Intelligent Aquaculture Monitoring and Automatic Feeding Cruise System Based on STM32

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Abstract: *There are some problems with traditional aquaculture, such as low efficiency of manual operation, late-stage water quality control, high labour costs, etc. Therefore, this paper presents an intelligent aquaculture monitoring and automatic feeding cruise system based on STM32. STM32F103 will be employed to control the Temperature and Humidity Sensor, pH Sensor, Dissolved Oxygen Sensor, Turbidity Sensor, Bluetooth Module, Motor Driver and Steering Gear Feeding Unit in this system. Application of PID Algorithm for Optimisation of Path Holding and Bluetooth Remote Control. According to the above test results, all the data for water quality, timed quantitative feeding and preset-path autonomous cruising are stable. Reduce the labour and operating costs of small and medium-sized aquaculture farms by means of economic and intelligent systems.*

Key words: *STM32, Aquaculture, Water Quality Monitoring, Intelligent Feeding, PID Control*

Introduction

As a necessary part of modern agriculture, the scale and output of the aquaculture industry have been continuously expanding, and now it is one of the important drivers for promoting rural industrial restructuring and raising farmers' incomes[1]. Most aquaculture enterprises in China are still using the old system of manual observation and experience-based management; thus, there are problems such as high labour costs, late detection of water quality problems, inaccurate feeding control and weak environmental regulation that hinder the development of intensive and ecological aquaculture[2-3]. With the rapid development of the Internet of Things and embedded systems and intelligent control technology, it has been widely accepted in the industry that aquaculture equipment should be upgraded to be intelligent, automatic and mobile[4].

In recent years, scholars at home and abroad have conducted many studies on the intelligent monitoring and control of aquaculture, and have developed a number of water quality monitoring systems and intelligent feeding devices that have achieved the basic functions of data collection, remote transmission and abnormal alarms[5-6]. Most of the current equipment is a fixed monitoring device or a single-function feeding device; there are very few integrated devices that can combine many parameters of water quality monitoring, automatic cruise mobility and accurate quantitative feeding, and thus they generally have problems of single functionality, lack of adaptability and limited control accuracy[7-8]. To solve the above problems, this paper proposes the Design of an intelligent aquaculture monitoring and automatic feeding cruise system based on STM32 that integrates modules for collecting all kinds of sensor data, fuzzy-adaptive PID control, Bluetooth wireless communication and automatic feeding execution; it can monitor all areas of water quality, autonomously cruise along a path, perform time-controlled precise feeding, etc., providing an economical and reliable intelligent solution for small and medium-sized aquaculture farms[10].

1. General System Design

The four parts of the whole are the perception stage, the control stage, the execution stage and the application stage, and they form modules. The whole shape of the system is as follows: Figure 1.

