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Design of Quantitative Risk Assessment System for Ship Longitudinal Motion Based on Analytic Hierarchy Process

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Abstract

In order to ensure the normal operation of ship navigation and reduce the risk of ship longitudinal movement, a quantitative assessment system of ship longitudinal movement risk based on Analytic Hierarchy Process (AHP) is designed. Through the Beidou positioning module, external antenna, single-chip control module and power supply module, the hardware part of the ship's longitudinal movement risk quantitative assessment system is designed. Through the determination of the ship's longitudinal movement risk evaluation index, the analytic hierarchy process is used to determine the speed, heading, sea condition and frequency. The relative importance of each risk index is evaluated, and the weight of the evaluation index is calculated. On this basis, the ship was built. The quantitative model of ship longitudinal movement risk assessment uses genetic algorithm to calculate the optimal solution of the parameters, establishes the risk assessment interval, and determines the degree of risk. Using embedded Linux technology, the AHP-based quantitative assessment system design for ship longitudinal movement risk is realized on the C/S client. The experimental results show that the quantitative assessment system of ship longitudinal movement risk based on the analytic hierarchy process has high accuracy, and can improve the confidence of the evaluation, shorten the evaluation time, and stabilize the frequency and speed of the ship's longitudinal movement.

Keywords: Analytic Hierarchy Process (AHP); Ship Longitudinal Motion; Risk Quantification; Evaluation System.

1. Introduction

Sea transportation has always been the most important mode of transportation in world trade. The development of shipping industry has a direct impact on the stability of the global economy. With the rapid development of shipping industry and navigation science and technology, ships are developing towards large-scale, high-speed and specialization, and the navigation density of ships is also increasing. With the continuous improvement of transportation efficiency, the shipping industry also puts forward higher requirements for maritime navigation safety. When a ship navigates at sea, it will produce rolling motion with six degrees of freedom: pitch, roll, heave, pitch, roll and yaw [1]. The disturbance of external environment includes wind force, wave force and current force, and its mechanism is very complex. Due to the risk of longitudinal motion of the ship during navigation, the wind will produce additional power similar to the random walk process, and the waves will lead to additional high-frequency oscillation of the bow to other degrees of freedom, resulting in the motion deviation of the hull, reducing the stability of the ship and leading to the navigation of the ship. In order to improve the safety management level of ship transportation, it is necessary to quantitatively evaluate the ship navigation risk, so as to predict the longitudinal movement risk in the process of ship navigation in advance and take necessary safety measures.

On the basis of comprehensively considering the needs of domestic inland river traffic safety management departments and relevant laws and regulations, Zhang et al. constructed an inland river ship navigation safety state evaluation system based on Fuzzy evidential reasoning [2]. The risk levels of qualitative indicators are divided into high, medium and low. According to the target information, the fuzzy evaluation level distribution map of quantitative indicators is constructed by using fuzzy theory, and the fuzzy reliability distribution of evaluation indicators at the index level is calculated. However, the confidence of longitudinal motion risk assessment is low, resulting in poor evaluation effect. Ma et al. proposed and designed a ship navigation environment risk assessment system based on Improved TOPSIS method [3]. A certain channel section is selected as an evaluation example to evaluate its navigation environment risk. Compared with the evaluation results of entropy weight matter-element model, the effectiveness and practicability of the system are verified. However, the evaluation of the system takes a long time, resulting in low efficiency. Jiang et al. analyzed the influencing factors of ship navigation efficiency under traffic conflict, and defined the delay time of waterway traffic conflict, and put forward the concept of conflict threshold [4]. By collecting the channel data of a "t" intersection, a channel traffic safety evaluation system is established, and the quantitative evaluation results are obtained. However, the evaluation accuracy of the system still needs to be further improved. Li et al. extracted relevant data from the information of automatic

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identification system (AIS) and the evaluation index system of multi-objective and multi-layer fuzzy optimization theory [5], calculates from low level to high level through the optimal relative membership vector ranking, and selects the sea area with high navigation risk. However, due to the need to process more data, the final risk assessment efficiency is low. Bye and Aalberg introduced the statistical analysis results of maritime accident data and AIS data, to identify navigation related accidents (grounding and collision) and can be used as risk indicators [6]. The ships involved in the accident reported in the accident database have been tracked in the historical AIS records, and the data related to each ship have been converted into variables to obtain the risk assessment results. However, due to the long research data of the system, the accuracy of the assessment results is insufficient.

In order to solve the problems of the above-mentioned system and to better ensure the safe navigation of ships in the waters, this paper designs a quantitative risk assessment system for ship longitudinal movement based on the analytic hierarchy process. The use of this system improves the efficiency of quantitative assessment of ship longitudinal movement risks, and provides a basis for ship navigation safety.

2. Hardware Design of Quantitative Risk Assessment System for Ship Longitudinal Motion

The hardware structure of the system consists of Beidou positioning module, external antenna, MCU control module and power module, as shown in Figure 1.

2.1. Beidou Positioning Module

Through the external passive antenna, Beidou module can receive the satellite signal in real time. After processing and saving, it can generate navigation and positioning data, and then output the navigation and positioning data through the standard serial port according to the relevant protocol. At the same time, the MCU (Microcontroller Unit) reads the Beidou navigation and positioning information through the standard serial port, analyzes, processes and assembles the information, and then forwards the packaging information through the Beidou satellite system.

