Research on Intelligent Navigation Collision Avoidance Decision-making for Typical Inland Waterway

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Abstract: Inland river vessel intelligent navigation and collision avoidance technology reduces the labor intensity for operators, ensures the safety of the vessels, improves the safety level and transportation efficiency of inland river shipping, and brings about certain economic and social benefits, showing a broad application prospect. The fundamental process of intelligent navigation and collision avoidance decision-making can be encapsulated into three phases: course maintenance, collision avoidance, and course resumption. During the collision avoidance phase, to prevent collisions, vessels take rule-compliant and effective evasive actions, which typically result in the vessel deviating from the planned route. The objectives of the course maintenance phase and the course resumption phase are primarily to guide the vessel along the intended route. This paper explores intelligent navigation and collision avoidance decision-making for inland river vessels from the perspectives of trajectory control and autonomous collision avoidance, thereby deriving intelligent navigation control methods and collision avoidance models, offering significant foundational theories and methodological support for the intelligent navigation and collision avoidance decision-making of inland river vessels.

Keywords: Intelligent Navigation; Ship Collision Avoidance; Inland Waterways; Heading Control; Trajectory Control

1. Introduction

Transport is a basic, pioneering and strategic industry in the national economy. As one of the five major modes of transport, waterway transport has the unique advantages of large capacity, long distance, low energy consumption, low cost and low pollution, and has a prominent position in comprehensive transport, making important contributions to China's economic development. The huge number of inland waterway transport vessels serves the stable development of China's society and economy at the same time, but also increases the probability of ship collision accidents [1,2]. Vessel collision is a major water transport accident, which will threaten the safety of life and property, pollute the water environment, and cause adverse impact on the society once it occurs. Therefore, preventing collision accidents of inland waterway transport vessels is of great significance to guarantee the safety of navigation of inland waterway vessels in China and to promote the construction of a strong transport country.

The inland navigation environment is complex, with restricted channel widths and changing hydrological and meteorological conditions, which bring many challenges to ship pilots in maneuvering and collision avoidance. In recent years, the number of oil tankers, chemical tankers, liquefied natural gas tankers and other dangerous goods transport ships has gradually increased, resulting in more serious economic losses and environmental hazards caused by collision accidents [3,4]. Research has shown that ship collision accidents mostly involve human factors, and negligent lookout, faulty judgement and improper operation of pilots occur from time to time, so how to reduce and eliminate the negative impact of human factors on the safety of ship navigation is an important research topic.

2. Intelligent Navigation and Collision Avoidance Decision Making for Typical Inland Waterway

Trajectory control and collision avoidance decision-making are important modules for the realization of intelligent navigation and collision avoidance for ships on typical inland waterways. In nautical practice, the route drawn up on the chart in advance is called the planned route line (referred to as the planned route), i.e. the planned route that the ship will navigate, and its function is to provide route navigation for the ship's pilots. When there is no navigational obstruction or other collision danger near the planned route, the planned route is the expected path for intelligent navigation to avoid collision. Therefore, by controlling the ship's movement direction, it is an important task for the ship's intelligent navigation and collision avoidance to enable the ship to navigate along the planned route. The ship track control system can apply motion control methods to control the ship's motion state and adjust the heading direction according to the current motion state of the ship and its relative position to the planned route, to achieve the maintenance and following of the planned route. The ultimate purpose of ship collision avoidance decision-making is to prevent the ship from colliding with other ships and navigational obstacles to ensure navigation safety [5]. From the starting point to the destination, when the ship meets with other ships that form collision danger during navigation, it will make situation identification and collision avoidance decision according to the "Inland Waterway Collision Avoidance Rules" and good shopcraft, and then execute the avoidance plan to ensure that the ship arrives at the destination safely.

2.1 Vessel Heading Control

Ship heading control is the core technology of ship motion control, which ensures that the ship sails in accordance with the set heading. Proportion Integration Differentiation (PID) control, as a simple, easy-to-engineer classical control method with high stability, is the most widely used in the application of practical completion of heading control. Since the ship motion has the characteristics of large inertia, hysteresis, and is easily disturbed by external environmental factors, the ship heading control is a kind of uncertain nonlinear control [6]. Traditional PID control as a linear control, its parameters are fixed, cannot form a real-time adaptive adjustment of the parameters, the adaptability of the system is relatively poor. The fuzzy adaptive PID heading control method is used to combine the fuzzy control with the traditional PID control algorithm and use the fuzzy inference method to form a real-time adjustment of the parameters of the PID, to realize the real-time control of the ship's heading, to improve the accuracy of the control, and to have good robustness and stability. The design of the fuzzy controller contains determining the input and output variables, designing the affiliation function and formulating the fuzzy control rules.

