (2) is workable. When the target ship relative to navigational position b satisfies: $292.5^\circ \leq b \leq 150^\circ$ or $0^\circ \leq b \leq 67.5^\circ$, or $67.5^\circ \leq b \leq 150^\circ$ and $C_r \geq b + 180^\circ$, or $210^\circ \leq b \leq 292.5^\circ$ and $C_r \leq b + 180^\circ$, or $v_r = 0$ and $b \leq 90^\circ$, or $b \leq 270^\circ$, thus, formula (1) is workable; otherwise, formula (4) is workable.

Among them, in formula (2):

$$R_f = SDA \min + v_t \cdot t + Adm \quad (3)$$

$$Adm = V \left(T + \frac{t_1}{2} + \frac{1}{K \delta_0} \tan \frac{\varphi_0}{2} \right) + R \tan \frac{\varphi_0}{2} \cos \varphi_0 \quad (4)$$

$$Trm = \tan \frac{\varphi_0}{2} \cdot \frac{V}{K \delta_0} \sin \varphi_0 \quad (5)$$

$$\text{—} \quad (6)$$

In the formula, v_r represents the speed of relative motion of ship sailing; C_r represents course of relative motion of ship sailing; V represents speed of ship sailing; K represents turning index of ship sailing; T represents the turning lag index of ship; δ_0 represents the current rudder angle in ship sailing; φ_0 represents the current redirection angle in the ship sailing; R represents turning radius of ship sailing; t_1 represents the time required from the steering rudder angle to the current rudder angle δ_0 in the ship sailing.

Thus, when head-on situation and overtaking situation happen in ship channel, the calculation formulas of the ship safe distance of approach are as follows:

$$SDA \min = 1/2(L_1 \cdot \sin \beta + B_1 \cdot \cos \beta) + 1/2(L_2 \cdot \sin \theta + B_2 \cdot \cos \theta) + B_{\max} + 2P \quad (7)$$

$$SDA = 1/2(L_1 \cdot \sin \beta + B_1 \cdot \cos \beta) + 1/2(L_2 \cdot \sin \theta + B_2 \cdot \cos \theta) + B_{\max} + 2P + Trm \quad (8)$$

In the formula, B_1 and B_2 represent the ship beam of two ships respectively; β and θ represent drift angles of two ships; B_{\max} represents the ship beam of the bigger one in two ships.

CALCULATION OF RISK DEGREE OF SHIP COLLISION BASED ON BIGDATA ANALYSIS

According to the calculation results of safe distance of approach of ships, we use the big data analysis to judge the risk degree of collision of ships, and calculate the minimum value and maximum value of time of last minute action in dangerous situation of ships collision and the different value ranges of ship initial time of last minute action to judge the degree of risk degree ships collision and danger level. The detailed steps are described below:

According to the big data analysis, usually the small rudder angle of ship sailing is 10°. The maximum rudder angle is 30°. Generally, the redirection angle of ship is C_1 , and the maximum redirection angle of ship is C_3 . According to the geometrical analysis of relative motion in the ship sailing, the PIDVCA theory establishes the model for solving the target ship motion element and predicting movement element after our ship changes direction, and calculates the equations of the straight line RML and the straight line $NRML$ respectively.

$$\begin{cases} y_{RML} = x \cdot \cot C_r + \frac{DCPA}{\sin C_r} \\ y_{NRML} = x \cdot \cot C_m + \frac{-SDA}{\sin C_m} \end{cases} \quad (9)$$

In the formula, C_r and C_m represent the course of our ship and the course of the target ship relative to our ship before and after the redirection. According to the formula (9), the coordinates of the intersection point b of two straight lines are calculated. Its expression is:

$$\begin{cases} x_b = \frac{\left[\frac{-SDA \min}{\sin C_m} - \frac{DCPA}{\sin C_r} \right]}{\cot C_r - \cot C_m} \\ y_b = x_b \cdot \cot C_m + \frac{-SDA}{\sin C_m} \end{cases} \quad (10)$$

