

On the Development of Typhoon Avoidance Simulation System with the Evaluating Method by Seakeeping Performance of Ship

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Abstract : A simulation system is needed to train students and mariners in order that they can take suitable actions to evade typhoon's strike promptly and sufficiently. In order to make such kind of system, three kinds of models about the typhoon are necessary, typhoon prediction model to generate typhoon's track, wind & wave-field model to make sea conditions around the typhoon and evaluation model of trainee's action whether their actions were suitable or not during simulation. We have developed the prediction and wind & wave-field models of typhoon, but the evaluation model has not been developed yet. In this paper, after making a method for evaluating trainee's actions by seakeeping performance, we propose an typhoon avoidance simulation system for training mariners so that they can promote their abilities to evade the typhoons at sea.

Key words : Typhoon avoidance simulation system, Evaluation by seakeeping performance, Models about the typhoon

1. Introduction

Typhoon always causes very great threat to vessels navigating at sea, and tends to make a lot of life losses and damages to property. The main cause of such disasters is that mariners are lack of not only necessary knowledge for avoiding typhoons at sea, but also relevant training. Therefore, a simulation system is needed to train students and mariners in order that they can take suitable actions to evade typhoon's strike promptly and sufficiently.

We have proposed a mathematical model for making the forecast information of typhoon's movement such as the estimated movement direction and positions after 24 and 48 hours. The proposed model calculated such kind of information of a typhoon by several past typhoon's track data which are selected with three similarity criteria(Jin, 2004a).

And also we have proposed a simple parametric model for calculating wind speed & direction and wave height & direction at any location around the center of typhoon. The proposed wind-field model of typhoon was asymmetric, and consisted of a circular symmetric wind-field caused by the pressure gradient of stationary typhoon and a moving wind-field caused by the movement of typhoon(Jin, 2004b).

The track prediction and wind & wave-field models of typhoon become possible that ship operators are aware of the weather condition(mainly, strong wind and rough sea) around

typhoon they are facing with, and take some actions on preventing typhoon's strike.

However, they don't know whether those actions are appropriate, effective, and safe enough. In view of this, we shall carry out an evaluation of their performances in order to advance their abilities through our simulation training.

In this paper, after making a method for evaluating trainee's actions with seakeeping performance, we will propose a typhoon avoidance simulation system for training mariners so that they can take suitable actions to evade the typhoons.

2. Evaluation of seakeeping performance

2.1 Evaluation factors of seakeeping performance

In order to evaluate the degree of navigational safety of a ship with special consideration to the crew, hull and cargo on board, which is navigating at rough and irregular sea, the factors in Fig.1 are considered for the evaluation.

Once each of evaluation factors exceeds the given critical value and its probability exceeds the given critical occurrence probability, a ship navigating at rough sea may loss its control and becomes dangerous. The systemic combination of those evaluation factors has the form of serial combination. If the probability of occurrence of just one factor exceeds the

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critical probability, then the overall seakeeping performance fails and the ship may be endangered(Kong, 2002; Kong et al., 2004).

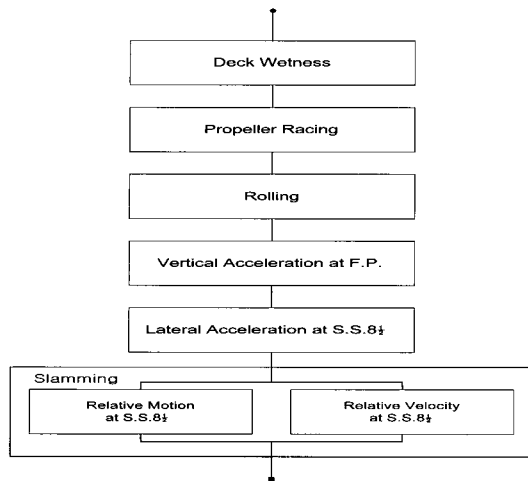


Fig. 1 Serial Combination of factors of seakeeping performance

2.2 Variance of the factors of seakeeping performance

When a ship is navigating at sea which has single wave distance and irregularity and is keeping constant course(x) and speed(V), spectrum S_{x_i} is defined as equation (1) if we put $X_i(t)$ (the random process of evaluation factors calculated from the response function of ship's motion according to OSM) as H_{x_i} :

$$S_{x_i}(\omega, \chi) = \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} |H_{x_i}(\omega, V, \chi - \theta)|^2 S_z(\omega, \theta) d\theta \quad (1)$$

