Design and Implementation of Multifunctional Smart Fish Tank Control System based on Water Quality Management

Li Fei[1] and Suchada Sitjongsataporn[2]*
[1]The Electrical Engineering Graduate Program, Faculty of Engineering and Technology, Mahanakorn University of Technology, Bangkok, Thailand
[2]Department of Electronic Engineering, School of Electrical Engineering (SEE)
Faculty of Engineering and Technology, Mahanakorn University of Technology, Bangkok, Thailand

Abstract: This research presents the design and implementation of a multifunctional smart fish tank system based on ESP32, which solves the shortcomings of traditional fish tanks with the automation management, and emergency response. The objectives consist of three parts. First, to enhance the intelligence level of fish tank management through sensors and remote monitoring technology. Then, to develop mobile applications to enable users to monitor and control the fish tank environment in real-time system. Finally, the real time monitoring of water quality parameters are using sensors, collecting data through ESP32 and transmitting it to the Alibaba Cloud IoT platform. The system has the automatic water change system, replenishment, feeding, and constant temperature control functions, which is equipped with a backup power supply to ensure power outage endurance. Tests and results have shown that the proposed system can work stably and reliably, and all functions have achieved the research objectives, significantly improving the intelligence level of fish tank management.

***Index Terms*— Smart fish tank, ESP32 board, water quality management, Cloud IoT platform.**

I. Introduction

With the vigorous development of the economy and the significant improvement of national income levels, people's pursuit of quality of life is increasing day by day. Fish farming, a fun and elegant leisure activity, is quietly becoming the new favorite of many families. It not only adds a touch of vitality and greenery to the home space, but also provides a habitat for the soul amidst the busy pace of life, bringing tranquility and joy [1]. However, it is difficult for people to maintain the aquarium environment in conditions suitable for fish growth for a long time, especially when people go out to work or travel. Ensuring the stability of the aquarium environment has become a major challenge [2]. Recently, the authors in [3] have designed a smart fish tank system based on Internet of Things technology, which has functions such as water quality detection, automatic feeding, and temperature regulation, greatly improving the intelligence level of fish tanks [3]. Meanwhile, his team also proposed a design scheme for a smart fish tank aquaculture system based on STM32 microcontroller. This system combines sensor technology and automatic control technology, effectively improving the convenience of ornamental fish farming [4]. However, there is a common problem of limited functionality, with fish tanks dying due to power outages and lack of oxygen, which in turn limits the healthy growth of fish and the display of optimal viewing conditions, affecting the overall improvement of aquaculture efficiency and viewing experience. Given this, designing a multifunctional smart fish tank is particularly urgent and important.

This research aims to design and implement a multifunctional smart fish tank based on a microcontroller. The fish tank not only has basic functions such as water quality detection, temperature regulation, automatic feeding, and automatic oxygenation, but also can operate on the backup power supply during power outages, improving the stability and reliability of the system.

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*Corresponding author: Assoc. Prof. Dr. Suchada Sitjongsataporn, Department of Electronic Engineering, School of Electrical and Electronic Engineering (SEE), Bangkok, Thailand. (Email: ssuchada@mut.ac.th).

II. Objective and Research Methodology

A. *Objective of this study*

The research goal of smart fish tanks is to design and implement a multi-functional smart fish tank based on microcontrollers, in order to solve many problems in the use of traditional fish tanks and improve the scientific and convenience of fish farming. The specific research objectives are as follows:

1) Improve the intelligence level of fish tank management: integrate multiple sensors to monitor temperature, turbidity, and pH values in real-time, ensuring stable aquaculture conditions.

2) Implementation of automated operations: Design functions such as automatic water change, automatic replenishment, and automatic feeding.

3) Emergency response: Equipped with backup power supply to ensure that the fish tank is not affected in case of power outage or other situations.

4) Convenient remote monitoring: Develop mobile applications to achieve real-time viewing of data.