When our ship and target ship encounter, assuming that our ship turns right to C_m , and the sailing relative displacement generated by ships is expressed as SS . The components of the horizontal axis and the vertical axis are expressed as X_s and Y_s , and its calculation formula is as follows:

$$\begin{cases} x_s = v_t \cdot Tn \cdot \sin C_t + Dc \\ y_s = v_t \cdot Tn \cdot \cos C_t + Fd \end{cases} \quad (11)$$

Among them, Tn shows that the time required for cycle that our ship turns to 90° at full speed and full rudder; Dc represents the tactical diameter of ships; Fd represents the cyclic advance distance of ships. The formula of relative displacement SS of sailing generated by ships is as follows:

$$SS = \sqrt{x_s^2 + y_s^2} \quad (12)$$

The point a is taken from the straight line RML , which makes the length of ab equal to the relative displacement of the ship which is generated by the ship. a is used as the estimated helm point of our ship when it is sailing. We can derive the coordinate of estimated rudder point a of the ship at this time:

$$\begin{cases} x_a = x_b \cdot SS \cdot \sin C_r \\ y_a = y_b \cdot SS \cdot \cos C_r \end{cases} \quad (13)$$

Thus, the calculation formula of maximum critical distance Did_{\max} of the ship imminent danger is as follows:

$$Did_{\max} = \sqrt{x_a^2 + y_a^2} \quad (14)$$

The time from the current moment $C(x, y)$ to estimated helm point $a(x_a, y_a)$ is the helm time of ships. Its expression is:

$$T \ln = \sqrt{(x - x_a)^2 + (y - y_a)^2} / V \quad (15)$$

If $a(x_a, y_a)$ is corresponding to the coordinate of initial rudder distance of ship, the calculation result in above formula (15) is the initial rudder time of ship $T \ln(SDA, C_1)$ if $a(x_a, y_a)$ is corresponding to the distance DE of close quarters situation of ship collision, the calculation result in above formula (15) is the last helm time $T \ln(SDA, C_3)$ of close quarters situation of ship collision; if $a(x_a, y_a)$ is corresponding to the distance DE_{\min} of close quarters situation of ship collision, the calculation result in above formula (15) is the last helm time $T \ln(SDA_{\min}, C_3)$ in imminent danger situation of ship collision.

According to the minimum $T \ln(SDA, C_3)$ and maximum $T \ln(SDA_{\min}, C_3)$ of last helm time from above calculation of ship collision in imminent danger situation and the different

range of value of initial helm time $T \ln(SDA, C_1)$ to determine the risk degree of ships collision and risk level.

(1) when $T \ln(SDA, C_1) \geq 3 \text{ min}$, if the sailing ship uses its minimum rudder angle and the minimum redirection angle to pass the safe distance of approach, the time is relatively abundant and it is a potential danger ($ek = 1$) of ship collision;

(2) when $T \ln(SDA, C_1) < 3 \text{ min}$ and $T \ln(SDA, C_3) \geq 0$, when the navigating ship uses its minimum rudder angle and the minimum redirection angle is close to the time of passing the safe distance of approach SDA , which is a common danger ($ek = 2$) of ship collision;

(3) when $T \ln(SDA, C_1) < 0$, however $T \ln(SDA_{\min}, C_3) \geq 0$, the initial rudder time of ship sailing has been missed, and it is an imminent danger situation ($ek = 3$) for the collision of ships;

(4) when $T \ln(SDA_{\min}, C_3) < 0$, the sailing ship is unable to travel from the minimum safe distance SDA_{\min} of approach, namely, it is unable to avoid the collision, which belongs to the imminent danger of ship collision ($ek = 4$).