Where the variance $\sigma_{x_i}^2$ of evaluation factors is as the following:

$$\sigma_{x_i}^2(\chi, V, S) = \int_0^{\infty} S_{x_i}(\omega, \chi) d\omega \quad (2)$$

2.3 Occurrence probabilities and critical standard variances of the factors of seakeeping performance

The change of the modulation width against an instant time of the $X_i(t)$ has the form of Gauss distribution and its extreme value has the form of Rayleigh distribution. Once the variance $\sigma_{x_i}^2$ is acquired, then Q_{X_i} (which means the probability that the extreme value of $X_i(t)$ exceeds a constant value X_1) is as follows(Kong, 2002):

$$Q_{X_i} = \exp\left\{-\frac{1}{2}\left(\frac{X_1}{\sigma_{X_i}}\right)^2\right\} \quad (3)$$

And then σ_{X_i} can be expressed as:

$$\sigma_{X_i} = \sqrt{-\frac{X_1^2}{2 \ln Q_{X_i}}} \quad (4)$$

When we consider critical probability $Q_{X_{ic}}$ (i.e. the probability of exceeding X_{ic}), then variance $\sigma_{X_{ic}}$ that is a value of danger can be found(Kong, 2002):

$$\sigma_{X_{ic}} = \sqrt{-\frac{X_{ic}^2}{2 \ln Q_{X_{ic}}}} \quad (5)$$

2.4 Evaluation values and dangerousness of the evaluation factors

The extreme value of the evaluation factors characterizes the form of Rayleigh distribution and the occurrence probability is expressed as $Q(\bar{X}_i)$. In this case E_{X_i} is defined as the evaluation value of X_i factors and is expressed as an inverse number with non-dimension.

$$E_{X_i} = \frac{1}{\sqrt{-2 \ln \{Q(\bar{X}_i)\}}} = \left[\frac{\sigma_{X_i}}{X_i} \right] \quad (6)$$

When the evaluation value becomes zero, then the reliability level of the random factor(X_i) is 1.0, and when the evaluation value E_{X_i} becomes infinite then the reliability level of the random factor (X_i) is zero.

We define $E_{X_{ic}}$ as the critical evaluation value done on critical occurrence probability of random factor of X_i and is defined as the dangerousness of X_i and expressed as follows(Kong, 2002):

$$\mu_{X_i} = \frac{E_{X_i}}{E_{X_{ic}}} = \frac{\left[\frac{X_i}{\sigma_{X_{ic}}} \right]}{\left[\frac{X_i}{\sigma_{X_i}} \right]} = \frac{\sigma_{X_i}}{\sigma_{X_{ic}}} \quad (7)$$

where, $\sigma_{X_{ic}}$ is the variance value of danger of factor X_i .

On the other hand, when $\mu_{X_i} \geq 1.0$, X_i (the factor of seakeeping performance) becomes dangerous, and when $\mu_{X_i} < 1.0$, it shows that the ship is safe.

3. Design of the simulation system

3.1 Over view of the system

This system is designed based on the Client/Server mode on Local Area Network(LAN). Here, the clients mean the trainees, and the server means the instructor. They are

connected using hub and can perform data exchange interactively based on TCP/IP protocol. The framework of the system is shown in the following Fig. 2.

Correspondingly, the software of this system includes two applications running on the server's computer and the clients' computers respectively. The instructor shall, through the Server's application, set up the scenario of training, including setting up the training waters, the parameters of ships and the time ratio of simulation, and choosing a sample of past typhoons, and controlling the training process if needed, and send these information to all trainees(clients) through LAN. Before starting to run, the trainees may set up ship's course, ship's speed and ship's position, but after running, the trainees cannot change the ship's parameters other than ship's course and/or speed.