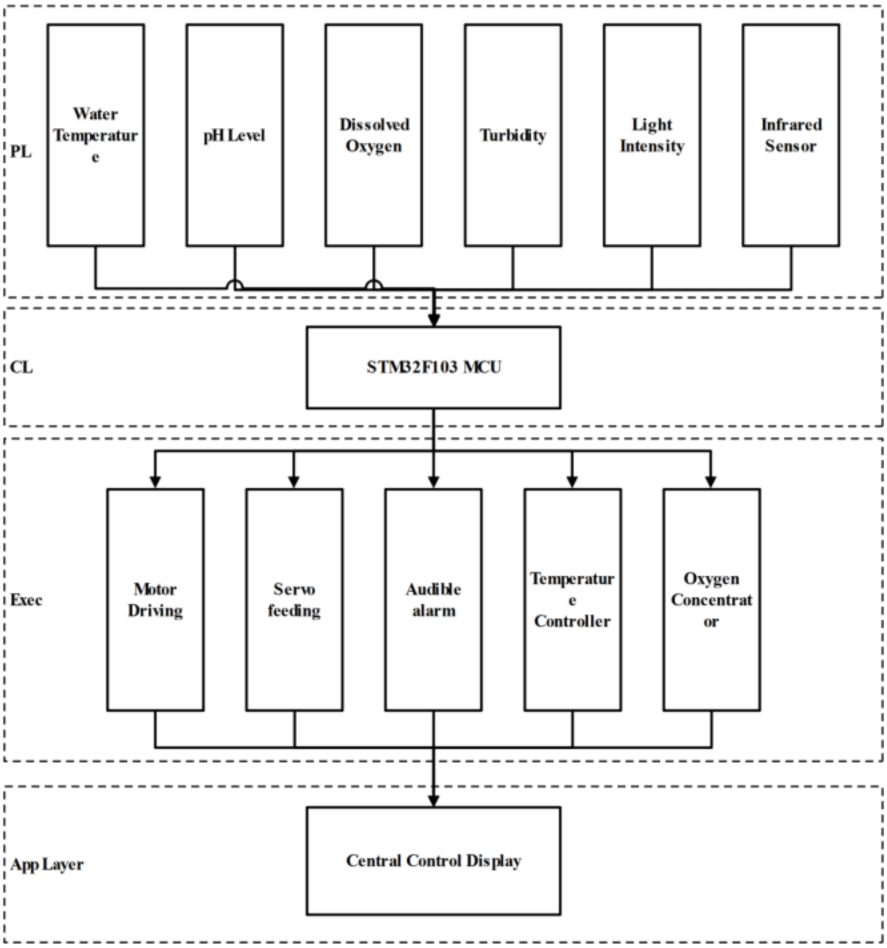

Figure 1. Block diagram of the overall system structure.

Perception Layer: At different times, collect environmental data in the fish pond, such as water temperature and pH, dissolved oxygen concentration, turbidity, light intensity, etc., automatically obtain signals from infrared sensors, and collect these signals. All the sensor data are in the control layer, and they are communicated through IO ports or ADC interfaces.

Control Layer: The main chip of the Control Layer in this system is STM32F103; it reads the data obtained by the Perception Layer, applies the PID cruise control algorithm, determines whether the water quality exceeds the upper and lower thresholds, and sends control commands according to the logic in this section. At the same time, the mobile APP can also be connected to it by Bluetooth.

Execution Layer: The L298N motor driver module and DC geared motors will be used to drive and move the wheels; Servos will be employed for the operation of the spray-feeding device, and if there is any abnormality, an audible and visual alarm will be issued. The other devices that will be employed are relay-controlled thermostats and oxygen generators.

Application Layer: Remote commands (such as start/stop, feeding, parameter modification) and received data (real-time water quality data display) can be sent and received through the Bluetooth Serial Assistant APP. At the same time, an OLED screen will also be displayed in the car.

2. System Hardware Design

Many of the levels in the System Hardware are modular, well-organised and have good anti-interference characteristics. The six modules of the main control unit are Power Supply, Perception, Motion, Feeding, Communication and Display. All the units have the same standard interface, so they can be arranged in a small and tidy way and work stably; they can also be used in the humid, wet and electromagnetically noisy environment of aquaculture. The model is as follows: Figure 2.

2.1 Main Control and Power Supply Module

STM32F103 is a strong microcomputer based on ARM Cortex-M3, and it will be the main control unit. The normal working voltage is 3.3 V. There are a few general-purpose I/O ports, some high-precision ADCs, many multi-purpose general timers, and all kinds of UART, I2C and RS485 communication interfaces on the chip. There are many rich resources and many tasks that can be done at the same time, such as collecting multi-sensor data, closed-loop motor control, adjusting servo angles, transmitting Bluetooth data, updating the OLED display, etc. It has the advantages of high computation speed, low power consumption and good stability, so it meets the control demands of mobile intelligent aquaculture equipment[10].