INTELLIGENT AVOIDANCE OF SHIPWRECK BASED ON GENETIC ALGORITHM

On the basis of the judgment of risk degree of ship collision, three evaluation functions of ship sailing are calculated, and the intelligent avoidance of shipwreck is realized by genetic algorithm. Specific practices are as follows:

Firstly, we determine the target ship which has the maximum risk of collision with our ship on each ship route at sea, and calculate difference between the minimum distance and safe distance in the target ship and our ship to determine the security of our ship route. Thus, the computational expression of the safety evaluation function of navigation:

$$S(x') = \sum_{i=1}^{N-1} clear(x'_i) \quad (16)$$

Among them, x' is the chromosome, which represents a route of ship; i represents the node of a path on this route. i is from 1 to $N-1$. N represents the total number of genetic factors of a path on the route (i.e. the turning point or node), there are $N-1$ short ship routes. Thus:

$$S(x) = \sum_{i=1}^{N-1} clear(x'_i) = \begin{cases} e^{k(g_i - \tau) - 1} & \text{if } g_i \geq \tau \\ h^*(\tau - g_i) & \text{others} \end{cases} \quad (17)$$

In the formula, τ represents the safe distance of approach of ships; k and h represent the evaluation coefficient of security; g_i represents the minimum of distance between the target ship which has maximum risk degree of ship collision the during the sailing, when our ship route is between the i -th node and the $i+1$ -th node in all target ships which are detected.

The economic evaluation function of ship sailing is calculated. The economic evaluation of ship sailing mainly includes the consumption of ship route in various aspects, such as the degree of smoothing of ship route, the voyage

consumption of ships, the time consumption, and other parameters. The calculation formula is as follows:

$$E(x') = w_d \sum_{i=1}^{N-1} dist(x'_i) + w_t \sum_{i=1}^{N-1} time(x'_i) + w_s \sum_{i=1}^{N-1} smooth(x'_i) \quad (18)$$

Among them, w_d , w_t and w_s represent the coefficient factor of economic evaluation function of ship sailing; $\sum_{i=1}^{N-1} dist(x'_i)$ represents the length of the whole course in the ship sailing, which satisfies $dist(x'_i) = d(m_i, m_{i+1})$. It shows the distance between two adjacent nodes on the ship route; $smooth(x'_i) = s(m_i)$ represents the maximum curvature of i at nodes on the route; $time(x'_i)$ represents the consumption time that ship pass two adjacent node on the route.

The evaluation function of traffic rules for ship sailing at sea is calculated. The formula is:

$$T(x') = \sum_{i=1}^{N-1} T_Cost(x'_i) \quad (19)$$

In the formula, $T_Cost(x'_i)$ represents the degree that ships abide International Regulations for Preventing Collisions at Sea.

According to the three evaluation functions mentioned above, supposing that the course of our ship and the target ship j is expressed as φ_o and φ_{Tj} , and the steering avoidance of ship is analyzed. The specific process is as follows:

1. if board angle θ_{Tj} of the target ship j which has the maximum risk degree of ship collision relative to this ship is:

- 1) $000^\circ \leq \theta_{Tj} \leq 006^\circ$ and $|180^\circ - |\varphi_{Tj} - \varphi_o|| \leq 6^\circ$, or
- 2) $354^\circ \leq \theta_{Tj} \leq 360^\circ$ and $|180^\circ - |\varphi_{Tj} - \varphi_o|| \leq 6^\circ$,

It shows that when our ship and the target ship j form the head-on situation on the voyage, we can judge that our ship is the ship which avoids the pass-by ship or has the same circumvention responsibility, and we should take the action of turning right:

1. If our ship has $dx'_i = (x'_{i+1} - x'_i) > 0$ at the next moment, and select $T_Cost(x'_j) = 0.01$, which shows that our ship complies with the requirements of International Regulations for Preventing Collisions at Sea;
2. If $dx'_i = (x'_{i+1} - x'_i) \leq 0$, it shows that our ship has taken the wrong evasive action or has not taken the evasive action, which is regarded as breaking the requirements of International Regulations for Preventing Collisions at Sea, thus we should select $T_Cost(x'_j) = 1$ at this moment.