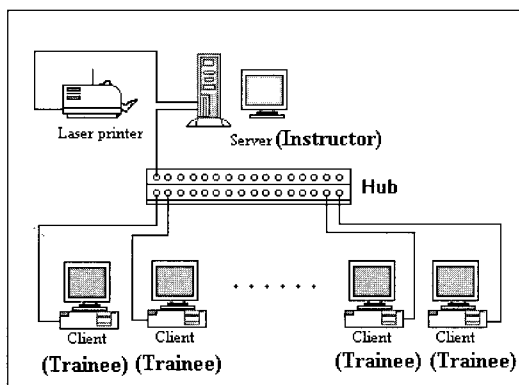


Fig. 2 Framework of the system

3.2 Applications of the system

The applications running on the server and the client respectively are almost same, and their interfaces are almost same too, but the one on the server is more functional than that on the client. Here, we mainly describe the details of the server applications, and it consists of nine functional modules as follows:

3.2.1 Electronic chart module

Strictly speaking, the electronic chart in our software is not a real electronic chart but a very simple chart, and it is designed specially for our software. This chart only contains the grids of latitude and longitude lines, coastlines and marks of some big cities. This electronic chart ranges from 100E to 180E/W of longitude and from 5N to 50N of latitude. But it can be freely zoomed in and out, and freely shifted up and down, left and right as required.

3.2.2 Assistant navigational mark module

There are three navigational marks: Line, Circle, and Circle with a Line. It is very easy to draw these marks using the

mouse, and their corresponding bearing and distance values are displayed on the Status Bar. And these marks cannot be erased while the electronic chart scale changing, but can be erased one by one from the last to the beginning using the Eraser tool. Therefore, we can conduct a route planning on the electronic chart through the determined way points or directly through the mouse. Moreover, the distance and the bearing between any two points on the electronic chart can be measured.

3.2.3 Dead reckoning plot module

By being set a point of departure (longitude and latitude), a course and a speed to a vessel, the vessel can be running on the electronic chart by dead reckoning at any time interval as required. During the period of dead reckoning, the vessel's dynamical parameters (position, course and speed) can be changed as required at any time manually, and these past tracks of vessel can be saved at 1-hour interval.

3.2.4 Typhoon animation demonstration module

In order to show the movement of the typhoon vividly, we use the skill of animation. For this purpose, we make an animation file and load this file into the animation control. This animation has two kinds of movement: one is translation, and another is twist.

The translation is made along with the typhoon's track at 6-hour interval, and the twist shows the spiral movement of atmosphere within typhoon. And the rate of twist changes with the maximum wind of typhoon, that is, the stronger the maximum wind, the higher the rate. And the animation may be visible or invisible by simply clicking a switch button.

3.2.5 Typhoon track prediction module

According to the month and date, forward speed and direction, present position and position at 12 hours before of the formed typhoon, this module searches the similar tracks in the database of past track data based on four similarity criteria, and then calculates the forecast positions in future 48 hours at 6-hour interval, and then computes the error radii of 24-hour and 48-hour forecast positions, finally, displays the forecast positions of 24 and 48 hours, and error circles in graphic on the electronic chart. These processes repeat once every 6 hours and get the latest information of typhoon.

3.2.6 Typhoon wind and wave calculation module

According to the present position, maximum wind and central pressure of typhoon, this module calculates the wind-field and wave-field within typhoon region, and the wind and wave information at the vessel's position is displayed at the right down corner of the screen, and such

information at any other location with distance less than 500 nautical miles is also displayed on the screen while the mouse moving around the typhoon on the electronic chart.

3.2.7 Navigation safety evaluation module

This module makes reference to the program of navigation safety evaluation and needs to be inputted two kinds of data: one is the current weather information of the area where the ship is navigating, which mainly includes wind speed, wind direction, wave height and wave period, and this information can be calculated from our wind-field model and wave-field model of typhoon; another is vessel's principal dimension and the condition of the body of the vessel. And then, through a series of computations, the program outputs both the evaluation values and the dangerousness of the evaluation factors of seakeeping performance. Finally, we can evaluate the degree of vessel navigation safety according to the dangerousness, that is, while the dangerousness is smaller than 1.0, the vessel is safe, and while the dangerousness is greater than or equal to 1.0, the vessel becomes dangerous.

