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# Design of Intelligent Ship Collision Avoidance Control System

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**Abstract.** In the overall design of ship intelligent collision avoidance decision-making and control system and some local decision-making models, there has not been a relatively unified consensus, and there is still a certain gap from the actual application. In this paper, the mathematical model of the ship intelligent automatic collision avoidance control system is studied, and the control rules and computer algorithm of the ship human-like intelligent automatic collision avoidance are given. The digital simulation of the system shows that the intelligent control algorithm of the system is feasible, and the control characteristics of the system are good.

**Keywords:** ship collision avoidance, intelligent control, navigation, multi-mode control.

## 1. Introduction

The intelligent collision avoidance of ships is the research direction actively advocated by the International Maritime Organization, and it is also the inevitable trend of the collision avoidance development of ships on the sea. With the increasing world trade, domestic and foreign ships are developing towards large-scale, high-speed and automation[1]. The direct or indirect losses caused by ship collisions continue to increase. On the other hand, in recent years, the increase in the intelligence of ships has led to a general reduction in the number of ship-tolerances, which has increased the crew's fatigue and the possibility of ship collisions[2]. The ship's intelligent collision avoidance decision-making and control system can effectively reduce the occurrence of ship collision accidents, thereby avoiding or reducing property damage, human casualties and marine environmental pollution caused by collision accidents. Strong technical support will also be provided to reduce the number of ship mannings. Ship collision avoidance decision-making is a very complicated process. It is not only the constraints of specific regulations such as "rules", but also affected to some extent by the personal factors of the traffic environment and the psychological, physiological and behavioral characteristics of the ship drivers at the time[3]. Simply using expert system technology or artificial intelligence technology, using simple inference rules, it is difficult to achieve the desired results.

At present, experts and scholars in the maritime industry at home and abroad generally use artificial intelligence technology or expert system technology to establish a ship intelligent collision avoidance decision-making and control system, and use neural network and fuzzy inference decision-making techniques to solve related collision avoidance decision-making problems[4]. The research in this area is still in the laboratory research stage[5]. The research results often only involve some or some areas of ship intelligent collision avoidance decision-making and control, and have not yet formed a systematic and practical ship intelligent collision avoidance decision-making and control system[5]. Regardless of the overall design of the system or some local decision-making models, there has not been a relatively unified consensus, and there is still a certain gap from the actual application. How to establish a collision avoidance knowledge base in line with the navigational reality to solve complex and variable ship avoidance The decision-making problem is the "bottleneck" problem that the existing system generally faces[6]. This paper uses multi-modal intelligent control to study the ship automatic collision avoidance control system. This research was very intentional for the design of the one-person bridge ship (OMBS) and the development of a fully self-guided intelligent ship in the 21st century.

## 2. Control System Overall Structure

In the ship collision avoidance decision, the ship driver usually experiences the process of information collection, meeting situation decision, collision risk decision, avoidance action and avoidance timing decision, avoidance action validity and return flight decision[7]. Any decision-making mistakes in any part may cause a ship collision accident. Figure 1 shows the block diagram of the ship intelligent collision avoidance decision-making and control system based on the "anthropomorphic" strategy. Considering the ship sailing near the turning point, the ship turns. The direction and magnitude will directly affect the decision of collision risk decision and avoidance action[8]. To this end, the system includes a ship navigation control subsystem in addition to the five subsystems of data acquisition, situation decision, collision risk decision, collision avoidance decision and return flight decision.

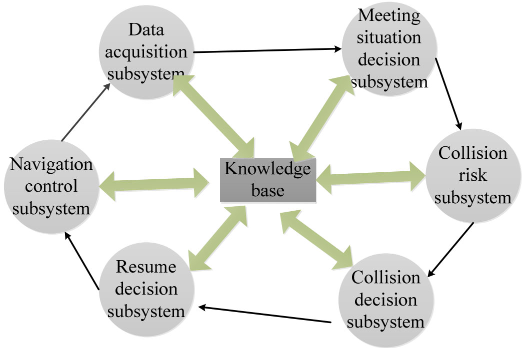


Figure 1 System block diagram

The above subsystems are relatively independent, have their own different functions, and are closely related to each other through the system public database. Different subsystems can be used to solve the problem, and artificial intelligence technology, expert system technology, neural network technology and fuzzy are comprehensively adopted. Judging techniques, etc. make corresponding decisions, in order to achieve real ship intelligent collision avoidance decision-making and control, and establish a systematic and practical ship intelligent collision avoidance decision-making and control system.