2. if board angle of the target ship i which has the maximum risk degree of ship collision relative to this ship is:

- 1) $000^\circ \leq \theta_{Tj} \leq 006^\circ$ and $|180^\circ - |\varphi_{Tj} - \varphi_o|| \leq 6^\circ$, or
- 2) $354^\circ \leq \theta_{Tj} \leq 360^\circ$ and $|180^\circ - |\varphi_{Tj} - \varphi_o|| \leq 6^\circ$, or

$$3) 006^\circ \leq \theta_{Tj} \leq 67.5^\circ \text{ and } |180^\circ - |\varphi_{Tj} - \varphi_o|| \leq 6^\circ,$$

It shows that our ship and the target ship j form the crossing situation on the voyage, we can judge that our ship has taken the action of turning to the right to avoid collision.

3. if board angle of the target ship j which has the maximum risk degree of ship collision relative to this ship is:

1) $67.5^\circ \leq \theta_{Tj} \leq 112.5^\circ$ and $|180^\circ - |\varphi_{Tj} - \varphi_o|| > 6^\circ$ show that our ship and the target ship form the crossing situation, and we can judge that the ship has taken evasive action of turning to the left;

2) $112.5^\circ \leq \theta_{Tj} < 247.5^\circ$ indicates the target ship overtakes our ship, or

3) $247.5^\circ \leq \theta_{Tj} < 354^\circ$ indicates that the ship is the crossing situation of larboard angle. According to International Regulations for Preventing Collisions at Sea, the ship can be judged as the direct route. The target ship which has maximum risk degree of collision gets out of the road. If our ship takes evasive action, which is inconsistent with the rules.

4) when our ship is overtaking the target ship, our ship is a given-way ship. because of the true bearing of our ship is a_o relative to the target ship, but our ship has not taken evasive action, which is inconsistent with the rules. Thus, the intelligent avoidance of shipwreck has been realized.

EXPERIMENTAL RESULTS AND ANALYSIS

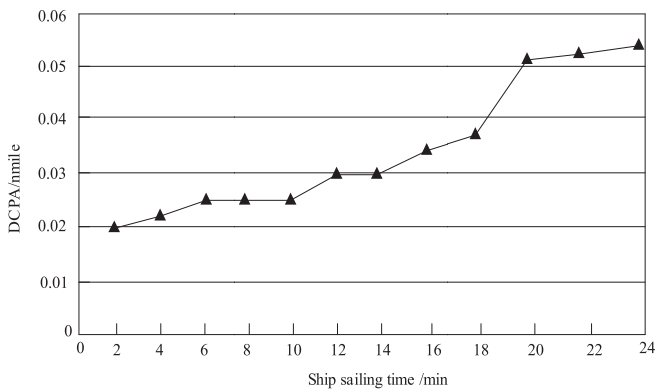
Experiment uses Visual Basic 8.0 as development platform, and use the big data analysis software and genetic algorithm to simulate the intelligent avoidance process of shipwreck, in order to test the effectiveness and feasibility of the proposed method.

At the initial time, the sailing speed of the target ship 1 is 12 kn, and the sailing direction is 302.8° . The sailing speed of the target ship 2 is 15 Kn, and the sailing direction is 152.7° . The two ships in the voyage are 0.37nmile apart, $DCPA = -0.04nmile$, $TCPA = 1.23nmile$, $SDA_{min} = 0.056nmile$. According to the calculation of risk degree of ship collision, two ships have formed the immediate danger situation. We use the method proposed in this paper to carry out the intelligent evasive action of shipwreck. The experimental test result is shown in Figure 1. According to Figure 1 (a), we can see that the collision avoidance of two ships is successful. Evasive parameters in the whole process of ship collision avoidance are analyzed, as shown in Figure 1 (b) & (c). $DCPA$ is increased from 0.02 nmile to 0.06, and the ship will pass through outside of SDZ_{min} . At this time, the ship $TCPA$ will gradually change from 1.73 to -0.67, which shows that the ship has passed the distance to closest point of approach.

