Research on Unmanned Ship Control System Based on Fuzzy PID

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Abstract. Unmanned ship is one of the typical representatives of unmanned intelligent equipment on water, which has been highly concerned by scholars all over the world. Since unmanned ship is unmanned in the process of surface operation, it must have the corresponding autonomous intelligence, which requires the stability of its autonomous control to be studied. This paper presents a control system of unmanned ship based on Fuzzy PID. The anti-jamming control system of unmanned ship is built. According to the power demand of unmanned ship control system, the hardware circuit is designed and the software code is written. Then the simulation experiment of the interference model in complex environment is carried out. Under the regulation of the control system, the unmanned ship can meet the requirements of fast response and high reliability.

Keywords: unmanned ship; fuzzy PID control; wind disturbance

1. Introductions

Unmanned ship is a kind of intelligent water surface motion platform which can complete autonomous operation. If the remote control system is added to it, it can replace manual to complete some complex tasks with high difficulty and high risk, so as to achieve the purpose of more efficient and safer. In practical application, the unmanned ship is just a carrier. In different occasions, it can carry different sensor equipment and control system to complete specific work[1]. For example, by installing various water quality sensors on unmanned ship, it can be used for water sample collection of lakes or reservoirs, or real-time reading of water quality data; carrying ultrasonic detector and infrared camera can be used for military reconnaissance or scientific investigation survey; carrying positioning device and life-saving equipment can be used for maritime rescue, etc.

Of course, no matter what purpose it is used for, the unmanned ship must have stable and reliable navigation ability. However, a large number of experiments and practices show that the motion process of unmanned ship, especially small unmanned ship, has obvious nonlinear and large steering inertia. At the same time, it is easy to deviate from the established course due to the interference of wind. The changeable application scenarios also challenge the anti-interference ability of unmanned ship. The traditional control technology has been difficult to meet the requirements of small unmanned ship tracking in complex environment, so it is necessary to use the control technology with higher precision and stronger anti-interference ability to control the unmanned ship.
2. hardware structure of unmanned ship

The main structure of the unmanned ship used in this paper is a catamaran. The middle part of the hull is a pod. The pod is not lower than the hull part. There are a small hole in the front and rear of the UAV, which can introduce the water flow to the receiving window of the water quality sensor. A peristaltic pump is installed on the left and right sides of the bow. After the pump is driven, the water will be pumped through the suction pipe at the bottom of the bow, and the water flow will enter the pipeline inside the ship, and the water flow will be measured by the flowmeter. A set of high-definition camera system is installed in the bow position, and the real-time image can be monitored in the upper computer. Ultrasonic detectors are installed on both sides of the bow, which can quickly detect the obstacles on the water surface, so that the unmanned ship can make timely obstacle avoidance action. The cabin is equipped with a detachable baffle plate, which is equipped with the master switch of the unmanned ship, the waterproof charging port of the unmanned ship and the sealing socket of the water quality sensor. Two motors are fixed at the stern, and two waterproof antennas are installed on the top of the stern, which are used for communication between the unmanned ship and the shore based control box or the upper computer of the unmanned ship. There are battery control switch, lithium battery pack and control box inside the cabin. This paper focuses on the control system is installed in this control box.

From the functional structure, the unmanned ship system is composed of hull, intelligent controller, sensor, motion control module and communication module. As shown in Fig. 1.

In the unmanned ship system, the intelligent controller, as the central processing core, receives the data information uploaded by the communication module and each sensor at the same time, and then processes according to the predetermined algorithm, and the processing results are sent to the motion control module and the communication module. The motion control module of unmanned ship is divided into automatic navigation module and manual control remote control module. The control module can control the speed of unmanned ship motor by changing the output voltage of motor. The two motors operate at the same time, and the unmanned ship can move forward, turn and retreat through the motor differential speed. It is not difficult to find that the speed control of the unmanned ship motor directly determines the trajectory of the unmanned ship, so the speed control of the unmanned ship becomes one of the research focuses of this paper, which lays the foundation for the navigation attitude control and route tracking control of the unmanned ship.
3. Conventional pid control principle

PID control is generally composed of three units, which are proportion (P) unit, integral (I) unit and differential (D) unit. The traditional PID controller can realize simple control, and its structure is easy to realize, and it is enough to deal with ordinary linear control scenarios.