Through a suitable interface of various navigation devices, the ship's closed loop control system becomes an intelligent automatic collision avoidance system.

The essence of multi-modal intelligent control is to imitate the driver's segmentation control of the system process, making the ship's steering or shifting more stable, and its control algorithm adopts various control rules.

$$MC_1: \text{ IF } \ e > e_M \text{, THEN } \ U_{(n)} = V_H$$

$$MC_2: \text{ IF } \ e < -e_M \text{, THEN } \ U_{(n)} = V_L$$

$$MC_3: \text{ IF } \ |\Delta e| < d \text{, THEN } \ U_{(n)} = U_{(n\text{-}1)}$$

$$MC_4: \text{ IF } \ \delta_1 < \left|\frac{e}{\Delta e}\right| \le \delta_2 \text{, THEN } \ U_{(n)} = U_0 + K_1 \bullet SE_m$$

Among them,

$$SE_m = \beta \sum_{i=1}^{n-1} e_{i\max} + e_{n\max} \tag{1}$$

We define it as the peak deviation memory sum. β< 1 in the formula is called a forgetting factor.

We establish a relative coordinate system, and the relative motion equations of the ship are as follows:

$$X = (X_w - X_L)\cos\phi_w - (Y_w - Y_L)\sin\Phi_w \tag{2}$$

$$\mathrm{Y} = (Y_w - Y_L)\cos\phi_w - (Y_w - Y_L)\cos\phi_w \tag{3}$$

$$\phi = \phi_{\mathrm{L}} - \phi_w \tag{4}$$

$$X(t) = V_L \sin\phi - Y \frac{V_w}{R_w} K_w \tag{5}$$

$$Y(t) = V_L \cos\phi - X \frac{V_w}{R_w} K_w - V_w \tag{6}$$

Where $\phi$ is the heading difference between the two ships.

## 3. Sub-control Systems for Ship Collision Avoidance

### 3.1 Data Acquisition Subsystem

The data acquisition subsystem is mainly composed of two parts: information collection and data converter and system public database. The information acquisition and data converter undertakes the position, type, heading, speed and route information of the ship and the ship required for collision avoidance decision. Information such as ship's azimuth, distance, DCPA, TCPA, and avoidance actions, as well as information about the ship's parameters and visibility at that time, are also collected. The collected information is converted into a system standard data format and stored in the system public database.

The system public database stores the basic information collected by the subsystem and is shared with the remaining subsystems. At the same time, it also stores the global state parameters and decision results from each subsystem, which is the link and bridge between the subsystems.

### 3.2 Meeting Situation Decision Subsystem

Meeting the situation decision-making subsystem is mainly to complete the decision-making task of meeting the situation between the ship and the ship. The situation decision should be based on the premise of obeying the "rules", taking full account of the ship's avoidance and maneuvering characteristics and the ship's driver. The customary practices are based on the principle of facilitating collision risk decision-making, avoiding timing and avoiding action decisions, and effectively solving the problem of uncoordinated avoidance that may occur during the collision avoidance process.

### 3.3 Collision Risk Decision Making Subsystem

The decision of ship collision risk is one of the key research contents of the ship intelligent collision avoidance decision-making and control system. The collision risk decision-making model should further reflect the danger degree and avoidance of ship collision on the basis of reflecting whether there is collision risk between ships. The difficulty level of collision, providing decision-making basis for avoiding collision timing, collision avoidance action and multi-ship collision avoidance.

Fuzzy comprehensive evaluation technology and expert system technology are effective technical means for ship collision risk decision under various encounter situations.

### 3.4 Navigation Control Decision Subsystem

On the one hand, the navigation control subsystem provides a corresponding decision basis for the collision risk and collision avoidance action when the ship approaches the turning point. On the other hand, once the ship deviates from the planned route for various reasons, the subsystem can make the corresponding timing and plan decision of "recovering the track direction" or "recovering the planned route" according to the specific route information to ensure the safety of the ship along the planned route.