The system selects TM8620 Beidou positioning module, which has built-in RNSs (Radio Navigation Satellite System) & GPS (Global Positioning System) module, which can receive navigation signals from RDSS and RNSs/GPS satellites, ensuring the reliability and accuracy of information receiving. The RDSS here is equivalent to the Beidou first generation positioning system, which belongs to active positioning. If you want to locate, you need to apply first, and it mainly transmits the alarm message information through the Beidou satellite system; While the RNSs it mainly refers to the satellite system including the Beidou II positioning system, which is a passive and all-weather positioning system, that is, it can obtain the ship position information without application, and can receive the ship position information according to the service frequency. TM8620 Beidou positioning module is a module with transmission power of 10 W and output of TTL (Time to Live) level. It has the following main characteristics:

1. It has high integration, low power consumption, positioning and short message communication functions. It is very suitable for real-time and high-precision positioning and speed measurement of mobile carriers.
2. Small size, 54*60*8 mm, very suitable for the volume design requirements of small alarm terminal.
3. The positioning accuracy is less than 15 meters, and the speed accuracy is less than 1.0 m/s.
4. The mean time between failures (MTBF) is more than 5000 hours and the reliability is high.
5. The RDSS part of the interface protocol adapts to the active I/O 4.0 protocol and the RNSs part conforms to the input and output statement format of the Taidou navigation and positioning module.
6. The serial port can be directly connected with 3 V to 5 V logic level with RS-232 polarity standard without level conversion circuit.
7. It has strong environmental adaptability and anti multipath interference.
8. PA is built into the module, which modulates and amplifies the l-frequency signal, and then transmits it to the external passive antenna.
9. RNSs & GPS module is built in the module, and LNA (Low Noise Amplifier) is built into the RNSs part of the module, which can realize the filtering of RNSs frequency points and low noise amplification. Users can directly connect to the passive antenna of RNSs without external LNA. The principle block diagram is shown in Figure 2.

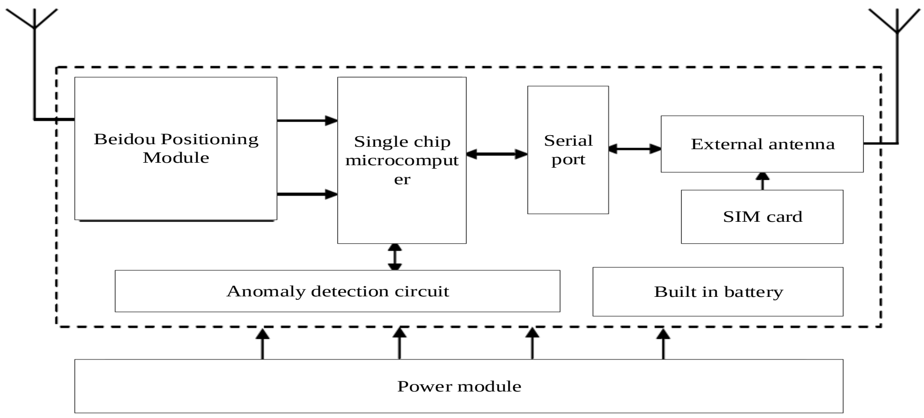

Figure 1. System hardware structure

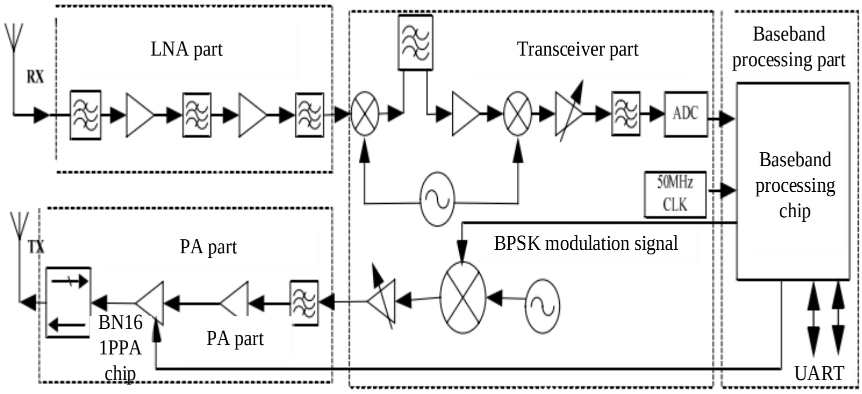

Figure 2. Principle block diagram of tm8620 Beidou Positioning Module

According to the principle of TM8620 Beidou positioning module, some important performance parameters of TM8620 are set, as shown in Table 1.

Table 1. Performance parameters of TM8620

RDSS parameters	Input VSWR	≤ 2.0
	Received signal sensitivity	-127.6 dBm
	Signal transmitting power	≥ 39 dBm
	Carrier suppression	≥ 30 dBc
	Modulation phase error	≤ 3°
	Positioning/communication	Positioning accuracy (continuous 24 hours): ≤ 100 m
RNSS parameters	Input frequency point	RNSS B1 + GPSL1
	Data update rate	≥ 1 Hz
	Horizontal position accuracy	≤ 5 m
	Vertical position accuracy	≤ 10 m
	Speed accuracy	≤ 1.0 m/s
	Capture sensitivity	-144 dBm

2.2. External antenna

Based on the satellite model received by Beidou module, and in order to improve the signal reception strength, the external antenna is designed.

When selecting external antenna, in order to match with TM8620 Beidou positioning module, at the same time, considering the signal-to-noise ratio and gain of antenna, TA-011 & GPS passive antenna is selected for receiving antenna in this paper. Its appearance and structure are shown in Figure 3.

During the circuit connection, the orientation of the antenna position may affect the sensitivity of the signal to a certain extent. According to the relevant test data, the antenna should be placed outdoors without obvious shielding to ensure that there is no obvious interference in the environment, and the receiving and transmitting direction is to the south, so the signal effect will be better. When connecting the antenna, it is necessary to ensure that the module interface is connected correctly and the antenna has been correctly connected before power on can be carried out. Special attention should be paid not to plug in and out the antenna with hot line, otherwise the module may be burnt out.

Figure 3. Ta-011 & GPS passive antenna

2.3. Single chip microcomputer control module

The single chip microcomputer control module is the core component of the hardware of the risk quantitative assessment system for ship longitudinal motion, which is equivalent to the “heart” of the system terminal. It mainly realizes the reading, parsing, comprehensive processing, packaging, evaluation and other control functions of Beidou positioning information, and finally controls the transmission of Beidou message data information. It also realizes the control and operation of abnormal power failure detection circuit, power battery switching circuit, built-in battery charging and discharging circuit and two serial interface data receiving and sending [7-10].

