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Research Article

The Marine Safety Simulation based Electronic Chart Display and Information System

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Navigation safety has a huge impact on the world economy and our everyday lives. One navigation safety simulation model in ECDIS based on international standard format (S-57) is put forward, which is mainly involved in route plan and route monitoring. The universal kriging interpolation is used in the route planning and to compute the water depth of any place in the sea bottom. The man-machine conversation method is taken to amend planned route to obtain autodeciding of feasibility according to ECDIS information, and the route monitoring algorithm is improved by enhancing its precision caused by screen coordinate conversion. The DCQA (distance close quarters situation of approach) model and TCQA (time close quarters situation of approach) model are adopted to judge if the close quarters situation or the risk of collision between own ship and target ship is emerging. All these methods are proven to be reliable through the navigation simulator made by Dalian Maritime University which is certified by DNV to class A.

1. Introduction

Nowadays, the marine safety problem becomes more and more important with the increasing of shipping and pleasure boating. A cargo ship that carries hazardous loads poses serious threats to marine safety, as well as to the lives inhabiting coastal zones. The disaster and damage caused by major sea collision is difficult to deal with [1]. The navigation safety simulation in ECDIS is important to marine traffic, so route plan and route monitoring are two key navigational functions [2]. The role of route planning is to select a safe and economical route to avoid sudden events as possible, and insure the ship's navigation safety while the role of route monitoring is to supervise ships and post a danger alarming. Based on the close quarters situation, how to reduce the risk of collision between own ship and target ship is also important.

Currently, route planning and route monitoring are required in bridge equipment and navigation simulators [3–5], and were investigated by many scholars. For one example, Christiansen studied the route planning method based on the optimization decision support system [6], and Gunnarsson et al. used the integrated macroeconomic mathematical model to conduct route planning [7]. At the same time, Xu put forward a route planning and route monitoring method and implemented them in the electronic chart display and information system (ECDIS) [8], while Zhang et al. proposed the preliminary thought of the automatic optimization for ocean route [9]. All above theories promoted the rapid development of the route planning and route monitoring theory.

In this article, based on international standard format (S-57), the navigation safety simulation model in ECDIS is put forward, which mainly studies on the route plan and route monitoring. The universal kriging interpolation is used in the route planning to compute the water depth of any place in the sea bottom. The man-machine conversation way is taken to amend planned route to realize feasibility autodeciding according to ECDIS information. Thus, the route monitoring algorithm is improved by enhancing its precision by screen coordinate conversion. The models of DCQA (distance close quarters situation of approach) and TCQA (time close quarters Situation of approach) are adapted to judge the close quarters situation or the risk of collision between own ship and target ship.

2. Automatic Feasibility Identification in Route Plan

2.1. Identification Basis of the Feasibility

As the international standard format S-57 is used in ECDIS which includes all the information about the chart, the feasibility in route plan can be identified automatically according to the chart information and ship navigation state. The key of route planning is to identify if the route is realtimely and accurately navigable, which is based on the ship navigation state and the ECDIS information for the ship navigational areas.

(i) Ship navigation state: it mainly includes the maximum draft, tonnage, maximum speed, and gyration radius Among them, tonnage, maximum speed, ship modelled breadth, and yarage determine the cross-track error which takes planned sea route as a medial axis.

(ii) ECDIS information in ship navigation areas: it mainly includes different obstructions information identification in the navigation area for the planned sea route, such as open reef, sunken reef, intertidal zone, wreck, and prohibited area, and acquisition of the depth value in any position and any scale level in ECDIS.

The ship navigation status parameters can be acquired from ship motion model database, and sea chart information can be obtained from S-57 ECDIS database. However, water depth data known from sea chart are a discrete and fixed position, so computing the water depth in any position is a key problem in feasibility evaluation of planned sea route, as the ship position cannot always have the known depth value. Li et al. [10] computes water depth through improving Hardy quadric surface method while Wang guo-fu uses large-scale interpolation of discrete data based upon nodal point interpolation to estimate water depth and so on. Here, the universal kriging interpolation is used to compute water depth in any position.

2.2. Universal Kriging for Computing Water Depth in Any Position

The basic premise of Kriging interpolation is that every unknown point can be estimated by the weighted sum of the known points:

$$Z_0^* = \sum_{i=1}^{n} \lambda_i^0 Z_i, \tag{2.1}$$

where Z_0^* represents the unknown point, Z_i refers to each known point, and λ_i^0 is the weight given to it. The Kriging algorithm body is involved in the appropriate weights selection. For the details about the Kriging interpolation theory, readers may refer to [11, 12].