An efficient LM2596 DC-DC step-down converter is used to regulate the power supply; that is to say, it will reduce the 7V input DC voltage to 24V and provide a stable 5V/3A output, which will then be distributed to all components in the system, such as the main control chip, water quality sensors, servos, Bluetooth modules, displays, etc. Modules have overcurrent protection, overvoltage protection, short-circuit protection, voltage regulation output functions, etc., so problems of insufficient power supply, voltage fluctuations and noise interference that may occur when multiple modules work together can be solved. With the addition of a second linear voltage regulator circuit, 3.3V will be supplied to the separate power supply of the digital and analog circuits, and thus the overall stability and accuracy of the system for data acquisition will be improved[11].

2.2 Environment Perception Module

The two tasks of the environment perception module are to gather information about the water environment and to know the position and movement of the vehicle. It has a water quality detection unit and a cruise position unit, and it can be used to monitor the water intelligently and drive automatically.

At the same time, some indicators of water quality are also collected together. High-precision thermistor-type sensor with a measurement range of 0-80 °C and a measurement error of $\leq \pm 0.5$ °C is used to obtain the temperature of the water in the aquaculture tank; it is stable in the environment of aquaculture water and has a long service life. Both the pH sensor and the dissolved oxygen sensor are industrial-grade digital probes that communicate with the main control chip via the RS485 bus; they have a long transmission distance, good immunity to interference, and can obtain real-time data on the acidity/alkalinity and dissolved oxygen concentration of water. An increase in the turbidity of the water will change the output voltage of the turbidity sensor. Filter and process the data obtained from the four kinds of sensors in the main control unit to determine the water quality and adjust the aquaculture environment[2, 7].

A module to detect the speed of the car in the slow-speed range will be placed near the bottom of the car. To find the preset black guide path on the ground in real time and promptly notice any side displacement of the vehicle from this path, it is used. At the same time, a deviation signal is used to continuously and steadily change the controller, and thus an error signal is given to the fuzzy PID algorithm to keep the car on the desired path smoothly[12-13].

2.3 Motion Control and Feeding Execution Module

L298N High-Power Motor Driver Module is employed as the Motion Control Unit to obtain PWM speed and direction signals from the main control chip and drive the two DC geared motors according to optical encoder feedback. A closed-loop speed control scheme is employed; that is, at any given time, the PID algorithm will calculate and adjust the PWM duty cycle to regulate the speed of the vehicle accurately, and it can also change the path of the vehicle dynamically; thus, the vehicle will drive stably and follow the desired road correctly, improving the reliability and precision of automatic cruising[13].

A High-Precision Micro-Servo is employed as the feeding actuator for the Special Spray-Type Feeder. The main control chip of STM32 produces a programmable PWM signal to set the position of the servo in the range of 0° to 180°. Change the rotation angle and action time of the servo to achieve an even distribution of the feed. First of all, we want to increase the feeding area and avoid problems such as fish aggregation, local oxygen depletion, and feed residue and waste caused by traditional fixed-point feeding; thus, we will improve feed utilisation efficiency and enhance the water environment of the aquaculture area[5-6].

2.4 Wireless Communication and Display Module

BT04 Bluetooth Serial Module will be employed for wireless transmission, and it will be linked to the main control unit via UART. Set the communication baud rate to 9600 bps so that it can be reliably communicated with the mobile APP. At any time, the module can send water quality data (such as water temperature, pH value and dissolved oxygen) and operating status via uplink, and on downlink, all kinds of remote control commands for all functions can be received, such as starting and stopping cruising, manual feeding, changing parameter thresholds, etc., to meet the short-range wireless control requirements of aquaculture farms[10].

The small display unit is an OLED that communicates via the I²C bus, has a resolution of 128x64, is relatively low power, has good contrast and a wide viewing angle. Update the screen in real time to display the current temperature, pH value, dissolved oxygen, time, cruise mode and feeding status, etc., so that it will be more convenient for staff to carry out on-site debugging, observation and operation, and improve the overall usability.