In this paper, STC12C5A60S2 single chip microcomputer is selected as the control chip of the system terminal. STC12C5A60S2 is a new generation of 8051 single-chip microcomputer, which is compatible with all functions of 8051 single-chip microcomputer, and has relatively unique functional characteristics. The MCU contains four 16 bit timers/counters, two universal full duplex asynchronous serial ports, and its RAM data memory is 1280 bytes. Its machine cycle is 1t, that is,

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single clock, and the instruction code is fully compatible with the traditional 8051. Therefore, 803x/805x assembler and compiler can still be used in software development. The MCU integrates 2-channel PWM (Pulse Width Modulation), 8-Channel high-speed 10 bit A/D conversion (250 K/s), and has on-chip debug circuit and max810 special reset circuit. STC12C5A60S2 MCU circuit connection schematic diagram is shown in Figure 4.

2.4. Power module

Generally, the voltage of shipboard power supply system is 220 V, while the input voltage of tm8620 module used for receiving and transmitting is 5 V, the typical voltage for module transmitting is 12 V, and the power input of MCU and other components is 5 V. Therefore, it is necessary to transform the 220 V AC supplied by the ship longitudinal motion risk quantitative assessment system through transformer, and then use lm2576 integrated chip to stabilize the power supply. Power supply voltage stabilization is an important part of single-chip microcomputer system. If the power supply is unstable, it may affect the technical indicators of the system and produce signal interference. In order to ensure the stability of multi-channel power supply voltage, this paper selects LM2576 series voltage stabilizing chip to form DC/DC conversion control circuit. The 12 V or 24 V voltage output by transformer is reduced and stabilized through the circuit, and 5 V is output for the protection circuit [11-14].

LM2576 series voltage regulator chip is a single chip integrated circuit, which can drive 3 A load, realize many functions of voltage drop switch regulator, and its efficiency is higher than that of three line regulator, and its heat dissipation function is very good. With the increase of using time, the temperature of the chip will not be very high, which will not affect the normal operation of the system. The principle of power supply in this design is shown in Figure 5.

In order to make the assessment system work normally when the ship power supply is abnormal, the backup battery is built in during the design of this paper. The ship's power module supplies power to the terminal of the evaluation system and also charges the built-in battery. In case of power failure, the ship is powered by lithium battery, which can realize 96 hours continuous operation [15-17].

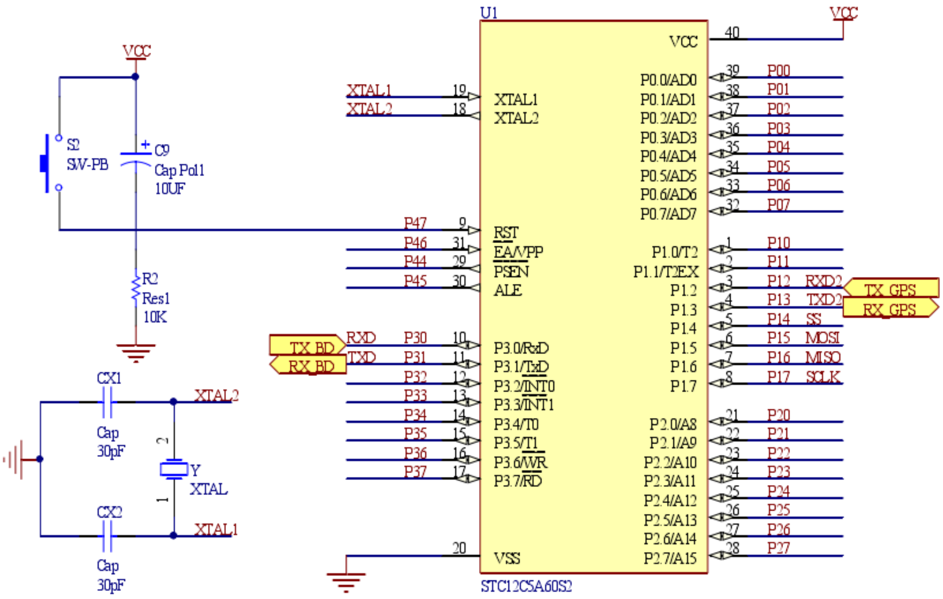


Figure 4. Circuit connection principle of STC12C5A60S2 single chip microcomputer

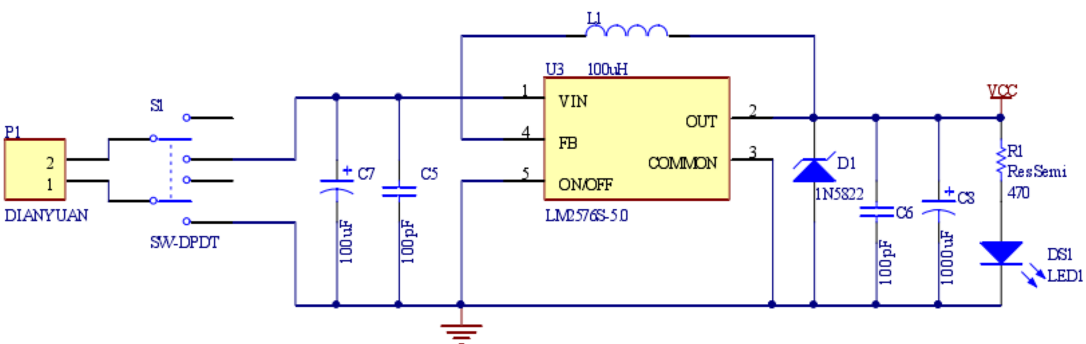


Figure 5. Power circuit principle

3. Software Design of Ship Longitudinal Motion Risk Quantitative Assessment System Based on AHP

3.1. Determine the risk assessment index of ship longitudinal motion

According to the ship hydrodynamic theory, the longitudinal motion equation of a ship sailing in waves can be expressed as follows:

$$\begin{cases}(a_{33}+D)z+b_{33}z+c_{33}z+a_{35}\theta+b_{35}\theta+c_{35}\theta=I_R+F_{w3}\\ a_{53}z+b_{53}z+c_{53}z+(I+a_{55})\theta+b_{55}\theta+c_{55}\theta=I_RX_R+F_{w5}\end{cases} \quad (1)$$

where z is the heave of the hull; D is the mass of the hull; θ is the pitch of the hull, F_{w3}, F_{w5} is the interference force of the wave heave and the interference moment of the sea pitch respectively. The wave force of a ship moving on the water surface is mainly composed of two parts, one is the linear inertial force generated by wave acceleration, the other is the nonlinear damping force generated by wave velocity. The disturbing moment is the tendency of the wave force to make the hull move up and down in the longitudinal motion of the ship; I_R is the horizontal rudder lift; X_R is the longitudinal distance from the rudder lift center to the center of gravity of the hull; $a_{ij}, b_{ij}, c_{ij}(i, j=3,5)$ is the hydrodynamic coefficient; I is the longitudinal moment of inertia.

By simulating the hydrodynamic coefficients of typical sea conditions, the hydrodynamic model which changes continuously with the course when the sea conditions and speed are constant can be expressed as follows:

$$w_{ij}(u,U,q)=au^2+bu+c \quad (2)$$

where u is the course, taking 30, 60, 90, 120, 150 and 180 degrees; U is the speed, taking 6 kN, 12 kN, 18 kN or 24 kN; q is the sea condition.

(1) When the speed U ≥ 8 kN:

$$w_{ij}(u,U,q)=(U-U_1)/(U_0-U_1)w_{ij}(u,18,q)+(U-U_0)/(U_0-U_1)w_{ij}(u,24,q) \quad (3)$$

where, $U_0=18, U_1=24$.

(2) When the speed U ≤ 18 kN:

$$w_{ij}(u,U,q)=w_{ij}(u,12,q)+\left[(U-U_2)(U-U_3)\right]/\left[(U_4-U_2)(U_4-U_3)\right]w_{ij}(u,18,q) \quad (4)$$

where, $U_2=6, U_3=12, U_4=18, q=3,4,5$.

According to Formula (3) and Formula (4), the hydrodynamic coefficient is related to the speed, course, sea condition and frequency. Therefore, the four indexes of speed, course, sea state and frequency can affect the risk of ship longitudinal motion.

3.2. Calculate evaluation index weight

On the basis of determining the risk assessment index of ship longitudinal motion, the weight of risk assessment index of ship longitudinal motion is calculated. When calculating the index evaluation weight, a judgment matrix is constructed. Before constructing the matrix, AHP is used to evaluate the relative importance of four risk indicators, namely speed, course, sea condition and frequency. The scale of the assessment set is 1 to 9. A judgment matrix is constructed according to the meaning of the evaluation set. The scale evaluation set used is shown in Table 2.

Table 2. Scale evaluation set

Serial number	Scale	Meaning
1	1	Indicates that two factors are equally important
2	3	Indicates that one factor is slightly more important than the other
3	5	One factor is more important than the other
4	7	It means that compared with two factors, one factor is obviously more important than the other
5	9	It means that compared with two factors, one factor is absolutely more important than the other
6	2, 4, 6, 8	The median value of the above two adjacent judgments
7	1, 1/2, ..., 1/9	The ratio of comparative judgment

By analyzing the assessment set in Table 2, it is assumed that the risk factor of longitudinal motion of ships of the same type is a risk layer, and n factor $C_1, C_2, ..., C_n$ in a certain layer is compared. The influence on a certain factor in another risk layer is assumed to be O. Two factors C_i and C_j are taken each time. a_{ij} is used to represent the ratio of the influence of C_i and C_j on O. The comparison matrix A formed is as follows:

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (5)$$

where $A=(a_{ij})_{n\times n}, a_{ij}>0, a_{ji}=1/a_{ij}$, $i, j=1,2,...,n$. In this case, Formula (5) is a positive reciprocal matrix. By using the positive reciprocal matrix, the largest eigenvalue of matrix A is marked as λ, and the eigenvector of eigenvalue is taken as the weight vector ω, then the weight coefficient is obtained:

$$A\omega=\lambda\omega \quad (6)$$

It can be seen from this formula that the eigenvalue and eigenvector of matrix a continuously depend on the factor a_{ij} of the matrix. Therefore, when a_{ij} meets the index consistency, the weight value of each index can be calculated, and the index weight value can be obtained by combining Formula (5) and Formula (6).

According to the weight coefficient obtained, AHP is used to evaluate the relative importance of four risk indicators, namely, speed U, course u, sea condition q and frequency p:

$$Q=s/A\omega\left(U,u,q,p\right) \quad (7)$$

In Formula (7), s represents the influence degree of influencing factors.

3.3. Construction of quantitative model for risk assessment

Based on the weight of the evaluation index, the quantitative model of ship longitudinal motion risk assessment is built to support the risk assessment system.

The basic model of ship longitudinal motion risk assessment is established:

$$R = F(V, T, C) \tag{8}$$

where R is the longitudinal motion risk of the ship; C is the existing risk control measures; V is the navigation efficiency of the ship; T is the risk control cycle.

In terms of the risk defined by ISO/IEC, it can be expressed by the vulnerability of the threat, the severity of the possibility, etc., then Formula (7) can be expressed as follows:

$$R = F(Pt, Pv, V) \tag{9}$$

where Pt is the probability of the threat and Pv is the severity of the vulnerability.

The value range of threat probability Pt is set as $[0,1]$ to reflect the possibility of risk events. The closer the probability of threat occurrence to 1, the greater the probability of ship longitudinal motion risk events; On the contrary, the probability of ship longitudinal motion risk events is smaller.

Vulnerability severity Pv is objective, but only when the threat is used, it will bring risks to the ship navigation. The greater the vulnerability, the greater the risk of longitudinal motion.