(a) Two Ships Run Safely Evading Each Other



(b) Data Analysis of Intelligent Avoidance of Shipwreck



(c) Data Analysis of Intelligent Avoidance of Shipwreck

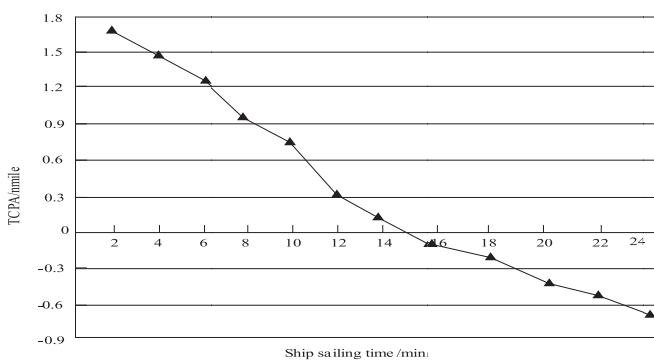


Fig. 1. Effect Diagram of Intelligent Avoidance Simulation of Shipwreck Based on Big Data Analysis

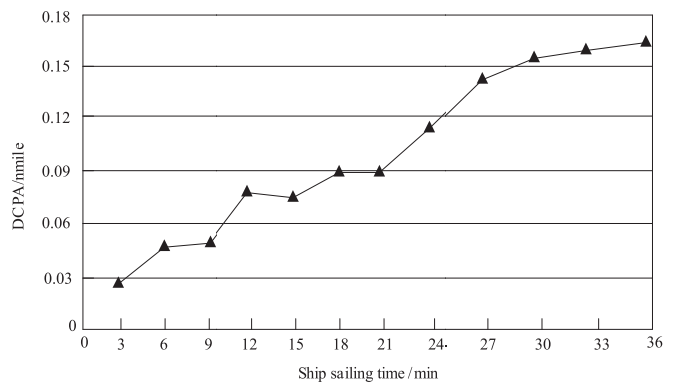
At the initial time, the sailing speed of the target ship 1 is 13 Kn, and the sailing direction is 308° . The sailing speed of the target ship 2 is 14 Kn, and the sailing direction is 199.2° . The two ships in the voyage are 0.46 nmile apart, $DCPA = -0.04nmile$, $TCPA = 2.05nmile$, $SDA_{min} = 0.12nmile$. According to the calculation of risk degree of ship collision, two ships have formed the immediate danger situation. We use the method proposed in this paper to carry out the intelligent

evasive action of shipwreck. According to Figure 2 (a), we can see that the collision avoidance of two ships is successful. Evasive parameters in the whole process of ship collision avoidance are analyzed, as shown in Figure 2 (b) &(c). $DCPA$ is increased from $-0.028nmile$ to -0.16 , and the ship will pass through outside of SDZ_{min} . At this time, the ship $TCPA$ will gradually change from 2.3 to -0.3 , which shows that the ship has passed the distance to closest point of approach.