2.2 Vessel Track Control

During the movement of the ship, the actual position of the ship is obtained through GPS or other positioning devices, and the current track section of the ship is determined; according to the planned route, the sailing deviation is calculated, and the value is sent to the track control system, and the track control algorithm is invoked to output the commanded heading; the ship's actual heading is obtained through the compass, and the deviation of the heading can be obtained by the difference between the actual and commanded heading, and the deviation value is sent to the heading control system[7]. The deviation value is sent to the heading control system, and the corresponding commanded rudder angle is obtained according to the heading control algorithm and transmitted to the ship's rudder; the rudder system controls the ship's heading and adjusts the ship's position by controlling the rudder angle, which ultimately ensures that the ship navigates along the planned route.

2.2.1 Determination of the segment of the track to which it belongs

A ship's planned route is a track line formed by several steering points connected in sequence. Typical inland waterway steering points are set up in strict accordance with the direction of the waterway, and the ship must pass through each steering point in turn, and cannot skip a steering point to the next steering point directly. Therefore, the track line between the previous steering point and the next steering point where the ship is located is the current track section to which it belongs, where the previous steering point is the latest steering point passed and the next steering point is the earliest steering point to be reached.

2.2.2 Calculation of navigational deviations

Sailing deviation mainly includes heading deviation and position deviation. Heading deviation indicates the deviation between the ship's actual heading and the planned heading, in which the planned heading is the number of degrees in the forward direction of the planned route measured clockwise from the beginning of the true north line to the termination of the planned route. Position deviation indicates the shortest distance from the ship to the track section to which it currently belongs.

2.3 Line-of-Sight Guidance Algorithm

Line of Sight (LOS) is a linear tracking method that can guide the ship to track and maintain a straight-line track segment, also known as line-of-sight guidance algorithm, which is widely used in ship track control. The guidance algorithm first sets a line-of-sight position point on the track section as the target for ship tracking, then guides the ship to sail along the direction of the target, and constantly updates the tracking target point during the sailing process, so that the deviation of ship sailing is constantly reduced, and finally sails in accordance with the planned route [8,9].

The forward positioning method and the closed circle method are the main methods for selecting the target point. The overshooting method requires the introduction of a fixed visual distance, i.e. the distance between the target point and the vertical projection point of the ship's current position on the track section, which is usually two to five times the length of the ship, and then the target point is determined according to the visual distance. The closed circle method is to take the center of the ship as the center, establish a closed circle with a certain distance value as the radius, and set the intersection point between the closed circle and the forward direction of the planned route as the target point. The size of the radius of the closed circle will directly affect the effect of ship track control. If the value of radius is too large, it will lead to the ship sailing to the planned route to spend a long time, and the efficiency of the trajectory control algorithm is low; if the value of radius is too small, there may be no intersection between the closed circle and the planned route, and the trajectory control algorithm will be ineffective. Inland waterway waters are restricted, the radius of the closed circle does not need to be too large, so it is suitable to use the closed circle method to determine the target point.

2.4 Steering Point Trajectory Control

When the ship sails along the current track section to the next track section, it follows the planned route by steering. To avoid the ship deviating too much from the planned route, it is necessary to steer the ship in advance before reaching the steering point to control the ship to steer safely and sail to the next track section. The ship's track control method at the steering point makes use of the characteristic elements of the ship's circle of gyration to make the circle of gyration exactly tangent to the planned route, and calculates the distance for the ship to steer in advance.

2.5 Ship Collision Avoidance Mechanism

The mechanism of ship collision avoidance, i.e. the change rule between the change of ship's velocity vector and the collision avoidance effect, reveals the physical process of the change of ship's velocity vector that causes the change of collision avoidance effect. According to the speed obstacle theory: if the moving object and the obstacle keep the current motion state unchanged, the collection of all the speed vectors that may lead to the collision between the moving object and the obstacle is the speed obstacle area of the moving object [10]. The traditional speed obstacle model directly calculates the feasible relative speed direction of the ship according to the real-time speed of the ship and the target ship, without considering the nonlinear motion process of ship steering, and the ship's motion trajectory is a straight line; the improved speed obstacle model combines with the mathematical model of the ship's motion to depict the nonlinear motion process of the ship's rerouting, and the ship steering is controlled by the fuzzy adaptive PID control heading control system, and the ship's The ship's motion trajectory is a curve.

2.6 Decision-making on Ship Collision Avoidance Action Plans

Assuming that this ship is an intelligent navigational collision avoidance ship travelling normally along inland waterways, the collision avoidance decision-making process of this ship is decomposed according to the "Inland Waterway Collision Avoidance Rules" and the requirements of good shopcraft.

Step 1: Determine if a collision hazard exists.

According to the target ship information collected by the ship sensor radar and AIS, etc., the ship collision danger judgement model is used to judge whether there is a collision danger for the two ship encounters. If there is no collision danger, the collision avoidance decision-making process is terminated; if there is collision danger, the collision avoidance decision-making process will be executed according to step 2.

Step 2: Determine whether the target ship is a special type of ship such as a project ship under navigation for construction or a sea-going ship limited to draught or a passenger ferry or a fast ship.