The change of the proportional coefficient $K_p$ can greatly reduce the response time of the system. The process of proportional regulation can be understood as reducing the control system's $K_p$ by doubling the speed, and even eliminate the error directly under ideal conditions. When the $K_p$ value is small, the correction is not in place, and the correction speed is slow. For the system with high real-time requirements, the control error may occur. When $K_p$ is large, the phenomenon of excessive correction control will appear, that is, in the zero error position, due to the error caused by small disturbance, under the large $K_p$ value, the system will also make large output control, and the system will jitter at the balance position with low frequency. Such control effect is not what we want.

The adjustment function of the integral coefficient $K_i$ is based on the accumulation of errors in time. As long as there is an error, the integral adjustment will continue until there is no error, and the integral adjustment will not stop. However, if the integral coefficient is too large, the system will take control action because of a small deviation, which is likely to cause the system to oversaturate, resulting in overshoot, and the time for the system to reach steady state becomes longer. If the integral coefficient is too small, it will take longer time for the system to reach the stable state, which will affect the dynamic performance.

The function of the differential coefficient $K_d$ is to change the change speed of the deviation signal, which mainly affects the dynamic characteristics of the system. If the change rate of the system error increases, it is equivalent to telling the system in advance that it should not increase any more, and the error should be restrained in advance as soon as possible. The rapid response of the system can be increased by means of differential. On the other hand, differential regulation is equivalent to adding damping motion. Damping motion can make the oscillating system attenuate rapidly, so as to suppress overshoot, improve dynamic performance and suppress external disturbance. However, with the increase of differential link, the output gain will also increase. If the measured data has noise, the differential link will be very sensitive to noise. The control law of PID can be expressed as $r(t)$, $y(t)$ and $e(t)$ respectively[2].

$$U(kT) = K_p e(kT) + K_i \sum e(jT) + K_d [e(kT) - e(kT - T)]$$

Where $K_p$, $K_i$ and $K_d$ are the proportional coefficient, integral coefficient and differential coefficient respectively.

Proportional, integral and differential parameters have different control tasks in different stages, which restrict each other and support each other. Therefore, the proper selection of PID parameters will affect the whole control system. Therefore, the value of PID parameters becomes the key factor to maintain the stability of the system, improve the accuracy and response speed of the system. The dual motor unmanned ship is a complex nonlinear system. There are many control factors that affect the motion of the unmanned ship. One feasible scheme is to decompose the control task of the unmanned ship into keeping in place, moving forward and backward, turning left and right. We can divide it into the following three basic control tasks: (1) keeping in position control, that is, controlling the unmanned ship to keep still or moving on the water surface State balance; (2) speed control, that is to control the forward and backward speed of unmanned ship; (3) steering control, that is, to achieve the steering effect by controlling the differential speed of two motors.

4. Principle of fuzzy pid controller

It is difficult to maintain the linearity of the motion attitude control system of the unmanned catamaran under disturbance. The principle of fuzzy control belongs to intelligent control for the nonlinear...
control of the system. In practical application, expert experience is often used to guide the systematic theoretical construction. In the actual operation, manual operators can deal with various uncertainties that may be encountered in navigation with their own experience, but this experience cannot be directly used as an algorithm[3]. The fuzzy control method and the traditional PID controller constitute the fuzzy PID controller. By tuning the input and output parameters of the controller, this is what this paper needs to do.