(a) Two Ships Run Safely Evading Each Other



(b) Data Analysis of Intelligent Avoidance of Shipwreck



(c) Data Analysis of Intelligent Avoidance of Shipwreck

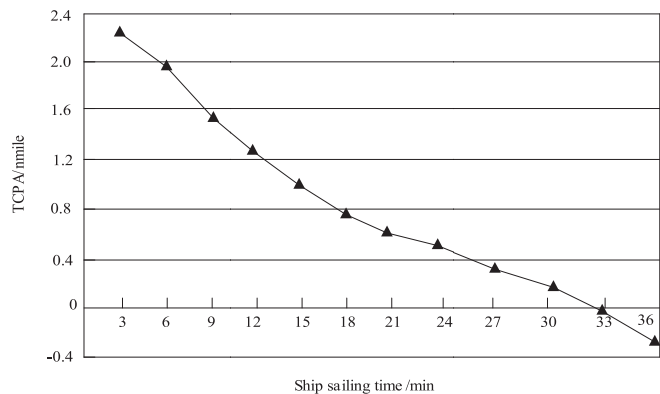


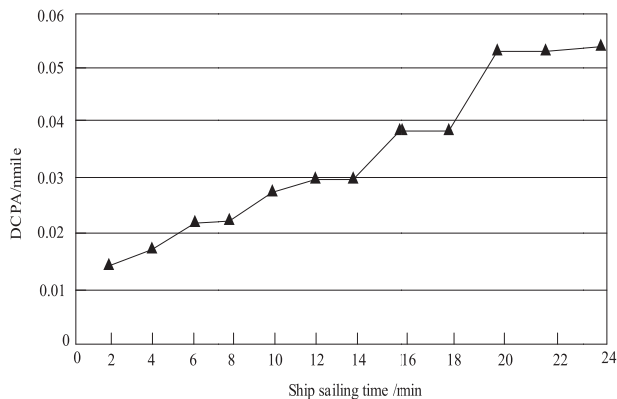
Fig. 2. Effect Diagram of Intelligent Avoidance Simulation of Shipwreck Based on Big Data Analysis

At the initial time, the sailing speed of the target ship 1 is 12 Kn, and the sailing direction is 305.2°. The sailing speed of the target ship 2 is 13 Kn, and the sailing direction is 195.1°. The two ships in the voyage are 0.44nmile apart, $DCPA = -0.05nmile$, $TCPA = 1.98nmile$, $SDA_{min} = 0.12nmile$. We judge that there is not enough room for ships handling in the left of target ship 1, and determine that the target ship 1 extends the encounter time by deceleration mode. The target ship 2 put full left rudder to 90°. According to Figure 3 (a), we can see that collision avoidance of two ships is successful. Evasive parameters in the whole process of ship collision avoidance are analyzed, as shown in Figure 3 (b) &(c). $DCPA$ is increased from 0.0013nmile to 0.055, and the ship will pass through outside of SDZ_{min} . At this time, the ship $TCPA$ will gradually change from 1.62 to -0.21, which shows that the ship has passed the distance to closest point of approach, and $DCPA$ is nmile. At this time, $|DCPA|$ is not more than SDZ_{min} , this is because two ships belong to the crossing encounter. According to the calculation of proposed method we can see that the two ships still can successfully realize collision avoidance.

(a)Two Ships Run Safely Evading Each Other



(b)Data Analysis of Intelligent Avoidance of Shipwreck



(c) Data Analysis of Intelligent Avoidance of Shipwreck

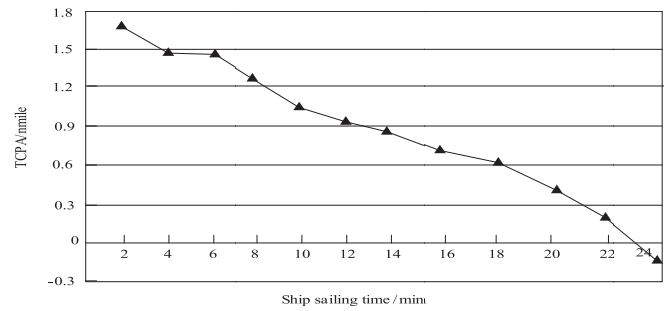


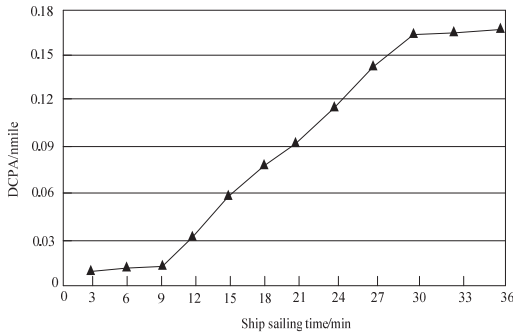
Fig. 3. Effect Diagram of Intelligent Avoidance Simulation of Shipwreck Based on Big Data Analysis