Universal Kriging assumes a general linear trend model. It includes the drift functions to calculate $m(x)$, which is the expectation of $Z(x)$. Considering

$$m(x) = a_0 + a_1 u + a_2 v + a_3 u^2 + a_4 uv + a_5 v^2, \tag{2.2}$$

where u, v are the coordinates of point x. Then, we can get

$$\sum_i \lambda_i^0 \left(a_0 + a_1 x_i + a_2 y_i + a_3 x_i^2 + a_4 x_i y_i + a_5 y_i^2 \right) = a_0 + a_1 x_0 + a_2 y_0 + a_3 x_0^2 + a_4 x_0 y_0 + a_5 y_0^2. \tag{2.3}$$

In order to set up (2.3), the following equations can be gotten

$$\begin{gathered} \sum_i \lambda_i^0 = 1, \qquad \sum_i \lambda_i^0 x_i = x_0, \\ \sum_i \lambda_i^0 y_i = y_0, \qquad \sum_i \lambda_i^0 x_i^2 = x_0^2, \\ \sum_i \lambda_i^0 x_i y_i = x_0 y_0, \qquad \sum_i \lambda_i^0 y_i^2 = y_0^2. \end{gathered} \tag{2.4}$$

Set

$$\sum_i \lambda_i^0 P_l(x_i) = P_l(x_0) \quad (l = 0, 1, 2, 3, 4, 5), \tag{2.5}$$

in which $P_l = \{1, x, y, x^2, xy, y^2\}$.

As

$$E\left[\left(Z_0^* - Z_0 \right)^2 \right] = \operatorname{Var}(Z_0) + \sum_i \sum_j \lambda_i^0 \lambda_j^0 c(x_i, x_j) - 2 \sum_i \lambda_i^0 c(x_i, x_0), \tag{2.6}$$

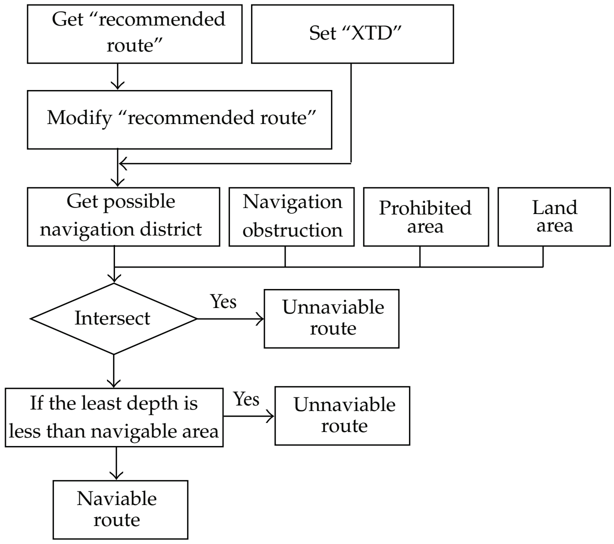

Figure 1: The simulation flow of route planning.

where $c(x_i, x_j) = \mathrm{COV}(Z_i, Z_j)$ and $c(x_i, x_0) = \mathrm{COV}(Z_i, Z_0)$, based on Lagrange multiplier rule, we have

$$\begin{gathered} \sum_j \lambda_i^0 c(x_i, y_j) - \sum_{l=0}^{5} \mu_l P_l(x_i) = c(x_i, x_0) \quad (i = 1, 2, \ldots, n), \\ \sum_i \lambda_i^0 P_l(x_i) = P_l(x_0) \quad (l = 0, 1, \ldots, 5), \end{gathered} \tag{2.7}$$

which could be rewritten in the matrix form such as $Ax = b$ to calculate the value of λ_i^0 $(i = 1, 2, \ldots, n)$. From (2.1), we could finally get the estimation of unknown points.

In order to enhance its efficiency, an improved universal kriging is adopted. Firstly, the contour-rectangle of the planned sea route is computed as the grid range of universal kriging calculation. Secondly, universal kriging is used to calculate water depth within the grid range based on the original water depth acquired from the navigation database. At last, if all the water depth values are larger than ship draft, the planned sea route is feasible, and if there are one or more water depth values smaller than ship draft, the planned sea route is unfeasible.

