Design and Research for Intelligent Typhoon Evasion System for Ships

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Abstract Based upon the previous experiences and typical cases of typhoon evasion for ships as well as the achievement in scientific research in this domain, we developed the Intelligent Typhoon Evasion System for Ships. It consists of five subsystems, including electronic charts, ship movement management, typhoon information query and automatic plotting, real-time calculation of ship-typhoon situation, intelligent typhoon evasion decision making. With the synthetical application of analogy theory, synoptic chart, satellite cloud picture analysis, typhoon digital forecast and other relevant technologies, we have established the typhoon evasion data bases, model bases and knowledge bases, which make it possible to automatically track the ships and typhoon paths. The system can realize ship-typhoon situation analysis, risk level assessment, typhoon paths correction and course synoptic forecast, and intelligent typhoon evasion decision making.

Keyword typhoon evasion for ships Intelligent decision making Self-navigation technology Simulation of typhoon evasion Comprehensive ship-typhoon situation

1. Introduction

There are about 80 to 100 typhoons to happen across the world every year, most of which happen in eight of the oceans. The Northern Hemisphere has most of the typhoons, accounting for 73 percent. But Northen Pacific and North-Westen Pacific to the westward of 180 east longitude (including South China Sea) is where typhoon happens most frequently and seriously.

Typhoon is one of the most harmful natural disasters, which results in numerous people dead and great economic loss. In history, there are more than 3 times of typhoon raid that caused more than 300,000 people dead. In April 29,1991, when typhoon raided Bengal gulf, 1,280,000 people lost their lifves. China is one of the countries that are badly affected by typhoons. Since 1949, every year, typhoons caused economic loss of thousands of million yuan and 100 to 1,000 people dead.

In order to reduce the loss caused by typhoons, World Meteorological Organization and many governments are enhancing the detection, analysis, forecast and warning of typhoons. In 1968, Asian Typhoon Committee come into existence, most of Asian countries and regions have taken part in the Committee, such as China, Japan, Hong Kong, Malaysia, Philippine, Korea, Thailand, Vietnam and so on, and thus the cooperation are enhanced between regions. With the development of scientific technology, measured error of the typhoon center has lowered from hundreds of kilometers to 30 kilometers, and the forecast precision has greatly increased too, all these changes ensured that typhoon evasion could be successfully carried out. The main objective of this paper is to utilize the modern high and new technology to realize typhoon information management across network and to add intelligence to typhoon evasion decision making process, and thus to realize the conversion from experience based evasion to knowledge based intelligent typhoon evasion.

2. Software components of the system

2.1 Electronic Chart subsystem

Except common charts information, this subsystem added 60 main anchorage grounds for typhoon evasion、inshore meteorologic radar station、main recommended courses、typhoon warning lines、typhoon security precinct、rescue area etc.

2.2 Ships movement management and automatic ship tracks plotting subsystem

The subsystem could manly or automatically offer ships the most common technical parameters, positions, courses, speed, real-time observed weather information[7].

2.3 Typhoon information query and automatic typhoon paths plotting subsystem (See figure 1)

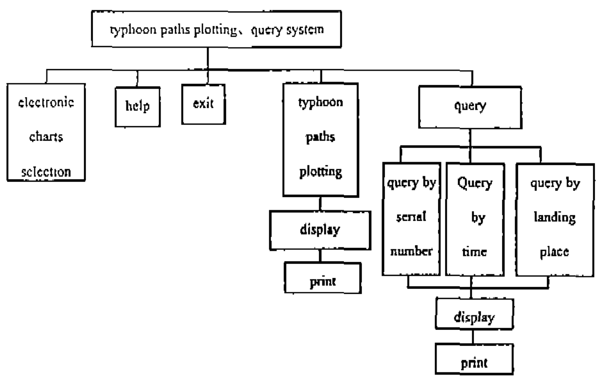


Figure 1

2.4 Real-time calculation of ship-typhoon situation and simulated typhoon evasion subsystem

2.4.1 Calculation of ship-typhoon bearing、distance

2.4.2 Calculation of moving speed and direction of typhoon

2.4.3 Calculation of ship-typhoon true movement situations

2.4.4 Calculation of ship-typhoon relative movement situations, including relative course、relative speed and the extrapolated typhoon and ship positions