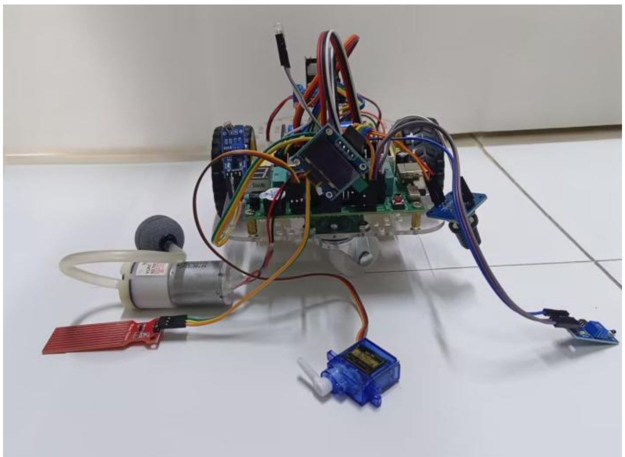

Figure 2. Model display diagram

3. System Software Design

3.1 Main Program Flow

After power-on reset, the system will sequentially carry out clock configuration, GPIO port setup, ADC acquisition setup, timer setup, UART serial port setup and I2C communication setup; then it will load the default configuration parameters, such as feeding time, water quality thresholds and control parameters, and finally start normal operation. After completing the system start-up self-test, it will enter the main loop for operation.

Periodically, several operations are carried out in the main loop, such as collecting data from the water quality sensor and digitally filtering this data every 100ms, and updating the displayed information on the OLED every 200ms. At the same time, it can also detect important situations in real time, compare them with the feeding schedule, run the automatic cruise control algorithm, parse and execute Bluetooth remote commands, etc., to ensure the coordinated and stable operation of all functions. It can quickly find problems in an early stage, and if any of the water quality parameters exceed the standard, or if there is a sensor failure or other operation problem, it will immediately issue an alarm and take corrective actions to protect the lives of aquatic animals. The structure of the main program is as follows: Figure 3.

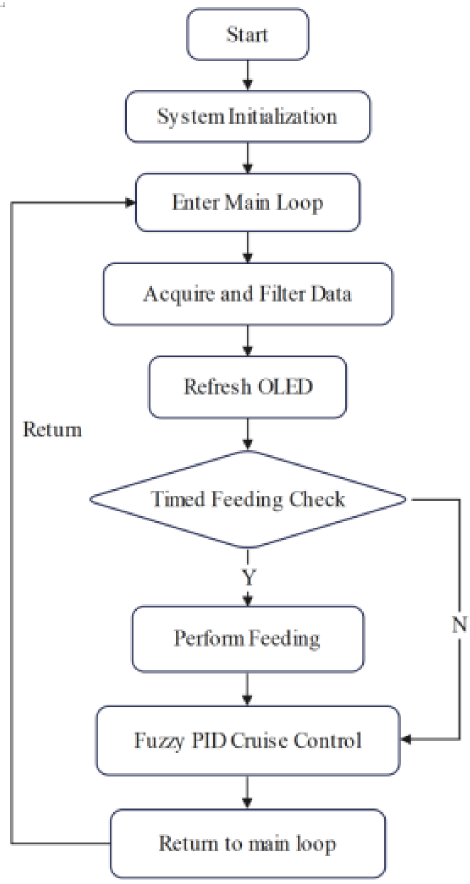

Figure 3. Flowchart of the main program

3.2 Sensor Data Collection and Processing

The two kinds of sensors are either analogue or digital, and they can be obtained. Get the signal from the water quality sensor at the ADC interface and serial port in real time. To reduce the fluctuations in the data caused by on-site electromagnetic interference, changes in water bodies, device noise, etc., and improve the stability of monitoring, a moving average filter algorithm is employed to smooth consecutive groups of raw sampled data and eliminate random noise[11].

Digital sensors that are in the form of pH or dissolved oxygen and use the RS485 interface are communicated with via the Modbus-RTU protocol. Periodically send a query frame from the main controller, and then verify that all the data received from the sensor has been transmitted correctly and without error by checking the CRC. Then, it reads the valid data bits and converts them into the unit of the actual physical quantity. For analogue output sensors, such as temperature and turbidity sensors, a multi-channel ADC is used to obtain a voltage signal, and then this voltage is converted into the corresponding engineering quantity for water quality assessment and abnormality detection according to the calibration formula. The Multi-Parameter Monitoring Circuit is as follows: Figure 4[8]..