3. Simulation Model of Route Plan

The planned sea routes can be acquired by referring to "recommended route" which is stored in the navigation database, and the XTE (cross-track error) is designed according to ship route information, and are generated through linking turning points set by man-machine conversation automatically. At the same time, the feasibility of the turning points and the routes that were mouse clicked is judged intelligently as is shown in Figure 1.

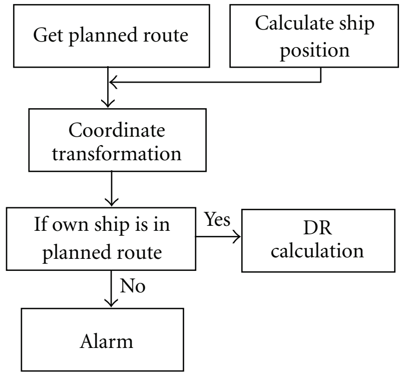

Figure 2: The simulation flow of route planning.

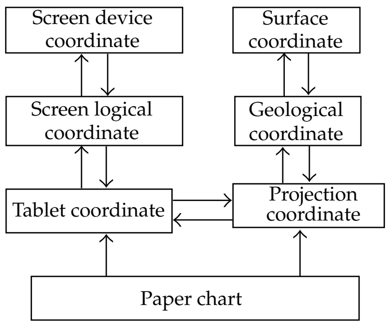

Figure 3: The conversion of coordinates.

4. Route Monitoring Simulation Model

The position of own ship is calculated realtimely according to the information that the operator inputs every 0.5 seconds, so that the route monitoring module can acquire the realtime ship position, display the figure of own ship and target ship, and send own ship information to instructor station, visual system, and radar display. The purpose of route monitoring is to warn and alarm by using dead reckoning to calculate yaw time and distance when the route is deviating, so that the operator can acquire the suggestion information. The simulation flow is show in Figure 2.

The key algorithm of route monitoring is to judge if the own ship is within the planned sea route. Xu judges if the ship position is in the range of route by using Windows API (application programming interface) which will produce errors because of utilizing screen coordinates. Here, a series of key coordinate transformations are used to enhance the safety and accuracy of the algorithm, as shown by Figure 3.

Then, the algorithm in route monitoring whether the point is in polygon is improved referencing to Z1-1 algorithm put forward by Zhou depei, first, different coordinate transformation models are built so that tablet coordinate can be transformed to geological coordinate according to Figure 4. Second, the own ship position (geological coordinate) is realtimely calculated according to the current parameters such as speed, rudder angle, course, and so on. In order to increase the algorithm efficiency, the contour-rectangle route area is computed to judge if own ship is within the rectangle. Furthermore, point (u) is judged if

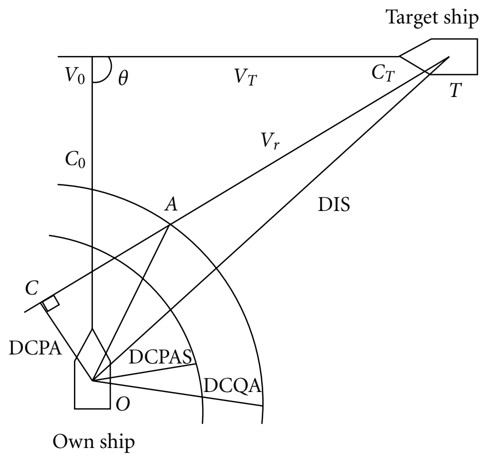

Figure 4: Relative motion diagram of own ship and target ship.

it is within the polygon $(u_1 : n_p)$, where u_1 is the structure array storing the points of route area and n_p is the polygon point number. The concrete method is presented as follows: a ray $T(u, v)$ is educed from test point to compute the intersection point number between array u_1 and ray T, according to the principles that odd is in and even is out to judge if point (u) is in the polygon u_1. Because geological coordinate is used in this algorithm and the ship position is calculated every 0.5 seconds, the accuracy and realtime can be satisfied in route monitoring.

5. Early-Warning Model of Own Ship Dynamic Information

According to ship size, ship velocity, ship manoeuvrability, radar observation error, navigation environment, and so on, the ship driver should know DCQA. In order to supervise the collision risk in ship sailing, DCQA should be calculated by the above factors, as shown in Figure 4. Setting own ship O, ship heading C_0, ship velocity V_0, target T, ship heading C_T, ship velocity V_T, relative velocity V_R, and the distance between own ship and target is DIS, θ is the intersection angle between own ship and route,

$$V_r = \sqrt{V_0^2 + V_T^2 - 2V_0 V_T \cos\theta}. \tag{5.1}$$

Then,

$$\begin{gathered} \text{TCQA} = \frac{TA}{V_r} = \frac{TC - AC}{V_r} = \frac{TC}{V_r} - \frac{AC}{V_r}, \quad V_r \neq 0, \\ AC = \sqrt{\text{DCQA}^2 - \text{DCPA}^2}, \quad \text{DCPA} \leq \text{DCQA}. \end{gathered} \tag{5.2}$$