The effectiveness of risk control measures also determines the possibility of risk events and affects the accuracy of risk assessment. The more effective the risk control measures are, the smaller the risk of ship longitudinal motion is. The calculation formula of the effectiveness of risk control measures is as follows:

$$Sm = 1 - \frac{Nv}{NR} \tag{10}$$

where Nv is the number of times the risk of longitudinal motion of the ship occurs; N is the total number of times the ship's navigation is threatened.

According to the actual situation, the occurrence of risk events of ship longitudinal motion has randomness and statistical regularity.

Poisson distribution sets random variable x, its value is $[0, +\infty]$, and the formula is as follows:

$$P(X = k) = \frac{e^{-\lambda}\lambda^{x}}{Sm} \tag{11}$$

where λ is a constant, which means the average occurrence rate of random events per unit time. The range is $[0, +\infty]$. The random variable x obeys the Poisson distribution of parameter λ, abbreviated as $x * \Pi(\lambda)$.

When λ reaches the maximum value, Poisson distribution formula can be transformed into normal distribution formula, which is expressed as follows:

$$P(X = n) = \frac{1}{\sqrt{2\pi\lambda}} e^{\frac{(n-\lambda)^2}{2\lambda}} \tag{12}$$

When λ is equal to 10, the Poisson distribution curve is close to the normal distribution curve, as shown in Figure 6.

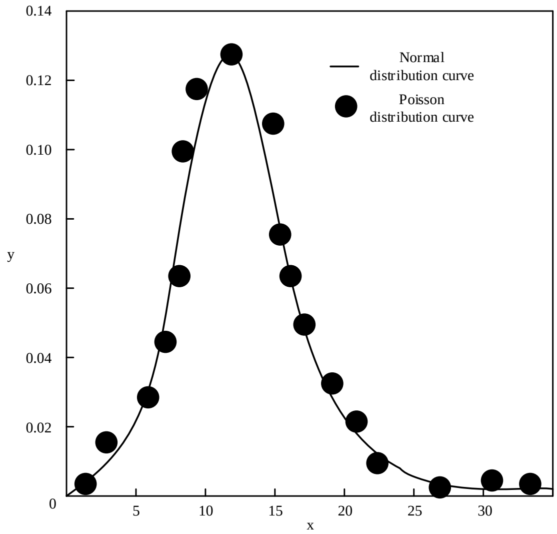


Figure 6. Poisson distribution curve and normal distribution curve of $\lambda = 10$

To sum up, Poisson distribution is used to quantify the risk assessment index. Combined with Formula (12), the quantitative model of ship longitudinal motion risk assessment is obtained as follows:

$$\begin{cases} Q = \sum_{k=1}^{k} \left(V \times \frac{e^{-\lambda}\lambda^{x}}{Sm} \times Pv \right), k < 10 \\ Q = \sum_{k=1}^{k} \left(V \times \frac{1}{\sqrt{2\pi\lambda}} e^{\frac{(n-\lambda)^2}{2\lambda}} \times Pv \right), k \geq 10 \end{cases} \tag{13}$$

3.4. Judgment of risk

Based on the above-mentioned quantitative model of ship longitudinal motion risk assessment, the genetic algorithm is used to calculate the optimal solution of the parameters, and the risk assessment interval is established to determine the risk degree, so as to realize the design of quantitative risk assessment system of ship longitudinal motion based on AHP.

According to Formula (12), it is necessary to calculate the values of Q and k. the specific solution process is as follows.

Set the initial population as

$$Chrom = \{(Rt1, k1), \cdots, (Rti, ki), \cdots (Rt20, k20)\},$$

where Rti and ki represent the real values in the range of Rt and k respectively.

The individual fitness of the population was calculated:

$$fitness = |V_j - V_i| \tag{14}$$

where V_j is the individual fitness value of the population; V_i is the expert evaluation value.

The smaller the $fitness$ value, the greater the chance that the individual will be retained in the new generation population. According to the calculation results of Formula (14), through selection, crossover and mutation operation, the optimal individual is obtained. The corresponding value is the optimal solution of model parameters. The optimal quantitative model of ship longitudinal motion risk assessment is obtained by substituting the corresponding value into Formula (12). The sample data is input into the model to obtain the risk assessment value of ship longitudinal motion. On this basis, the risk degree is determined in Table 3.

Table 3. Risk degree judgment rule table

Degree of risk	The assessed value	Explanation
No risk	[0,60]	The ship sails normally and there is no possibility of risk
Low risk	[60,75]	Ship navigation is basically stable, there is a possibility of risk
Medium risk	[75,90]	The ship's navigation status fluctuates, and there is a possibility of obvious risks
High risk	[90,100]	The ship's sailing condition deteriorates and risks may occur

3.5. System software development

On the basis of the algorithm design of the ship longitudinal motion risk quantitative assessment system, the software development and design of the system are carried out. The software development of the system is carried out by using embedded Linux technology in C/S client. The system includes data processing module, information control module, program loading module, cross compiling module and human-computer interaction module Using SQL Server database as the data management engine of ship longitudinal motion risk quantitative assessment system, the equipment catalog table and equipment attribute table of ship longitudinal motion risk quantitative assessment model are established, and dma0 is configured_ START_ Addr register Dmax is implemented by cross compilation_ Y_ MODIFY, DMAx_ PERIPHERAL_ Map and other registers are configured, and the program loading module is used to load the quantitative assessment algorithm of ship longitudinal motion risk, and the software implementation diagram of the system is obtained, as shown in Figure 7.

Through the above process, the design and operation of the risk quantitative assessment system of ship longitudinal motion based on AHP is completed, which provides more effective guarantee for the safety of ship navigation.

4. Experimental Results and Analysis

In order to prove the application performance of the risk quantitative assessment system of ship longitudinal motion based on analytic hierarchy process (AHP) in actual ship navigation, the inland river ship navigation safety state evaluation system based on fuzzy evidence reasoning and the ship navigation environment risk assessment system based on Improved TOPSIS method are set as the contrast system of the experiment the risk of ship longitudinal motion is quantitatively evaluated.