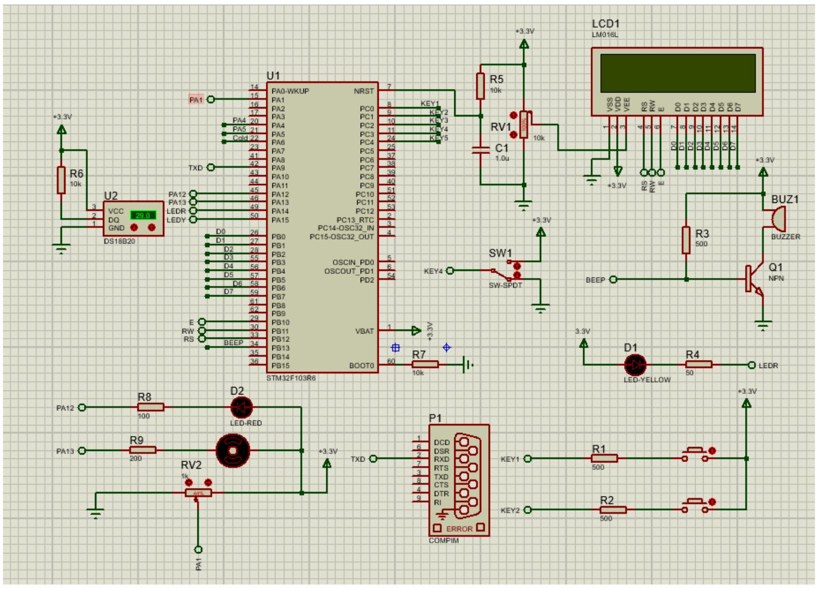

Figure 4. Multi-parameter monitoring circuit diagram

3.3 Fuzzy Adaptive PID Control Algorithm for Automatic Cruising

Fuzzy logic rules are used to modify the dynamic parameters of a traditional positional PID controller so that the model can move smoothly and accurately along the set path; in actual operation, there are often problems such as uneven ground and frequent disturbances in fish ponds, but the developed fuzzy adaptive PID controller can deal with them effectively and thus has achieved good results in both the accuracy of path tracking and driving stability.

The two inputs to the control system are the path deviation signal e(t) and the deviation change rate ec(t) obtained from the infrared tracking sensor, and the output is the differential control amount u(t) of the left and right motors. Path deviation here refers to the lateral offset of the model's centre at the current time from the pre-set path, and the rate of change of deviation shows both the direction and the speed of change in deviation. The Discretisation Calculation Formula is as follows:

$$e_c(t) = \frac{e(t) - e(t-1)}{T} \tag{1}$$

Equation (1) is: e(t-1) is the path deviation of the previous sampling period, and T is the system control period, which has been set to 100 ms in this system.

The system is a Positional PID discrete-time control algorithm, and the main formula is as follows:

$$\mathrm{u}(t) = K_p e(t) + K_i \sum_{j=0}^{t} e(j) + K_d [e(t) - e(t-1)] \tag{2}$$

Kp, Ki, and Kd are the proportional, integral and differential coefficients in Equation (2).

The seven fuzzy subsets of the input quantity are {NB, NM, NS, ZO, PS, PM, PB}, and a complete fuzzy rule base of 49 rules has been established for the tracking control method in the fuzzy control stage. Mamdani inference and centre-of-gravity defuzzification are employed to vary the three parameters Kp, Ki and Kd in time. If the deviation is too large, increase the proportional coefficient of the fast correction; if the rate of change of the deviation is too high, strengthen the derivative term to avoid oscillation; near the steady state, adjust the integral coefficient to eliminate steady-state error, and thus the model can quickly centre on a straight road, turn smoothly at a curve, and rapidly suppress disturbances caused by bumpy roads. Engineering tuning and fuzzy rule optimisation have been used to increase the tracking speed of the model, reduce overshoot, improve stability, and meet all the path-cruising requirements of aquaculture[12-13].