2.4.5 Calculation of the DCPAT、TCPAT between the ship and typhoon

2.4.6 Calculation of the encountering time an.distance when ship enter seven-grade gale circle

2.4.7 Calculation of risk level of typhoon and warning

2.4.8 Decision of the time for typhoon evasion and warning

2.4.9 Simulation of typhoon evasion process

2.4.10 Analysis of relative ship-typhoon situation and weather forecast along sea rout

2.5 Intelligent typhoon evasion decision making subsystem

2.5.1 Typhoon paths correction

2.5.2 Typhoon evasion expert system

2.5.3 Typhoon evasion course decision making

3. Hardware components of the system

3.1 Intelligent typhoon evasion system for headquarters (see figure 2)

3.2 Intelligent typhoon evasion system for standalone ship (see figure 3)

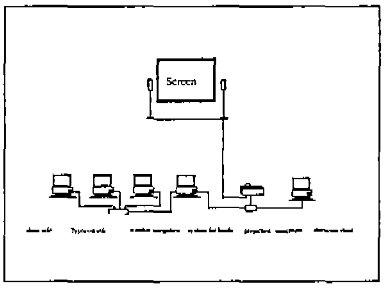


Figure 2 Intelligent typhoon evasion system for headquarters

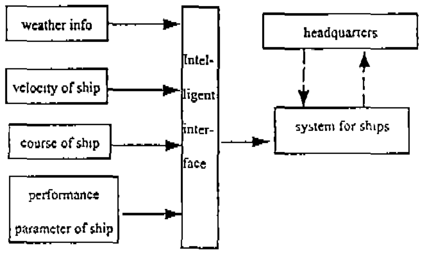


Figure 3 Intelligent typhoon evasion system for standalone ship

3.3 Mechanism of typhoon evasion command (see figure 4)

4. Design for typhoon evasion route

4.1 Objective: construct comprehensive ship-typhoon situation model, real-time calculation of relative ship-typhoon parameters.

4.2 Mathematical model

4.2.1 Calculation of ship-typhoon bearing and range F_{WTi} D_{WTi} (i=1, 2, 3 ······ n)

$$F_{WTi} = \mathrm{arctg}\left[(\lambda_t - \lambda_w)\cos\left(\frac{\Phi_t + \Phi_m}{2}\right) / (\Phi_t - \Phi_m)\right]$$