In addition, compared with the traditional PID control, the self-tuning fuzzy PID control method has the advantages of on-line adaptive function, and can output more accurate results by combining the experience of manual operation and PID control algorithm. Therefore, in order to solve the problem of yawing that may be encountered in the navigation process of unmanned ship, a parameter self-tuning fuzzy PID controller is designed and implemented for the dual motor speed control system of unmanned ship. Even if the precise mathematical model of the motor is not known, the fuzzy technology can be used and the system is simple and effective.

Since the self-tuning fuzzy PID controller is designed to improve the control performance generated by the PID controller, it keeps the simple structure of the PID controller and does not need to modify any hardware part of the original control system. In order to make the system stable, the system can be divided into three levels by using the fuzzy control method. By continuously changing the parameters, the system performance is gradually optimized to make the system adapt to the changes of nonlinear environment with robustness[4]. The principle of self-tuning fuzzy PID control is shown in Fig. 2.

In Fig. 3, r is the set value of the real-time acquisition system; y is the output of the real-time acquisition system; e and ec get the set of fuzzy output through fuzzy rules, and the output is obtained by deblurring, that is, the adjustment amount of each parameter. After tuning with the initial PID parameters, the new PID parameters are obtained.

\[
\begin{align*}
K_p &= \Delta K_p + K_p0 \\
K_i &= \Delta K_i + K_i0 \\
K_d &= \Delta K_d + K_d0
\end{align*}
\]

(2)

![Flow chart of parameter self-tuning fuzzy PID](image-url)
5. Mathematical model of unmanned ship

When unmanned ship works in lake or sea area, the influence of wind will cause unmanned ship to deviate from the course or the preset path. However, the traditional PID control method used by unmanned ship is difficult to play a role in wind and wave environment. Therefore, in ship maneuvering, in addition to the control force of the hull itself, the external force of wind interference on the hull should also be considered. It is of theoretical significance and practical value to study the maneuverability of ships under wind disturbance.

The simulation of UAV course keeping control can truly reflect the navigation situation of unmanned ship on water after wind disturbance. In the design process of ship course control system, linear Nomoto model is generally used[5]. This model can describe the navigation attitude of unmanned ship under course keeping. The formula is as follows:

$$ G(s) = \frac{K}{s(Ts + 1)} $$

Among them, K is the turning index of the unmanned ship, and t is the tracking index of the unmanned ship. These two performance indexes can be measured by turning simulation experiment and Z-type simulation experiment. By setting the length, width, speed, rudder angle and the selected experimental type in the model software, the performance index of the unmanned ship can be calculated.

6. Mathematical model of wind disturbance

Wind interference can be divided into mean wind interference and fluctuating wind interference. Fluctuating wind interference is produced by atmospheric turbulence, and the influence is small. The average wind can be generally equivalent to white noise. The following describes the main ideas of modeling the average wind.

In order to establish the model of unmanned ship disturbed by mean wind, it is necessary to establish a coordinate system. Generally, two different coordinate systems are used in the study of ship motion, which are appendage coordinate system and inertial coordinate system. The attached body coordinate system takes the center point of unmanned ship as the origin, the bow direction is x axis, the starboard side of the ship is Y axis (rotate 90° clockwise along the X axis), and the Z axis is from the ground to the center of the earth. The X axis of the inertial coordinate system points to the north, the Y axis points to the due east, and the Z axis points to the geocentric.

In order to establish the representation of wind disturbance in the coordinate system, now we define the absolute wind vector direction as the positive X-axis direction, and then calculate the vector difference between the absolute wind speed and the absolute velocity, and then measure the angle between the wind vector and the true north direction by the gyroscope in real time, and obtain the wind speed expression. Assuming that the wind speed of unmanned ship is uniform and constant in all directions, the mathematical expressions of wind pressure and wind pressure moment can be obtained according to trigonometric function. Through the regression equation formula of wind pressure coefficient and wind pressure formula, as well as the measured absolute wind speed and ship speed,
we can calculate the wind side angle we need.