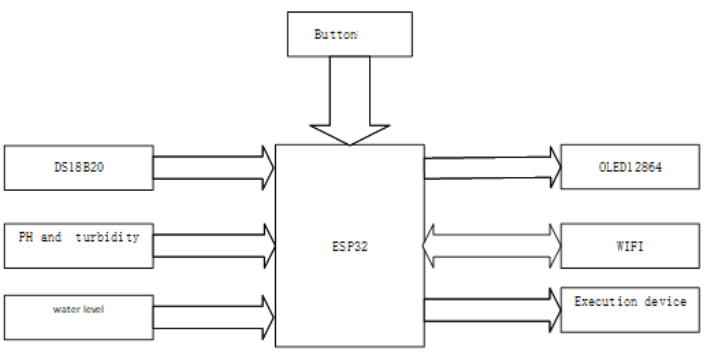


Figure 1 Block Diagram of Smart fish tank

B. Research Methodology

The research scope of smart fish tanks is to use ESP32 as the main control unit and OLED12864 as the auxiliary display device. It has functions such as temperature monitoring, water level measurement, automatic water change, automatic feeding, pH value detection, turbidity detection, backup power supply, WIFI networking, etc. Water level detection uses pressure sensors and connecting pipes, water temperature detection uses waterproof DS18B20, automatic water change is controlled by the main control of the inlet and outlet pumps, automatic feeding is controlled by the rotation of the deceleration motor.

pH detection uses pH electrodes and analog-to-digital conversion, turbidity detection uses an external turbidity sensor, uses a 12V lithium battery as a backup power source, uses ESP32's built-in WIFI function for networking, and uses Alibaba Cloud as a cloud server. The LCD display can display temperature, turbidity, water level, pH value information of the fish tank, and adjust the threshold and automatic feeding interval through buttons. WIFI can transmit information to the cloud and view current temperature, turbidity, water level, and pH information through mobile applications.

III. Hardware Design

The first step in building hardware modules for smart fish tanks is to select components with superior performance, high cost-effectiveness, and wide application. Next, plan the functional allocation of each pin to ensure that all connections are properly pre-arranged to avoid device failures caused by serial port conflicts. The quality of hardware design directly affects the user's intuitive experience, so it is not only necessary to ensure the normal operation of all components, but also to strive for a simple and clear design layout. Block diagram of smart fish tank is shown in Figure 1.

Figure 2 Transparency glass fish tank and size of 60cm*30cm*36cm

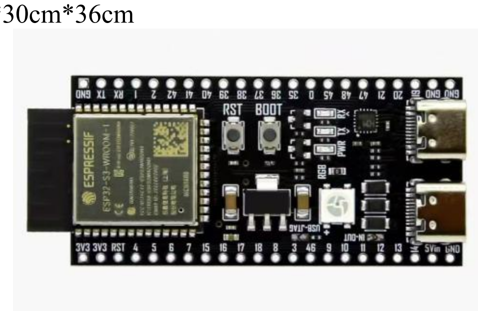


Figure 3 ESP32-S3-N16R8 [9]

This glass fish tank features an elegant rectangular design with dimensions of 60cm in length, 30cm in width, and 36cm in height shown in Figure 2, making it ideal for placement in indoor environments such as homes or offices for viewing purposes.

A. Microcontroller ESP32-S3-N16R8

The ESP32-S3-N16R8 is used as the main control system of smart fish tank. This module is manufactured in China uses the ESP32-S3 chip, equipped with 16MB FLASH and 8MB SRAM. ESP32-S3 integrates 2.4GHz Wi Fi (802.11b/g/n) and supports 40MHz bandwidth; Its low-power Bluetooth subsystem supports Bluetooth 5 (LE) and Bluetooth Mesh, and can achieve remote communication through CodedPHY and broadcast extensions.

It also supports 2Mbps PHY to improve transmission speed and data throughput. The Wi Fi and Bluetooth LE RF performance of ESP32-S3 is superior, and it can also work stably at high temperatures [5].

Figure 4 DS18B20 temperature sensor [10]

B. DS18B20 temperature sensor

The DS18B20 temperature sensor [10] uses a unique oscillator counting principle to achieve temperature measurement. The gate period is set internally by a high temperature coefficient oscillator, and the low temperature coefficient oscillator counts pulses during this period to obtain the temperature value.