We know $\text{TCPA} = T_C / V_r$, $V_r \neq 0$, so,

$$\text{TCQA} = \text{TCPA} - \frac{\sqrt{\text{DCQA}^2 - \text{DCPA}^2}}{V_r}, \quad V_r \neq 0, \ \text{DCPA} \leq \text{DCQA}. \tag{5.3}$$

Table 1: The parameter of variogram.

Largest range (m)	Nugget	Sill	Ellipsolid parameter (m)			Ellipsolid angle parameter (degree)		
			Primary	Second	Third	Bearing	Plunge	Dip
51.241	0.322	1.7	51.241	50.3	48.8	−45	135	90

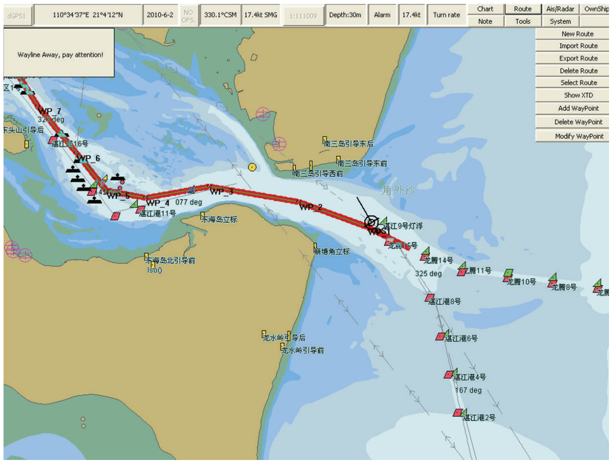

Figure 5: Simulation of ownership outside of planning route.

6. Experiment and Analysis

Taking international standard format S-57 chart of ZhanJiang port and its adjacent sea area (chart number: CN581201, scale: 1 : 35,000), the ship position is set randomly to make the simulation of route planning and route monitoring. As the route in the coastal is complicated, "recommended route" is found out from navigation database, and the way of human-machine interaction is taken to amend the planned sea route to realize the feasibility autodeciding according to the ECDIS information. The navigable area is yellow range (XTE), and the own ship is a black circle, as shown in Figure 5. Meanwhile, the universal kriging interpolation is used to calculate the water depth within the navigable area. To judge if the route is feasible, the steps are as follows.

(1) 3156 original water depths are acquired as sample data for calculation.

(2) Experiment variogram error conditions of universal kriging: lag distance: 2 m, angle tolerance: 30°, lag tolerance: 1 m. The parameters fitted by experiment variogram computation are showed in Table 1.

The water depth calculation range is defined for the navigable area: the whole area is regarded as a grid system, the grid size is: 10.0 m (X direction), 10.0 m (Y direction), and the grid number is: 1056 (X direction), 885 (Y direction).

Water depth calculation with universal kriging: water depth of every grid point is calculated according to the grid system definition, and the improved judgment method between water depth and ship draft is also used.

Simulation experiment is conducted in Dalian Maritime University navigation simulator (identified to class A by DNV) with visual system cooperatively, and the operator can manipulate own ship from start to destination and amend planned sea route in ECDIS realtimely. The whole process has no touching bank, grounding, and collision.

The improved route monitoring calculation can supervise whether the ship heading is away, when it is beyond the boundaries of XTD, and the autoalarm will appear on the top left of screen, as shown in the Figure 5.

7. Conclusions

The navigation safety simulation model in ECDIS based on international standard format (S-57) is put forward, which mainly studies route plan and route monitoring. The universal kriging interpolation is used in the research of the route planning to compute the water depth of any place. The man-machine conversation way is taken to amend the planned route and realize feasibility autodeciding according to the ECDIS information. The route monitoring algorithm is improved by enhancing the precision caused by screen coordinate conversion. The model of DCQA and TCQA is adopted to judge the close quarters situation or the collision risk between own ship and target ship. So, the model cannot only enhance the simulator training efficiency and accuracy but also the assistant decision-making in some fields such as port programming and reasoning and navigation safety. In addition, the model can be used in IBS (integrated bridge system).

Acknowledgments

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