By means of the AIS static information data, it is possible to know whether the target ship is a project ship or a sea vessel limited to draught under navigation or a passenger ferry or a fast ship. If the target ship is a project ship under navigation or a sea vessel limited to draught, the ship is a give way ship and proceeds to step 7; if the target ship is a passenger ferry or a fast ship, the ship is a direct sailing ship and proceeds to step 7; if the target ship and the ship are motorized ships of the same type, proceeds to step 3.

Step 3: Determine whether the target vessel is a transiting vessel.

Determine whether the target vessel is a transiting vessel according to the inland waterway vessel encounter situation recognition model, if so, the vessel is a straight vessel and proceed to step 7; if not, proceed to step 4.

Step 4: Determine whether the vessel and the target vessel are the same as a counter-current or down-current vessel or an up- or down-current vessel.

According to the classification of vessels, in tide-sensitive river sections, it is determined whether the vessel and the target vessel are counter-current vessels or downstream vessels; in non-tide-sensitive river sections, it is determined whether the vessel and the target vessel are upstream vessels or downstream vessels. From this, determine whether the vessel and the target vessel are the same as counter-current or down-current vessel or upward or downward vessel. If different, go to step 5; if the same, go to step 6.

Step 5: Determine whether the meeting situation between the two ships is a head-on encounter or a cross-over encounter.

According to the inland waterway vessel encounter situation identification model, judge whether the two vessels are sailing opposite to each other, if yes, the counter-current vessel or the upstream vessel is the give way vessel, and go to step 7. unless the situation is special, all vessels should change to the right direction to avoid the encounter; if necessary, avoid meeting the vessel in the curved or narrow section, and the give way vessel should wait for the other vessel to pass underneath the above section. If not, the two vessels are to meet each other in a crossroads, and the upstream or upstream vessel is to be the giving way vessel, proceeding to step 7.

Step 6: Determine whether the two vessels are in a pursuit or cross-encounter situation.

According to the inland waterway vessel encounter situation identification model, first judge whether the two vessels are pursuing each other, if yes, the pursuing vessel is a give way vessel, go to step 7, and stop pursuing each other in the curved, narrow, and dangerous section of the navigation section, as well as in bridges, locks, and pilotage ways, and other water areas. If not, the two ships are in a cross-encounter situation, the ship is on the port side of the target ship, the ship is a give way ship, enter step 7.

Step 7: The giving way vessel takes feasible avoidance action in accordance with the rules, while the direct vessel shall take care to verify the validity of the giving way vessel's action and take reasonable and effective action to assist in the avoidance in accordance with the prevailing water environment.

There are three main avoidance methods available to ships: steering alone, speed change alone, and a combination of steering and speed change. In nautical practice, steering is the most used way of avoidance by ship drivers, and only when steering alone cannot avoid the target ship effectively, will they adopt the way of avoidance by changing speed alone or the combination of steering and changing speed. In inland waters, due to the limited maneuverability, the ship needs to be ready to sail, to keep the ship's speed adjustable at any time, the speed gears are as follows: (1) Forward: full speed forward (Full), half speed forward (Half), slow speed forward (Slow), micro-speed forward (Dead Slow); (2) Stop (Stop Engine); (3) Backward: full speed reverse (Full), half-speed reverse (Half), Slow speed backward (Slow), Slight speed backward (Dead Slow).

When the vessel is a give way vessel, according to the avoidance principles and vessel collision avoidance mechanism stipulated in the Inland Waterway Collision Avoidance Rules, find out the effective avoidance action plan under the constraints of the channel boundary, including the angle of redirection and speed gear, and give priority to the avoidance action plan based on steering alone.

When this vessel is a straight-ahead vessel, it shall observe the actions of the giving way vessel, verify the validity of the avoidance action, and calculate the probable passing distance between the two vessels. If, at the latest point in time acceptable to the vessel, the giving way vessel does not take evasive action or the evasive action taken does not enable the safe passage of the two vessels, the vessel will determine an effective evasive action programmed based on the current movement situation and take evasive action in a timely manner.

3. Conclusion

Based on the initial motion data of the vessel and the other vessel, judge whether the vessel is a straight vessel or a give way vessel in the encounter in accordance with the provisions of the Inland Waterways Collision Avoidance Rules. If the ship is a straight ship and the other ship has taken actions that can ensure effective avoidance, the ship will keep the course and speed unchanged; if the ship is a give way ship, or if the ship is a straight ship and the other ship has not taken effective avoidance actions, then the ship needs to take the ship's effective avoidance action plan.

The decision-making process of intelligent navigation collision avoidance for typical inland waterway ships is the process of using machines to replace ship drivers in decision-making based on summarizing the Inland Waterway Collision Avoidance Rules and good shopcraft. Specifically, the basic process of intelligent navigation and collision avoidance decision-making can be summarized into three stages: track keeping stage, collision avoidance stage and resumption stage. In the collision avoidance stage, when a ship takes effective avoidance action in accordance with the rules to avoid collision, it usually causes the ship to deviate from the planned route. The tasks of the track keeping stage and the resumption stage are mainly to make the ship travel in accordance with the planned route.

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