4. Test and Result Analysis

4.1 Test Environment and Scheme

A constant-temperature and constant-humidity laboratory were used for the test, and the temperature was 25 ± 1 ° C and the relative humidity was 60 ± 5%, to avoid the influence of the environment on the test results. The test equipment are as follows: Design device, High-precision water quality calibrator (accuracy class 0.01), Infrared tracking path simulation board, DC-regulated power supply and data acquisition recorder.

The test plan will meet the demands of the laboratory test for embedded intelligent equipment and be based on the combination of fixed-point calibration, repetitive tests and comparisons. Synchronous sampling comparison is used to verify the accuracy of water quality monitoring; that is, for each parameter, 10 consecutive sets of data are collected, and after excluding extreme values, the average is taken to find the absolute error between the measured values of this system and those of the standard instrument. A closed-loop test track in the shape of a fish pond has been built to simulate the path of automatic cruising, and both the conventional PID algorithm and the fuzzy adaptive PID algorithm put forward in this paper have been tested separately; the main performance indicators of 10 round trips have been collected to verify the control effects of the two algorithms.

4.2 Analysis of Water Quality Monitoring Results

The four main indicators of the aquaculture environment are water temperature, pH, dissolved oxygen and turbidity; thus, standard water samples were taken in the laboratory. At the same time, the reference instrument is a high-end water quality calibrator, and it was also measured. The test results are as follows: Table 1.

Table 1. Comparison of multi-parameter monitoring accuracy.

Parameters	Measured Value	Standard Instrument Value	Absolute Error	Allowable Error
Water Temp（°C）	24.3	24.1	0.2	±0.5
pH	7.8	7.6	0.2	±0.3
DO（mg/L）	5.2	5.0	0.2	±0.3
Turbidity（NTU）	12.5	12.0	0.5	±1.0

Based on the laboratory test data, the absolute measurement errors of the four main water quality parameters in this model are all much smaller than the permissible error range for regular monitoring of aquaculture, and there is no significant drift in the data. The Moving-Average Filter algorithm can reduce some of the fluctuations in the data caused by device noise and electromagnetic interference, meet the daily operation monitoring needs of small and medium-sized aquaculture farms, and it has been confirmed that the reliability of the water quality acquisition and processing module.

4.3 Analysis of Automatic Cruise Performance Results

A few typical driving situations on the closed-loop test track that imitate the path of a fish pond are straight roads and bends. At the same time, at the same speed and with the same initial parameters, both the traditional PID algorithm and the fuzzy adaptive PID algorithm in this paper were employed to conduct 10 closed-loop cruise tests. Collect the lateral deviation data of the path, and then plot the comparison curves of the control effect in MATLAB, as shown in Figure 5.