$$D_{WTi} = |\Phi_t - \Phi_m| / \cos F_{WT}$$

4.2.2 Calculation of relative ship-typhoon course C_{R0}, relative velocity V_{R0}

$$C_{R0} = C_{WI} + \alpha$$

$$\alpha = \cos^{-1}\frac{V_W^2 + V_{R0}^2 - V_T^2}{2V_W V_T}$$

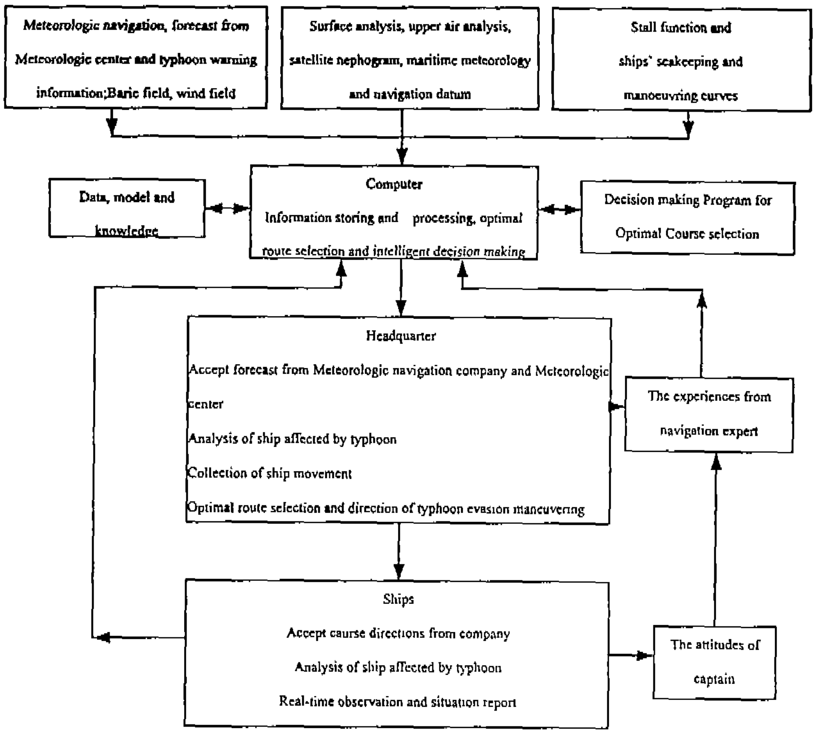


Figure 4 Mechanism of typhoon

$$V_{R0} = \sqrt{V_W^{\,2} + V_T^{\,2} - 2V_W V_T \cos\beta}$$

$$\beta = \cos^{-1}\frac{V_W^{\,2} + V_T^{\,2} - V_{R0}^{\,2}}{2V_W V_T}$$

4.2.3 Calculation of distance to closest point of approach and time to closest point of approach (D_{CPAT} and T_{CPAT})

$$D_{CPAT} = D_{WT} * \sin\left|F_{WT} - C_{R0}\right|$$

$$T_{CPAT} = \overline{p_w p} / V_{R0} = D_{WT} * \cos\left|F_{WT} - C_{R0}\right| / V_{R0}$$

4.2.4 Calculation of D_{R7} and T_{R7}

$$T_{R7} = T_{encounter} = \overline{p_w p_o} / V_{RO}$$

$D_{R7} = \overline{P_W P_O} = \overline{P_W P} - \sqrt{D_{CPAT}^2 + R_7^2}$

4.2.5 Calculation course、speed and time of typhoon evasion

① Going front typhoon

Course of typhoon evasion: $C_{W2} = C_{W1} + \theta'$

$$c_{w1} = c_{R1} + 90$$

$$V_{w1} = V_T * \sin(C_T + 180 - C_{R1})$$

$$\theta' = \arccos \frac{V_{W1}}{V_{W2}}$$

$$\beta' = \arccos \frac{V_{W1}}{V_T}$$

Speed of typhoon evasion: $V_{W2} = V_{W2} + \triangle V$

Stall function: $\triangle V = k_1 * h + k_2 * h^2 - k_3 * q * k^3 (G - k_4 * D * V_0)$

h : wave height (m), q : the angle between bow and wave (deg) , D : displacement (t), V_0 : still water velocity (Kn), and k_1、k_2、k_3、k_4: real constant。