### 3.5 Resume Decision Subsystem

The resumption decision-making subsystem undertakes the re-entry timing and the re-decision action decision-making task in the collision avoidance process. Under different encounter situations, the re-entry actions taken by the ship's pilots often differ. The decision of the re-entry action should be ensured. Under the premise of creating a new encounter situation, minimize the yaw caused by the ship collision avoidance action or the resulting voyage loss.

## 4. Control System Design

The whole system consists of two sub-systems, namely the expert decision-making subsystem and the intelligent collision avoidance control decision-making subsystem. The analysis is as follows.

### 4.1 Expert Decision-making Subsystem

As shown in Figure 2, the expert decision sub-system consists of a knowledge base, a push rule, and a user interface.

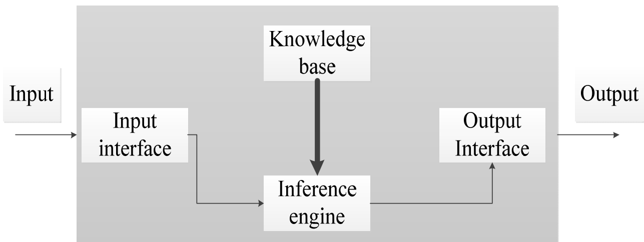

Figure 2 Expert decision-making subsystem

Figure 3 shows a block diagram of the information input of the expert decision subsystem, which is entered by a multi-information sensor.

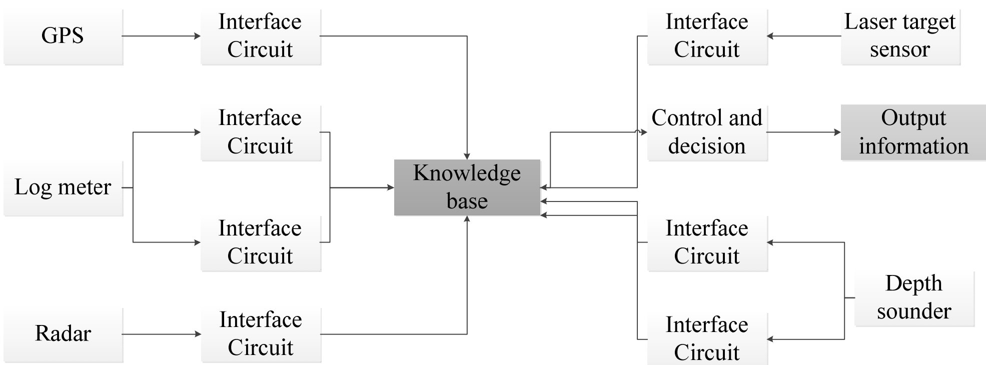

Figure 3 Knowledge base signal input diagram

The input of information is in three categories. The first category is the environment, including hydrology and meteorology, visibility, wind, waves, currents, water depths and waters, oceans, open waters, and narrow waters.

The second type is the characteristics of the ship: the type of the ship, the state of the ship, the maneuverability and the characteristics of the host. This type of information is entered by the driver in advance based on the information of the ship.

The third type of target ship characteristics: including speed, heading, relative ship speed, relative heading, bearing, distance, etc. This information is obtained by gyrocompasses, Doppler instruments, and radar or laser sensors. Radar is mainly used to detect information about the target. Due to the presence of radar in the sea and the effects of blind spots, advanced target laser sensors can be used to complete the target exploration. The instrument provides the own ship's speed and range to obtain the relative speed of the target ship. The gyro compass provides heading information to obtain the relative heading of the target ship. GPS provides information on the ship's precise position and differential pressure.

Avoiding behavioral information output, when it is divided into mutual observation and when visibility is poor. In the case of mutual observation, the DCPA and D outputs are forwarded to the avoidance information and sent to the autopilot signal. When visibility is poor, there are usually two types of signals, such as evasive, parked, or steered and decelerated. The parking and deceleration signals control the speed of the main unit via the clock controller.

### 4.2 Intelligent Avoidance Control Decision Subsystem

In the case of poor visibility, it is assumed that the ship will take refuge and the target ship will be insured. We regard the ship and the target ship as a dynamic system, and its dynamic system is shown in Figure 4.