C. Turbidity sensor

Excessive suspended solids such as food residues and metabolic waste in fish tanks can harm fish health and affect water quality transparency. To monitor turbidity, we have chosen an economical and practical household grade turbidity sensor [13]. This sensor utilizes the refractive effect of optical diodes and transistors on wavelengths to detect the transmission and scattering intensity of light in water to evaluate turbidity: the clearer the water quality, the higher the transmittance, and the higher the output voltage; On the contrary, the voltage decreases. Compared to industrial grade sensors, this solution significantly reduces system costs while ensuring basic detection functions [6].

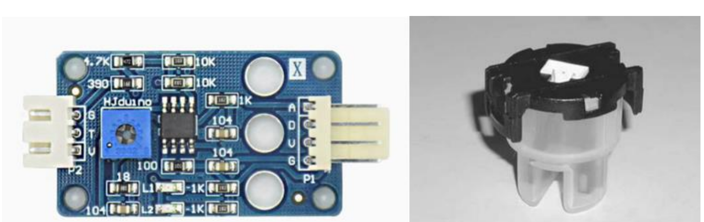


Figure 5 Turbidity sensor module [12]

According to the relationship between the measured voltage value and turbidity, the relationship between voltage value and turbidity is shown in the Table 1. It is noticed that the higher turbidity has the smaller voltage value.

Table 1
The relationship between voltage value and turbidity

Turbidity level	Voltage parameter values
Level 1	2 .96V-5V
Level 2	2.64V-2.96V
Level 3	1.84V-2.64V
Level 4	0-1.84V

D. pH sensor

The pH value of water quality is a key parameter that affects the survival of fish. After market research, we have selected a cost-effective pH testing electrode module [12] that is lower in cost compared to industrial grade sensors and has good compatibility for secondary development. This module outputs standard voltage signals, which can be directly connected to MCU for processing. The measurement accuracy meets the requirements, and procurement and maintenance are relatively convenient [7].

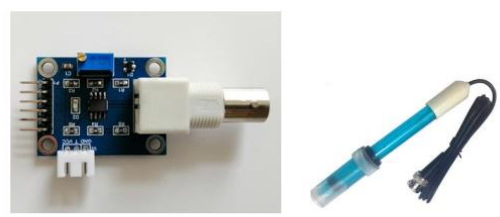


Figure 6 Schematic diagram of pH sensor module [12]

E. Water depth sensor

Due to transpiration, the amount of water in the fish tank gradually decreases, or the water level changes due to automatic replacement of the water in the tank. Therefore, the system requires real-time measurement of water depth values to maintain water level stability. The XGZP type piezo-resistive pressure sensor [11] converts the sensed pressure into a change in resistance value by utilizing the piezo-resistive effect and resistance strain principle, and outputs an electrical signal corresponding to the pressure through a bridge circuit. After amplification and calibration, an accurate standard voltage signal can be output for subsequent processing or display use [8].

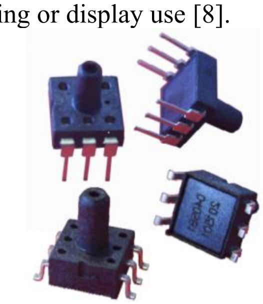
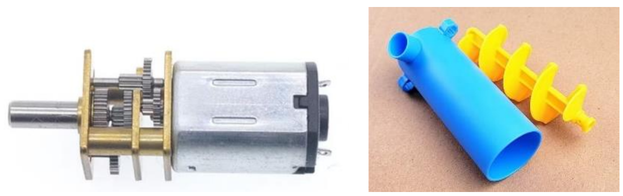


Figure 7 XGZP type piezo-resistive pressure sensor [11]

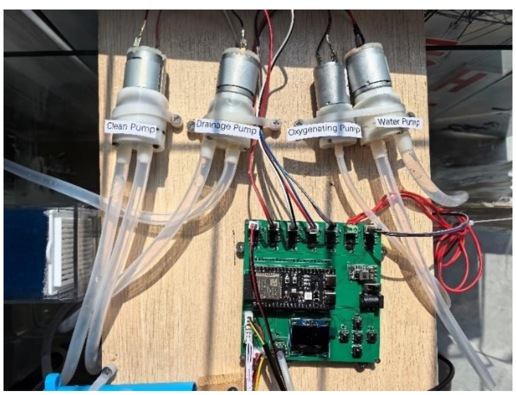
F. Design of automatic feeding module

This system uses GA12-N20 deceleration motor (15rpm, 12V) as the core driving component of the automatic feeding module. This motor has the characteristics of small size, high energy efficiency, and low-speed high torque, making it particularly suitable for situations that require precise control. By driving the spiral conveyor mechanism with a motor, quantitative feeding of fish food can be achieved, and the feeding amount control is precise and reliable. This design balances system stability and energy efficiency while ensuring feeding accuracy [8].