4.1. Experimental preparation

According to the above software design, the software test of ship longitudinal motion risk quantitative assessment system is carried out. The buffer data word length is 16 bits, the length of sampling data of ship longitudinal motion risk is 1024, and dma0 of test set_ X_ Modify is 2.

(1) In this paper, the longitudinal motion of the ship as the research object, as shown in Figure 8.

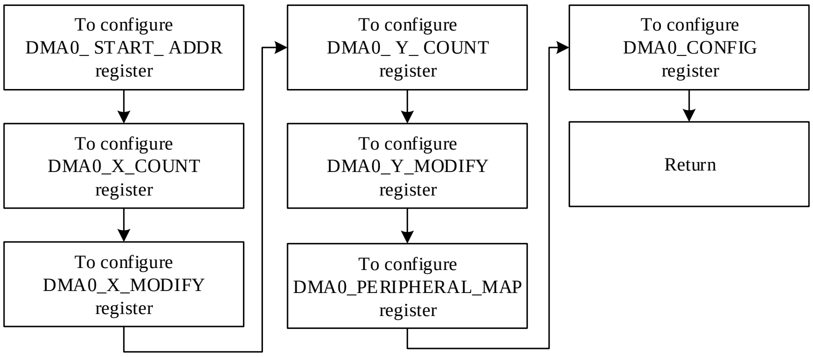


Figure 7. Software implementation diagram of the system

Figure 8. Ships in longitudinal motion

(2) The ship information is shown in Table 4

Table 4. Ship dimensions

Model ship name	Total length (m)	Width (m)	Mould depth (m)	Tail draft (m)	Full load tonnage (t)	Age of vessel (years)
200 seats	35.3	6.6	2.8	2.2	145	4

(3) Navigation route: from the south side of Jinxianding tourist wharf to the berth of Liugong Island tourist wharf.

(4) Expected working environment:

Visibility: 1500 m

Wind force: 4

Maximum flow rate: 2.0 knots

Channel width: minimum 100 m

Minimum channel depth: 5.0 m

Ship type composition: fishing boats and other passenger ferries

Traffic flow: dense traffic flow

Navigation aids: general

The nearest distance to the obstruction: 110 m.

Speed: 10 knots

Age of crew: 7 years

After selecting the route and inputting the estimated sailing time and speed, the system can calculate the position of the ship once an hour and the risk level of the ship's longitudinal movement at sea in the whole route from the port of departure to the port of destination.

The sensor is used to collect the longitudinal motion pose data of the ship, as shown in Figure 9.

4.2. Confidence level

The data of the quantitative assessment of the longitudinal motion risk of the ship is collected, and the results are shown in Figure 10.

Taking the data in Figure 10 as the research object, the ship's longitudinal motion risk assessment is carried out, and the level set of risk characteristic distribution is obtained as shown in Figure 11.

Based on the horizontal value of the ship's longitudinal motion risk characteristic distribution, the quantitative risk assessment system of ship's longitudinal motion based on analytic hierarchy process, the evaluation system of navigation safety status of inland ships based on fuzzy evidence reasoning, and the ship's navigation environment risk based on improved TOPSIS method are adopted. The evaluation system tests the confidence level of the ship longitudinal motion risk assessment, and the results are shown in Table 5.

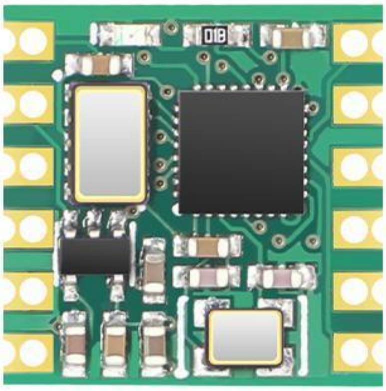


Figure 9. Sensor

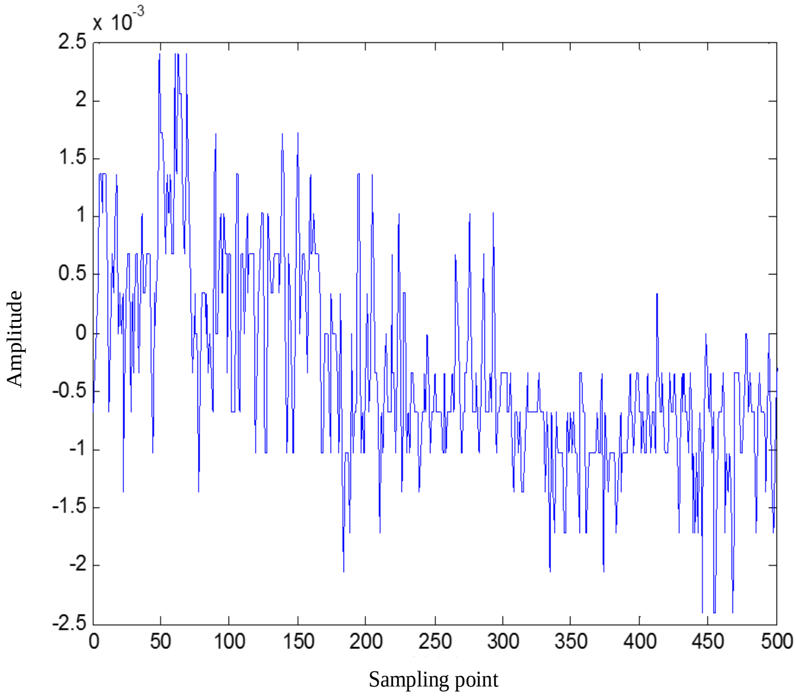


Figure 10. Data collection results

Based on the horizontal value of the ship's longitudinal motion risk characteristic distribution, the quantitative risk assessment system of ship's longitudinal motion based on analytic hierarchy process, the evaluation system of navigation safety status of inland ships based on fuzzy evidence reasoning, and the ship's navigation environment risk based on improved TOPSIS method are adopted. The evaluation system tests the confidence level of the ship longitudinal motion risk assessment, and the results are shown in Table 5.