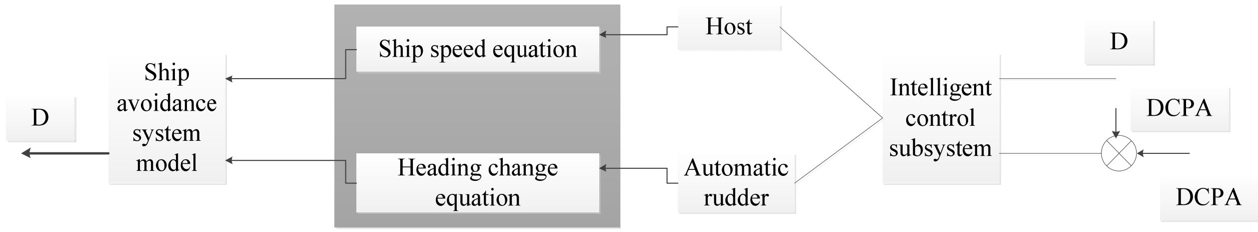


Figure 4 Dynamic system diagram

The algorithm of intelligent avoidance is usually available with the fuzzy control algorithm (discussed by the fuzzy control algorithm) and the multimodal human intelligence algorithm.

The system proposed above is based on the assumption that the visibility is not good. If the target ship operates according to the collision avoidance rules, the system is safe for mutual use.

## 5. Multi-modal Intelligent Control Algorithm

To automatically avoid, first determine if the target ship is at risk of collision. This measurement is done with a laser sensor or a marine radar. The multi-modal controller design principle is to use the high-order generation structure of hierarchical information processing and decision-making, and the human-like expert uses heuristics and direct reasoning logic. An expert system is a computer software system with the ability to process knowledge and solve problems that is equivalent to multiple experts. The level of knowledge processing is similar to the expert's group level and higher than the individual expert level.

The control rules for multi-modal PID controllers are established based on the expert's ability to avoid ships. The working process of MC is to determine the current state of motion of the system through feature recognition, and immediately adopt the corresponding control mode. For example, when the target ship has a strong collision risk with the ship, a strong control is used to make the ship early and wide, so as to quickly reduce the risk signal. When the dangerous signal is reduced to a certain value, in order to reduce the overshoot of the ship due to inertia, the mode switching reduces the control effect or gives a reverse compensation energy to achieve the smooth elimination of the residual.

Due to the influence of the ship's changing factors, the operational mathematical model of the ship's automatic avoidance is difficult to establish accurately. On the other hand, an experienced driver can't accurately master the ship's mathematical model but can handle the boat. This makes it possible to see the importance of manual experience in ship maneuvering. Using MC's human intelligence control theory, it can be designed as an automatic collision avoidance system by translating the experience of a superior driver into a smart control rule. Therefore, MC's control of the ship's motion process is an imitation of the driver's heuristic and intuitive reasoning logic.

The control system of this paper not only runs fast but also stabilizes, which proves the effectiveness of the system. The time comparison of control system control is shown in Figure 5.

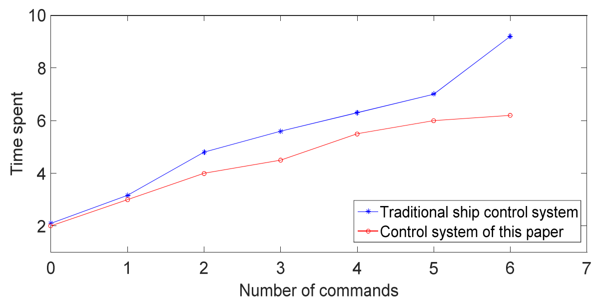

Figure 5 Control system control time comparison

## 6. Conclusion

The ship intelligent collision avoidance decision-making and control system is a complex system involving the ship's maneuverability, navigation aids, traffic environment, relevant international rules, and personal factors such as the psychological, physiological and behavioral characteristics of the ship's pilots. Using the overall structural block diagram of the system and the flow chart of the main subsystems, this paper is conducive to the comprehensive application of expert systems, intelligent control, fuzzy decision-making and neural network to establish a systematic and practical ship intelligent collision avoidance decision-making and control system. Specific issues remain to be further studied in the future.

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