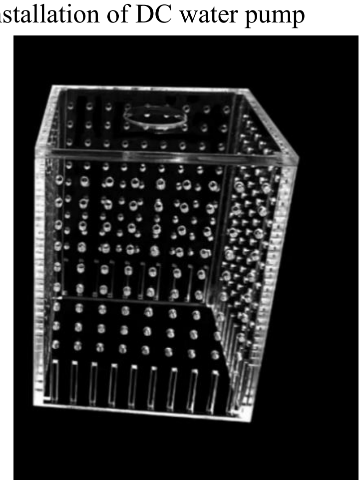


(a) GA12-N20 gear motor (b) Spiral feeding structure

Figure 8 Automatic Feeding Module



(a) Installation of DC water pump



(b) Anti-suction fish isolation cover

Figure 9 Water Change Control system

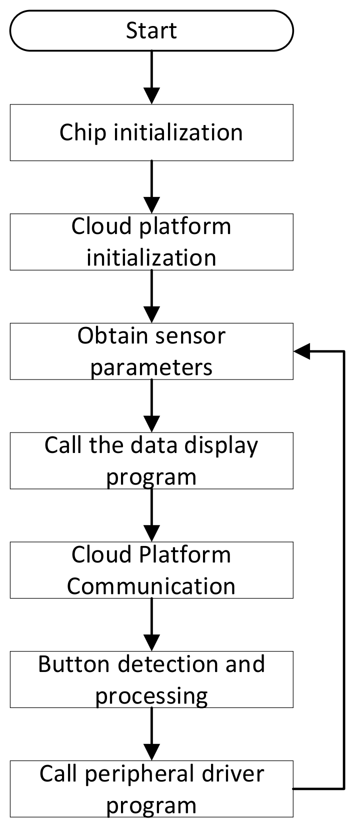
G. Design of Water Change Control Module

This system adopts an external non submersible installation scheme, placing the DC water pump outside the fish tank and connecting the inlet and outlet through rubber hoses. Compared to submersible installation, this solution has three major advantages: 1) saving internal space in the fish tank; 2) Extend the service life of the water pump; 3) Easy to maintain and repair. To prevent small fish fry from being sucked into the water pipe, a special isolation protective cover has been installed, which not only ensures the efficiency of water exchange but also avoids fish damage. This installation method achieves the best balance between space utilization and safety.

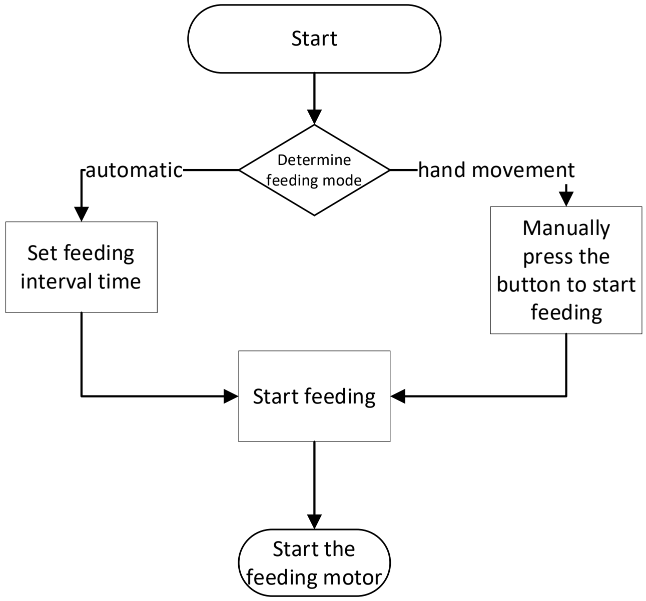
IV. SOFTWARE DESIGN

A. Software design of smart fish tank system

The smart fish tank system adopts a modular software design method and develops driver programs after hardware construction is completed. The software architecture strictly follows the hardware circuit design, divided into independent modules according to functions such as feeding control, water change control, so on. It achieves sensor data sharing through sub modules such as pH data for the water change module.