Table 5. Confidence level of ship longitudinal motion risk assessment

Number of tests	Risk quantitative assessment system of ship longitudinal motion based on Analytic Hierarchy Process	Evaluation system for navigation safety status of inland river ships based on Fuzzy evidential reasoning	Shipping navigation environmental risk assessment system based on Improved TOPSIS method
100	0.963	0.871	0.811
200	0.983	0.891	0.872
300	0.992	0.901	0.881
400	0.998	0.912	0.913

Table 5 shows that the level of confidence in the ship's longitudinal motion risk assessment system based on the analytic hierarchy process method designed in this paper is higher than the confidence level based on fuzzy evidence inference for the inland river navigation safety assessment system and the improved TOPSIS method. The ship navigation environment risk assessment system has a high level of confidence.

4.3. Evaluation accuracy

In order to further verify the effectiveness of the design system in this paper, a quantitative assessment system for ship longitudinal motion risk is based on the analytic hierarchy process, and an inland ship navigation safety assessment system is based on fuzzy evidence reasoning, and a ship navigation environment risk assessment based on improved TOPSIS. The accuracy of the ship's longitudinal motion risk assessment system is compared and analyzed. The analysis results are shown in Figure 12.

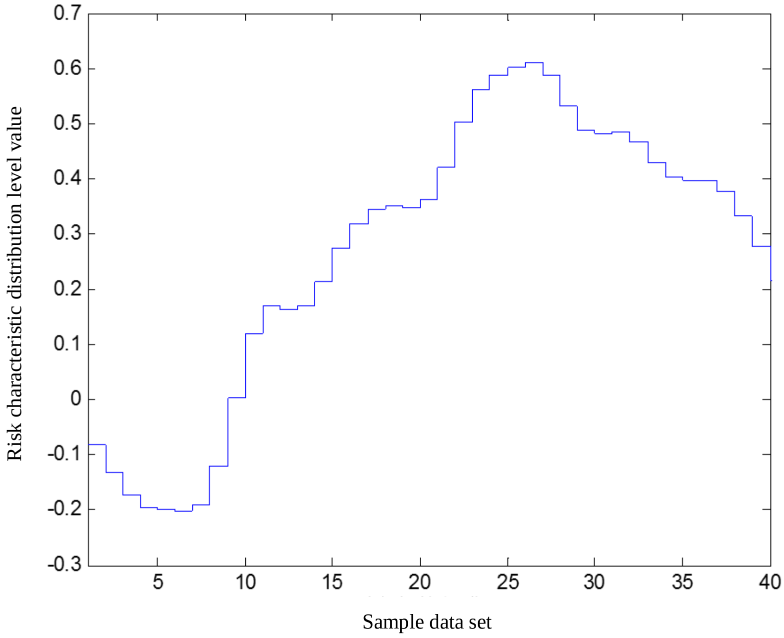


Figure 11. Horizontal values of risk distribution of ship longitudinal motion

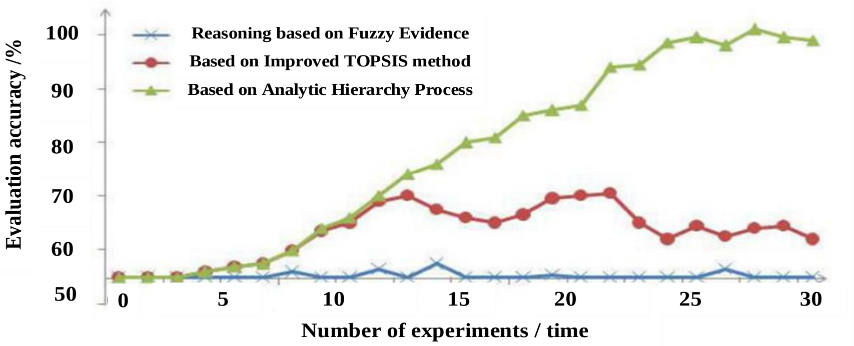


Figure 12. Comparison results of ship longitudinal motion risk assessment accuracy

According to Figure 12, the ship longitudinal motion risk quantitative assessment system based on the analytic hierarchy process has a ship longitudinal motion risk assessment accuracy of up to 100%, while the inland river navigation safety assessment system based on fuzzy evidence reasoning and the ship based on the improved TOPSIS method. The risk assessment accuracy of the longitudinal movement of ships in the general navigation environmental risk assessment system is only 59% and 70%. The method of this paper is better than the traditional method for the ship longitudinal motion risk assessment.

4.4. Assess efficiency

In order to verify the effectiveness of the system in this paper, the quantitative evaluation system of ship longitudinal motion risk based on the analytic hierarchy process, the evaluation system of inland ship navigation safety based on fuzzy evidence reasoning, and the ship navigation environment risk evaluation system based on improved TOPSIS. The time cost of the longitudinal motion risk assessment of the ship is compared and analyzed. The comparison results are shown in Figure 13.

Figure 13 shows that the time cost of using this system for quantitative assessment of ship’s longitudinal motion risk is higher than that of inland river navigation safety assessment system based on fuzzy evidence reasoning and ship’s longitudinal motion risk assessment system based on improved TOPSIS method of ship navigation environment risk assessment system. The short time overhead indicates that the system’s responsiveness is better.

4.5. Risk index testing

The quantitative risk assessment system for ship longitudinal motion based on AHP designed in this paper, the navigation safety assessment system for inland ships based on fuzzy evidence reasoning and the ship navigation environment risk assessment system based on improved TOPSIS method are used to speed the ship’s longitudinal motion. And frequency is tested. The test results are shown in Figure 14 and Figure 15.