Time of typhoon evasion: $T_2 = D_{WT} * \cos \theta_1 / V_{R2}$

$$V_{R2} = \sqrt{V_T^2 + V_{w2}^2 - 2V_T V_{w2} \cos(\beta' + \theta')}$$

② Going behind typhoon

Course of typhoon evasion: $c_{w4} = c_{w3} + \theta''$

$$c_{w3} = c_{R2} + 90$$

$$V_{w3} = V_T * \sin(C_T + 180 + C_{R2})$$

$$\theta'' = \arccos \frac{V_{W3}}{V_{W4}}$$

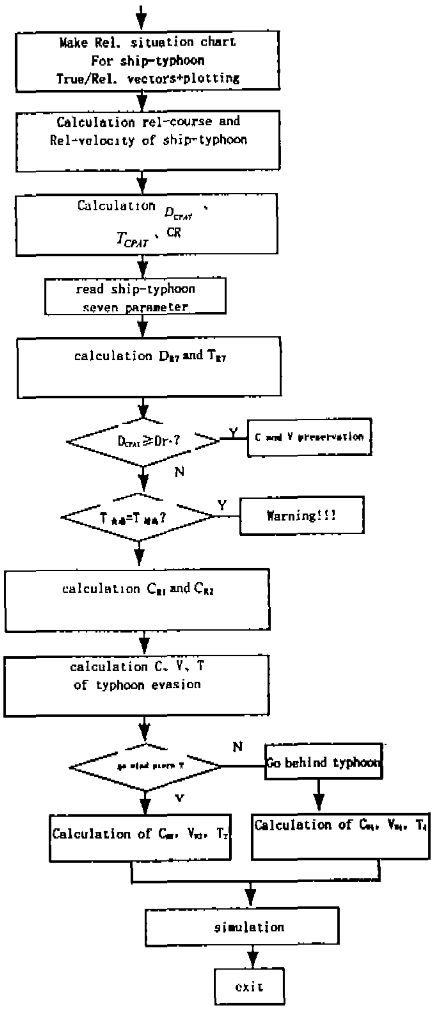
$$\beta' = \arccos \frac{V_{W1}}{V_T}$$

Speed of typhoon evasion: $V_{W4} = V_{w4} + \triangle V$

Time of typhoon evasion: $T_4 = D_{WT} * \cos \theta_2 / V_{R4}$

$$V_{R4} = \sqrt{V_T^2 + V_{w4}^2 - 2V_T V_{w4} \cos(\beta'' + \theta'')}$$

4.2.6 Calculation flow chart for typhoon evasion course (FIGUER 5)



Figuer 5

5. Design Of The Intelligent Shipboard Typhoon Evasion System

5.1 Typhoon risk level evaluation as opposed to the ship

The model for typhoon risk level evaluation was established by the application of artificial neural networks based on back propagation algorithm.

5.1.1 Selection of input parameters and their processing

By summarization of expert knowledge in the area of typhoon evasion for ships, wind power, center pressure, radius of the grade-seven gale, the distance to the closest point between typhoon and ship, the time to the closest point of approach, and wave height were selected as neural network's input parameters. In order to speed the convergency during training, the input parameters have been preprocessed accordingly.

5.1.2 Output parameters

The output parameter is the risk level, ranged between 0 and 1.

5.1.3 The topology of artificial neural network model

The network is composed of four levels, the input layer has 6 nodes, the second layer 5 nodes, the third 3 and the output 1. The network topology was listed as figure 6.

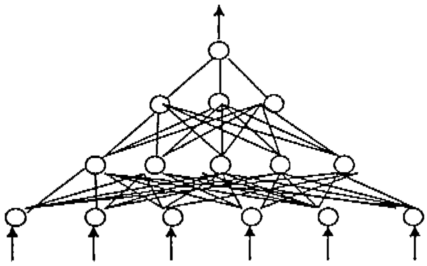


Figure 6 Topology of neural network

5.2 Typhoon track correction and supplementary weather forecast along sea route

Within the forecast valid periods, the ship and typhoon tracks could be any among straight, curve or bow, and the rate of travel could be any among uniform velocity, acceleration, deceleration, or zero speed. According to the principle of ship maneuverability, each (ship and typhoon) takes actions based on its own law of motion, so their relative tracks could be drawn on ECDIS. By optimally assembling the ship movement, real-time typhoon tracks, forecast typhoon tracks, weather forecast and actual situations on ECIDS, the model for comprehensive ship-typhoon situation could be established [5][6](see figure 7a and 7b).