At the initial time, the sailing speed of the target ship 1 is 8 Kn, and the sailing direction is 304.9°. The sailing speed of the target ship 2 is 12 Kn, and the sailing direction is 185.3°. The two ships in the voyage are 0.62nmile apart, $DCPA = -0.02nmile$, $TCPA = 2.38nmile$, $SDA_{min} = 0.062nmile$. According to the calculation of risk degree of ship collision, two ships have formed the immediate danger situation. We use the method proposed in this paper to carry out the intelligent evasive action of shipwreck. According to Figure 4 (a), we can see that the collision avoidance of two ships is successful. Evasive parameters in the whole process of ship collision avoidance are analyzed, as shown in Figure 4 (b) &(c). $DCPA$ is increased from 0.01nmile to 0.16, and the ship will pass through outside of SDZ_{min} . At this time, the ship $TCPA$ will gradually change from 2.32 to -0.38, which shows that the ship has passed the distance to closest point of approach, and $DCPA$ is nmile. This also shows that two ships in the closest point of approach are 0.13 nmile apart, which can achieve successful avoidance.

(a)Two Ships Run Safely Evading Each Other



(b) Data Analysis of Intelligent Avoidance of Shipwreck



(c) Data Analysis of Intelligent Avoidance of Shipwreck

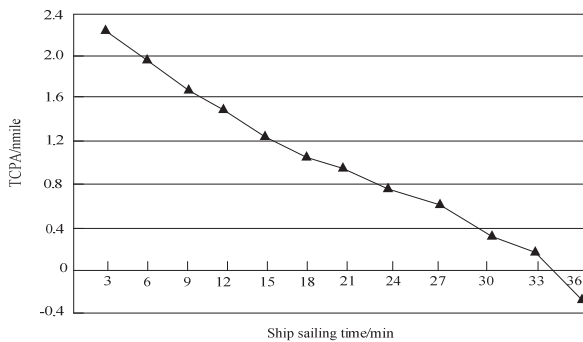


Fig. 4. Effect Diagram of Intelligent Avoidance Simulation of Shipwreck Based on Big Data Analysis

According to the analysis of above simulation test results, when the ship is sailing in the immediate and dangerous situation, the method proposed in this paper can realize the intelligent avoidance of shipwreck.

CONCLUSION AND DISCUSSION

The method proposed in this paper analyzes the basic principle for avoiding shipwreck and the corresponding mathematical model of ship motion on the basis of previous research, and builds intelligent method for avoiding shipwreck based on big data analysis, combined with the mathematical model of ship motion, we carry out the simulation experiment based on the full analysis of genetic algorithm. The main research results are as follows:

(1) select a reasonable genetic code structure, and reasonably indicate the intelligent avoidance ship route of shipwreck.

(2) the method proposed in this paper considers the safety and economic performance of ships, and also takes into account the cases of observing International Regulations for Preventing Collisions at Sea.

(3) three operations such as the selection, crossover and mutation are used, and the way of parallel operation is used to realize the intelligent avoidance of shipwreck.

(4) this paper has fully analyzed the different situations that ship encounters, and makes a correct judgment according to

the dangerous degree of the close quarters situation of ship so as to realize the intelligent and safe avoidance of shipwreck.

(5) but the intelligent avoidance method of shipwreck realizes the avoidance only through the ship altering, which does not take into account the ship slowdown. Usually, in port water area, especially the junction of many sea-routes, more often, the ships achieve collision avoidance by the way of slowdown, which shows that the proposed method remains to be study on in depth.

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