Table 1 Data formats between instructor and trainee systems

| Data | Format | Transfer direction |
|------------------|--|------------------------|
| Typhoon YearNo | "YN" str(YearNo) (6*String) | Instructor→ Trainee |
| Ship's Position | "PO" format(y,"00000.00") format(y,"00000.00") (18*String) | Instructor↔ Trainee |
| Ship's Course | "CO" format(course, "000") (5*String) | Instructor↔ Trainee |
| Ship's Speed | "SP" format(speed, "00.0") (6*String) | Instructor↔ Trainee |
| Time Ratio | "TR" format(Ratio, "0000") (6*String) | Instructor→ Trainee |
| Run | "RN" (2*String) | Instructor→ Trainee |
| Pause | "PS" (2*String) | Instructor→ Trainee |
| NewExercise | "NE" (2*String) | Instructor→ Trainee |
| On/Off line | "NF" (2*String) | Instructor→ Trainee |
| Initial Own-ship | "IO" (2*String) | Instructor↔ Trainee |

3.2.8 Information display module

This module is designed for displaying various data relating to typhoon's dynamical state and vessel's dynamical state. It mainly includes four parts: the forecast results of typhoon, the vessel's parameters, the latest information of typhoon, the relation between vessel and typhoon, the indicator that shows the geographical area the electronic chart is presently displaying by a rectangle frame and the past typhoon track that we choose for the present exercise, and the client status where it shows that a client is on line or not and shows the

number of the ship whose information are being displayed on the interface.

3.2.9 Network Communication module

A WinSock control allows us to connect to a remote machine and exchange data using either the User Datagram Protocol (UDP) or the Transmission Control Protocol(TCP). Both protocols can be used to create client and server applications. Like the Timer control, the WinSock control doesn't have a visible interface at run time. In this module, we use the WinSock control to carry out data exchange between instructor and trainee, which is based on TCP protocol. Table 1 shows the formats of data exchanged between instructor and trainee.

4. Implementation of the simulation system

Just like a common window application, the whole interface of the application, as shown in the following Fig.3, is well designed easily to operate, and has five functional zones described as follows:

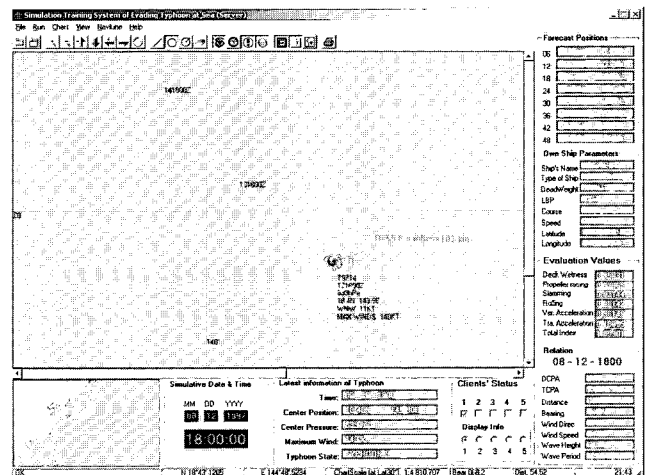


Fig. 3 The application's interface

4.1 The menu bar

The Menu bar has mainly five menus of File, Run, Chart, View and NaviLine. The **File** menu is to reset the system, to open or save a sample file of track data of past typhoon for training, and the **Run** menu is to start or pause the program temporally if needed. The **Chart** menu is to decrease or enlarge the image size of the electronic chart in order to display geographical area, and to move the electronic chart in every direction.

The **View** menu is to control the ToolBar's visibility and to control that whether the present information of typhoon is displayed on the electronic chart or not. The **NaviLine** menu

is to draw a line or circle on the electronic chart by dragging the mouse, and to check the distance and the bearing between the beginning and the end points.

4.2 The toolbar

The toolbar, which is located just below the menu bar, has twenty-one buttons as shown in Fig. 4. It provides quick access to file operations, electronic chart status change, NaviLine drawing, and so on. Each button in the toolbar has the corresponding menu item, which has the same function with it.

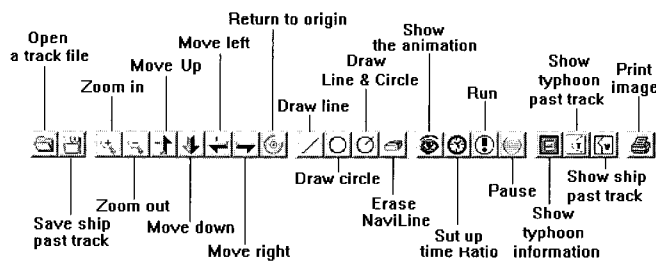


Fig. 4 Toolbar

4.3 The window for displaying electronic chart

The window for displaying electronic chart is shown as the following Fig. 5. This window has the vertical scroll bar and the horizon scroll bar. The window is fixed, but the geographical range displayed is changed by changing the chart scale and shifting the central position.