7. Fuzzy pid controller
Route tracking control is to decompose the navigation control of unmanned ship into two modules: course keeping module and automatic navigation module. In other words, the angle control and speed control of the unmanned ship are carried out by acquiring the sensor information and the instructions issued by the upper computer. The angle control is to achieve a stable course control effect, and the goal of speed control is to continuously reduce the position deviation between the next target point and the current real-time position, and adjust the speed before reaching the target point to prevent the unmanned ship from exceeding the target point. The essence of route tracking control is to decompose the complex navigation control process of unmanned aerial vehicle into fuzzy PID control with two closed loops. On the one hand, it can simplify the control logic, and more importantly, it can not only keep the unmanned ship in a straight line, but also maintain the course stability, and timely correct the deviation angle in the navigation process ensure the reliability and adaptability of unmanned ship navigation. As shown in Fig. 4.

The control system consists of two control units: angle control and speed control. When modeling the angle control of unmanned ship, the angle difference between the bow direction of unmanned ship and the next target point of unmanned ship should be calculated. Take this difference as the input value of the system. The difference calculation mainly obtains the heading information through the 6-axis gyroscope on the unmanned ship, and calculates the deviation of the heading angle by the system to get the output of the angle control system.

![Fig 4. Schematic diagram of fuzzy PID navigation control](image)

The input of the speed control loop is the GPS reference information of the target point, the real-time position information of the unmanned ship and the motor speed of the unmanned ship sent by the upper computer. The position deviation between the starting point and the end point is obtained by real-time calculation, and the speed change of the unmanned ship is obtained by setting up the control relationship between the position deviation and the speed of the unmanned ship.

8. Experimental analysis
The traditional PID control algorithm is used to obtain KP, Ki and KD parameters through experimental measurement. During the simulation, the unmanned ship is set to move forward to the north, and the traditional PID control and parameter self-tuning fuzzy PID control are used as the controller of the unmanned ship. According to the previous wind disturbance model, when the wind speed is 4 meters per second, the Kp of the traditional PID controller is 1.4, Ki is 0, Kd is 1.3.

In order to control the two systems have the same initial value and observe the simulation results conveniently, the Kp, Ki, Kd values of the traditional PID controller are taken as the initial values of the self-tuning fuzzy PID controller, and the simulation experiment is carried out. As shown in Fig. 5. And Tab. 1.

It can be seen from Tab. 1 that the performance of the self-tuning fuzzy PID controller is obviously better than that of the traditional PID controller in the case of wind interference, and it can better realize the tracking of unmanned ship steering angle more stable.
Fig 5. Simulation diagram of two systems with wind disturbance

Tab 1. Performance of two systems with wind disturbance

| Controller       | Response time(s) |
|------------------|------------------|
| Traditional PID  | 19               |
| Fuzzy PID        | 14               |

Compared with the output results of self-tuning fuzzy PID control system and PID control system, it can be observed that the steering control of self-tuning fuzzy PID control system is more accurate. Compared with the traditional PID controller, the self-tuning fuzzy PID control system has smaller vibration and faster response speed. It can keep the unmanned ship stable when steering at a large steering angle, and can still control the course when there is wind interference Accurate and reliable.

9. Conclusions
Based on the microcontroller platform, the fuzzy self-tuning PID controller is designed, and the wind disturbance model is established. The navigation control problem of unmanned ship is solved from angle control and speed control. In this paper, the wind disturbance model is established. According to the wind vector direction and wind speed as well as the data of unmanned ship, the wind interference is converted into rudder angle interference of unmanned ship, which lays a foundation for the study of the control performance of the controller. The control principle of traditional PID controller and parameter self-tuning fuzzy PID controller is analyzed, and the route tracking controller based on PID control algorithm is designed. The performance of the two controllers is compared under wind disturbance. In this paper, the research of parameter self-tuning fuzzy PID controller can basically meet the actual requirements of unmanned ship navigation, and has a certain reference value for the research of unmanned ship motion control.

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