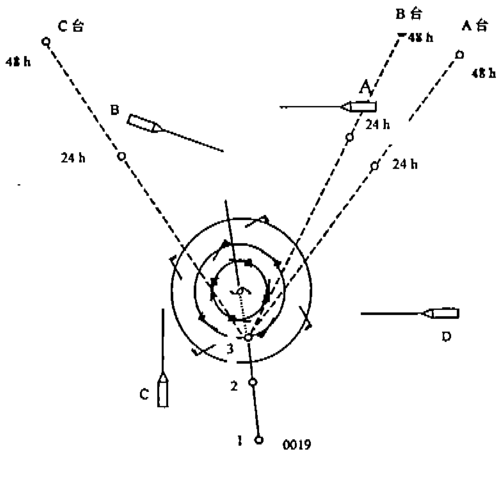


Figure 7a

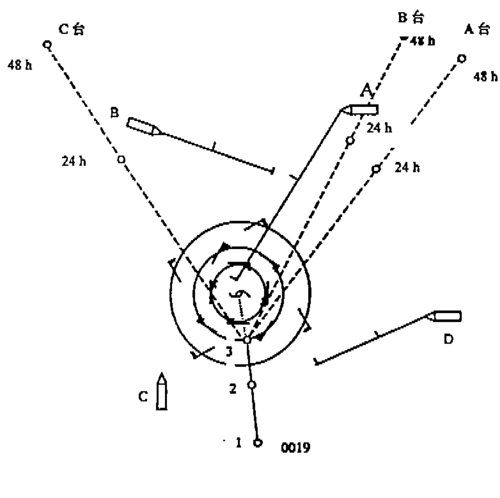


Figure 7b

Based upon the trend extrapolation, true tracks and the expert experiences extracted from the impact of inner and outer factor of meteorological system on typhoon tracks, the system automatically generate corrected typhoon tracks. Between the true typhoon positions, real-time typhoon moving direction and speed were calculated and historical typhoon tracks per hour were recorded, then based upon the corrected typhoon tracks, the relative movement between typhoon and ships was constructed, thus the parameters, real-time true movement and future relative positions between typhoon and ships could be predicted .

The model is key to typhoon preventing headquarters and maneuvering typhoon evasion for ships, which also set the bases for automatic typhoon evasion. We can see from the model that there are forecast typhoon tracks A, B and C from three different observatories, which are also the important evidences for typhoon evasion. User could be first chosen as the base, then the relative movement between ship and typhoon could be constituted. To take one more observatory into consideration is just as to consult one more weather expert to forecast the weather along the sea route. This is the continuous real-time weather forecast, which is strictly related to the successful typhoon evasion direction of typhoon evasion headquarters to ship. The position 1 to 3 on the figure are the recorded positions, and the track after position 3 is extrapolated by the system, which is keep extrapolating until next true typhoon position is forecasted. Then based on the true position, the future typhoon track is extrapolated according to the new parameters. The extrapolation continues until the typhoon is disappeared. The extrapolation could be artificially interfered to correct the extrapolated track.

Figure 6a intuitively shows the true movement of ship A, B, C, D and the typhoon. The seven parameters can be calculated instantly, which set the bases for typhoon evasion decision making.

Figure 6b shows relative velocity, which intuitively forecast weather change along the sea route.

Ship A: sail before wind, speed of ship will increase in some sort. Wind change counterclockwise from north to north westly to west to north westly, and will strengthen to the maximum power. In 8 hours, the ship will enter the danger quadrant of the danger semisphere, the pressure gradient will keep increasing with max 990 bps. Wave height will become higher and higher with speed loss high. In 12 hours, the ship will pass through the danger area of the typhoon.

Ship B: will pass forward road of the typhoon in 8 hours, 160 nm away from center, wind 5 to 6, about 1000Hpa, beam sea and crosswind at port , speed loss low, and will pass the danger semisphere in 12 hours.

Ship C: tag after the typhoon, 120 nm away from center, winds south westly below 6.

Ship D: go wind stern, 200 nm away from center, winds north eastly below 6.

5.3 Intelligent Typhoon Evasion Decision Making

Expert system is the computer program system, which consists of massive expertise knowledge and can apply these knowledge to solve particular domain problems. In the past period, the technology used for shipboard typhoon evasion came from expert experiences and map manoeuvre. With the rapid development of scientific technology, shipping management modernization and intelligent typhoon evasion are the trend of the day. The typhoon evasion headquarter of GuangZhou Maritime Transport Group Co., LTD and its hundreds of large ships, which sailed over North-West Pacific Ocean in the past tens of years, has safely evaded thousands of typhoons and acquired massive valuable experiences and great achievement To construct intelligent typhoon evasion system for ships is to apply new technology and new theory to automate typhoon evasion for ship, and thus inject new life into the business of typhoon evasion.

5.3.1 Intelligent Typhoon Evasion Decision Making System Based On ECDIS

With the increasingly development of ECDIS and its becoming more and more perfect, it is possible to store relevant information digitally on the ECDIS. Therefore, ECDIS is the best basic platform for intelligent typhoon evasion decision making.