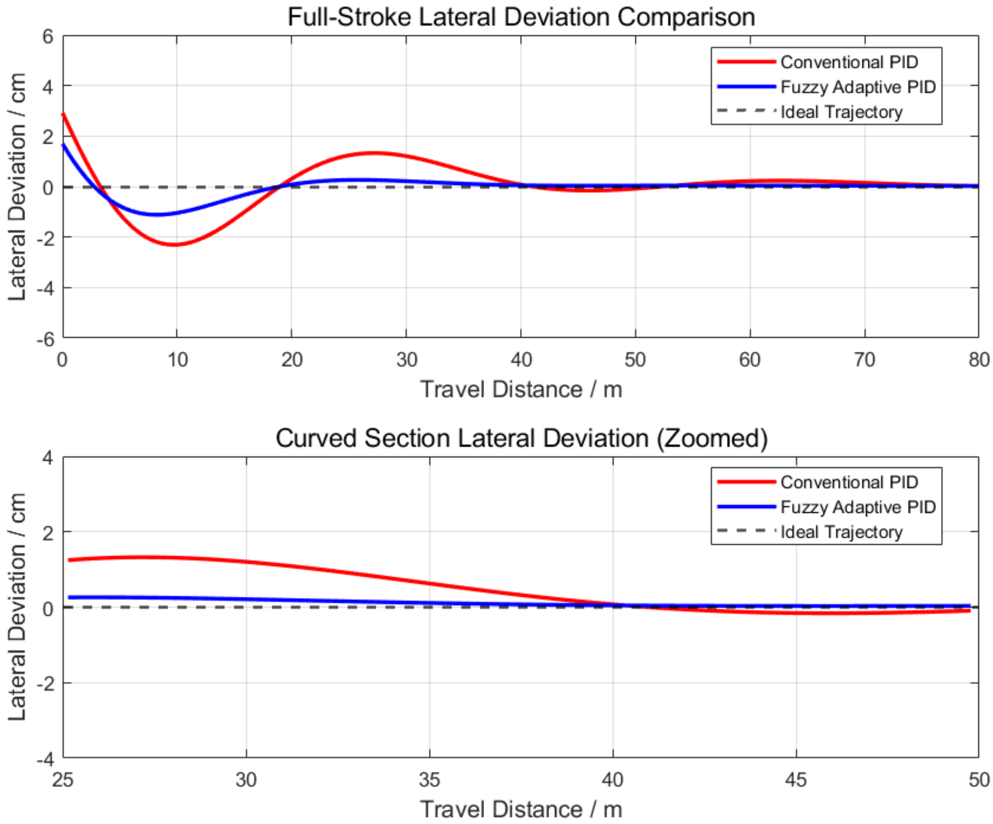

Figure 5. Comparison of control effects between traditional PID and fuzzy adaptive PID

According to the results of the cruise test, the traditional fixed-parameter PID algorithm has a small jitter in the model on a straight road, but at a curve, there is a relatively large path deviation; the maximum lateral deviation is 3.2cm and the average path deviation is 2.1cm; out of 10 tests, the tracking success rate was 90%, but there were some minor overshoot and deviation phenomena. At the same time, the fuzzy adaptive PID algorithm will also change the control parameters automatically according to changes in the actual position error and how quickly that error is changing. The model ran stably in the straight section, did not jitter, and at the bend, it corrected itself and turned smoothly. The largest side offset has been reduced to 1.8cm, the mean path error is now 1.1cm, and it has been continuously successful in the past 10 tests. Improvements have been made in the anti-disturbance ability, path-tracking accuracy and driving stability; therefore, it can be concluded that the fuzzy adaptive PID control algorithm is better and more reasonable[11].

5. Conclusion

The purpose of this paper is to solve the problems of low manual management efficiency in the industry, delayed water quality monitoring, inaccurate feeding, high labour costs, etc., and, in light of the actual needs of small and medium-sized aquaculture farms, a smart aquaculture monitoring and automatic feeding cruise system based on STM32 is designed and implemented. STM32F103 is the control core of this chip, and the five functions it can perform are multi-parameter water quality monitoring, fuzzy-adaptive PID automatic cruising, precise quantitative feeding, Bluetooth remote control, and abnormal alarm linkage. It is relatively small, reasonably priced, has a good modular structure, is not easily interfered with, and simple to use. Based on the above laboratory tests, the accuracy of the water quality monitoring by this device meets the requirements of the aquaculture industry, and the fuzzy adaptive PID algorithm can keep the robot on a stable and smooth path according to the preset path; thus, both of these basic goals have been achieved. Many of the daily operations of the facility, such as water quality tests, regular feeding and environmental monitoring, can be done manually to reduce labour costs and improve the efficiency and quality of management in aquaculture.

Mobile Cruising, Online Water Quality Monitoring and Intelligent Feeding are the three, and together they can solve the problems of single function, poor integration and lack of practicality in current aquaculture equipment. It has good innovative and practical promotion values, and can provide an inexpensive and reliable way to promote intelligent upgrading of small and medium-sized aquaculture farms in the Northwest China region.

Fund Projects

Automatic Cruise Vehicle Integrating Monitoring and Feeding for Aquaculture Based on STM32.

Project Number: 2025339.

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