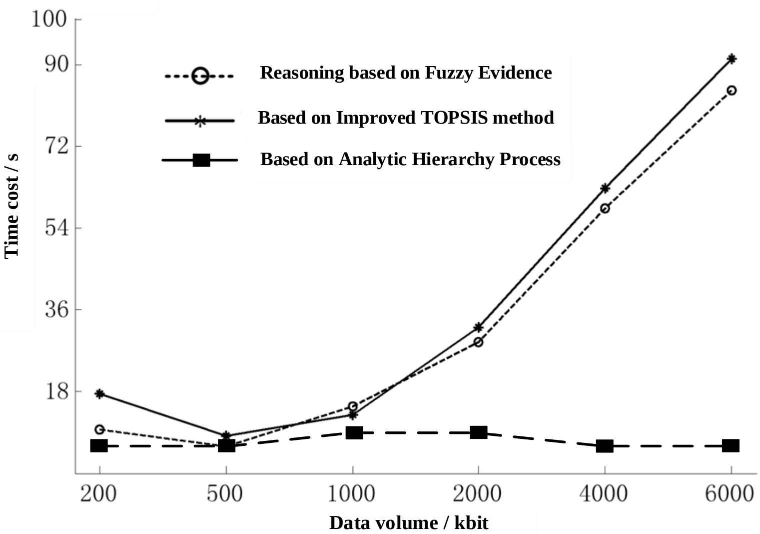


Figure 13. Time cost of ship longitudinal motion risk assessment

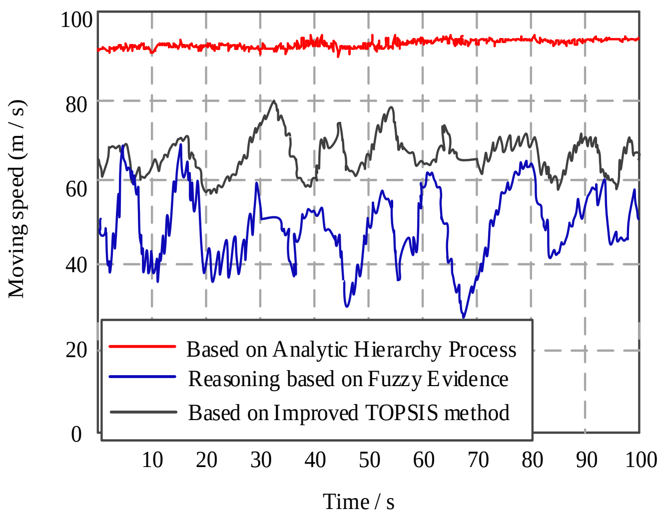
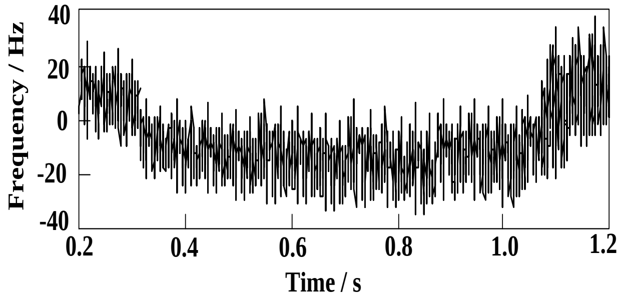
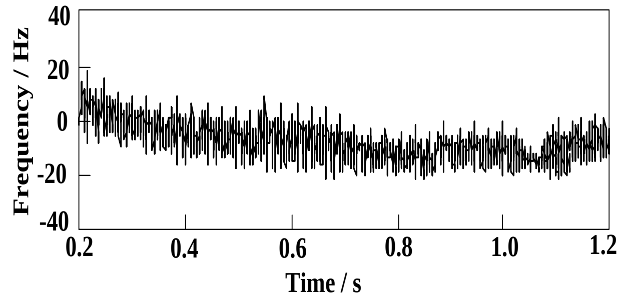


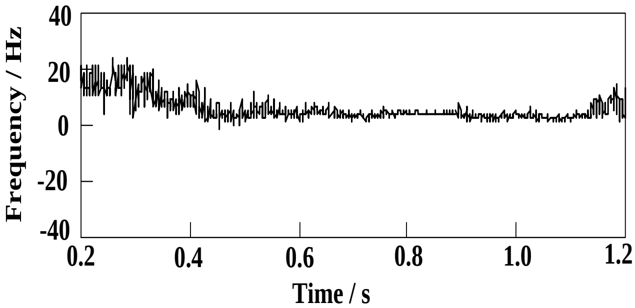
Figure 14. Ship longitudinal motion speed test



(a) Motion frequency based on fuzzy evidence reasoning



(b) Movement frequency based on improved TOPSIS method



(c) Movement frequency based on AHP

Figure 15. Frequency test of ship's longitudinal motion

According to the data in Figure 14 and Figure 15, the quantitative evaluation system of ship longitudinal motion risk based on the analytic hierarchy process designed in this paper is more efficient than the ship's longitudinal motion speed and frequency based on fuzzy evidence reasoning. The improved ship navigation environment risk assessment system of TOPSIS method has stable speed and frequency of ship's longitudinal movement, and has high effectiveness.

5. Conclusion

Aiming at the problems of low confidence, poor evaluation effect and long time-consuming in the traditional ship longitudinal motion risk assessment system, a method based on analytic hierarchy process is proposed and designed (AHP). The system hardware is mainly composed of Beidou positioning module, external antenna, single chip microcomputer control module and power supply module. The risk assessment index is determined, the relative importance of the four risk indexes of speed, heading, sea state and frequency is evaluated by analytic hierarchy process. The weight of the evaluation index is calculated, and the risk assessment model of ship longitudinal motion is established. The risk degree is determined, and the design of ship longitudinal motion quantitative risk assessment system based on analytic hierarchy process is realized. The experimental results show that the system designed in this paper has high reliability, good evaluation effect, short evaluation time, feasibility and rationality. It lays a foundation for the analysis and research of ship navigation risk and the effective control of ship risk, and is of great significance to improve the safety of ship navigation. In the future research work, it is necessary to conduct a comprehensive analysis on other factors affecting the safety of ship operation, so as to improve the effectiveness of risk assessment and provide practical guarantee for the safe operation of ship.

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