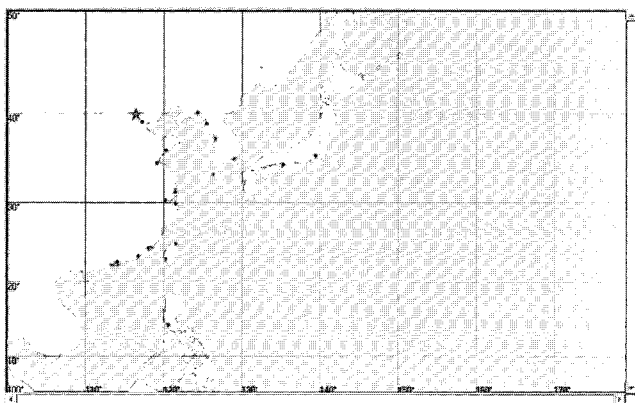


Fig. 5 The window for displaying the electronic chart

The geographical range to be displayed can be changed by using Chart menu, the corresponding buttons of the Toolbar as the above-mentioned. Additionally, we can zoom in and out the chart by the middle roll of the mouse, and shift the chart by two scroll bars on the left side and on the bottom of the window respectively. In practice, we can display the suitable geographical area according to the specific training exercise.

4.4 The information display panels

This part includes seven frames of Latest Information of Typhoon, Forecast Positions, Own-ship Parameters, Relation between ship and typhoon, Indicator, Clients' Status, and Date & Time. And each frame has some items of interest. The trainees shall pay attentions to there information, and shall take the corresponding actions to avoid the typhoon. The rectangle frame in the Indicator shows the geographical area displayed in the electronic chart window.

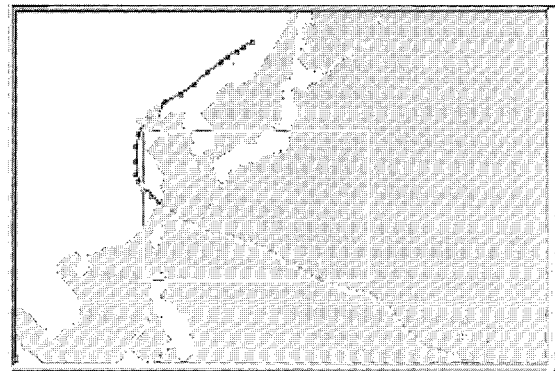


Fig. 6 Indicator for the electronic chart and past typhoon track

4.5 The status bar

The status bar includes some panels of prompt, geographical position at the mouse point, present chart scale, parameters of the present NaviLine and system time. The detail of the status bar is shown in Fig. 7.

5. Conclusion

We developed a typhoon avoidance simulation system with a method for evaluating trainee's seakeeping performance.

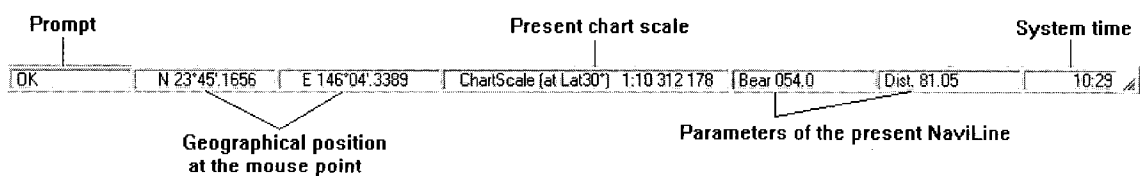


Fig. 7 Status bar

This method evaluates the degree of ship navigation safety in order to confirm whether the actions are appropriate, effective and safe enough.

In the period of training, the system can, at any time, calculate the dangerousness of six evaluation factors of seakeeping performance, and shows these information to the instructor so that he can evaluate the training effects of trainees. If the dangerousness is smaller than 1.0, the ship is safe, otherwise, if it is greater than or equal to 1.0, the ship becomes dangerous.

We designed the simulation system based on the Client/Server mode using the TCP/IP protocol, and developed two application programs running on the server machine and the clients' machines respectively. The client application program has the most functions of the server's, the main difference is that the server application has the function of supervising ships' states of all clients and controls the whole system's running. The interfaces of the applications are friendly and easy to operate. The whole system runs steadily.

In future, we'll try to improve the accuracies of the wind-field, wave-field and typhoon track forecast models, to advance the quality of the electronic chart, to increase the types of client ship, and to increase the number of clients.

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