Intelligent Decision Support System (IDSS) intergrates Decision Support System (DSS) with Expert System (ES). DSS is composed of: (1) human machine interactive system (including language system and problem processing system); (2) model base system (including model base and model base management system); (3) database system (including database and database management system) . Expert system is mainly composed of knowledge base, inference engine and dynamic database. IDSS has, which integrates DSS with ES, not only has the characteristic of problem solving by knowledge inference of the expert system, but also has the characteristic of quantitative problem analysis of DSS based on model calculation. The proper integration of qualitative analysis and quantitative analysis greatly improves the problem solving capability and increases the scope of problem domain.

5.3.2 Intelligent Typhoon Evasion Decision Making System Based On ECDIS, which is the optimal integration of typhoon evasion expert system with relevant model base systems, is the senior form of the typhoon evasion system. Relative information is integrated on the ECDIS, such as ship movement information, typhoon information, the comprehensive ship-typhoon situation, GPS, RADAR, LOG, COMPASS and so on. It's the ECDIS that provide the information needed for typhoon evasion decision making, which , in company with typhoon evasion rule base, form the knowledge base for the intelligent typhoon evasion decision making system. The integrated system is composed of knowledge base, inference engine and dynamic databases of the expert system and the model bases of DSS core component, listed as figure 8.

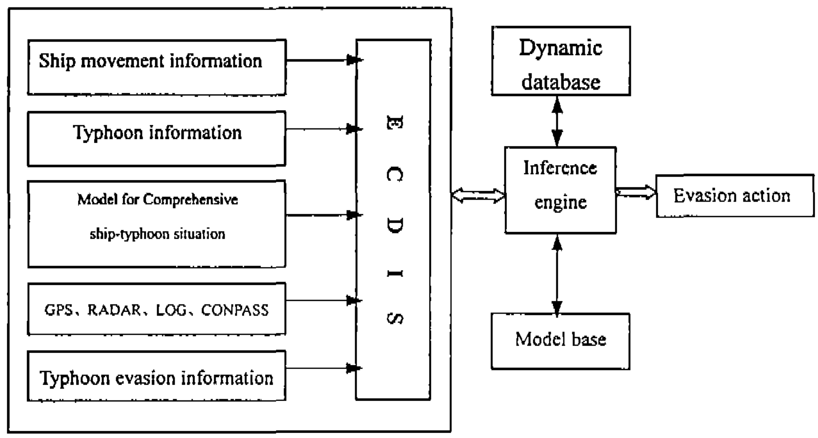


Figure 8 Intelligent Typhoon Evasion Decision Making System Based On ECDIS

6. Conclusion

Intelligent typhoon evasion system for ships is an another successful application of information technology into classic nautics following GPS and ARPA. Its implementation will inject new life to the business of traditional typhoon evasion for ships, and will have profound significance to the prosperity of our country's nautics and to the development of automated typhoon evasion for ships. The initial research work of the system has achieved great success, and now it has been installed in the typhoon evasion headquarter of GuangZhou Maritime Transport Group Co.,LTD to further examine the suitability of choosing such technical criterion and the validity of so many performance parameters. The model about supplementary typhoon track correction and weather forecast along the sea rout in the system need to be further studied, and the legality of ECDIS has to be settled. Only when all those problems have been properly solved, would the system exert great use value and present a bright future.

References

[1] 朱乾根等　天气学原理与方法　气象出版社　2000 年 10 月
[2] 龚 鉴等　最新实用船舶防台　广州航海学会 1992 年 9 月
[3] 新田尚等　最新天气预报技术　气象出版社　1997 年 6 月
[4] 龚国庆等译　全球热带气旋预报指南　气象出版社 1995 年 2 月
[5] 85 国家科技攻关项目 台风预报技术研究　气象出版社 1996 年 3 月
[6] 吴永芬　船舶自行气象导航　天气与航海安全论文集 1997 年 10 月
[7] 林明智　海洋气象导航数据库及其应用　天气与航海安全论文集 1997 年 10 月
[8] 林乐云等　防台抗台经验介绍　防台抗台经验论文集 1998 年 11 月
[9] 孙凤羽　论西北太平洋船舶防台　天气与航海安全论文集 1997 年 10 月
[10] 陈文伟　智能决策技术　电子工业出版社　1998 年 6 月