(a) Workflow of the main program



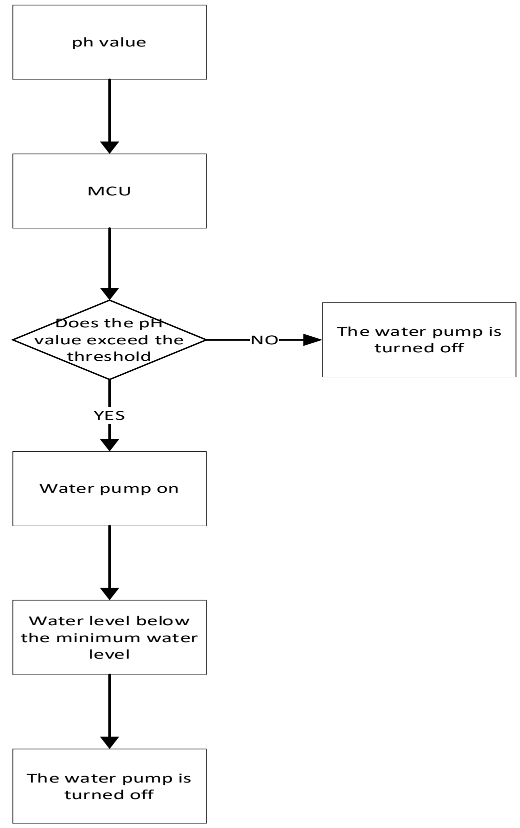
(b) Process diagram of feeding module

Figure 10 Main Program and feeding module

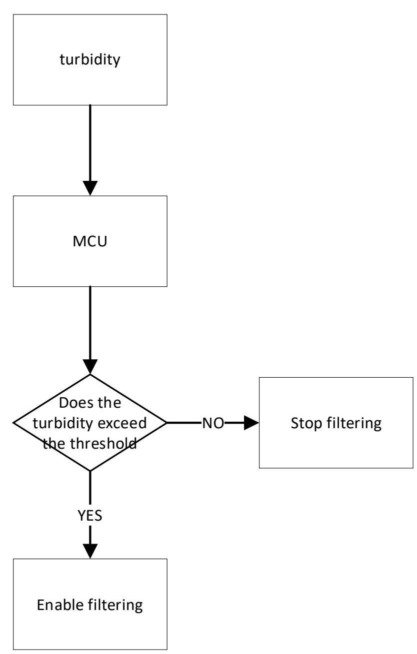
This layered design not only ensures the independence of each function, but also achieves data interoperability, while avoiding code redundancy and ensuring stable system operation. The smart fish tank system is developed based on the Arduino platform. Main program module design is shown in Figure 10(a). The feeding module in Figure 10(b) is based on a reduction motor to control the feeding amount. The feeding amount set in the program is fixed for each feeding, and the precise control of the rotation number of the reduction motor through programming determines the feeding amount for each feeding. For the control of feeding time, this program provides a timing function that can be set by users. Users can set the feeding time according to the different species of fish they raise.

B. Software Design for Water Change Module

The management of fish tank water change requires a moderate principle. Frequent water change can disrupt microbial balance and water quality stability, leading to fish stress; However, a long interval between water changes can lead to the accumulation of metabolic waste, abnormal pH, and insufficient dissolved oxygen. This system uses intelligent monitoring of water quality parameters to automatically replace water at the best time, maintaining ecological balance and avoiding water quality fluctuations caused by human intervention, providing a stable growth environment for fish. Therefore, this system monitors water quality in real time through pH sensors. When the detection value exceeds the preset threshold, it automatically triggers a water change program: first drain the water to the lowest water level, and then inject new water to the standard water level. The system supports dual modes of timed water change and threshold triggering, and users can customize the water change frequency based on their breeding experience. This intelligent design significantly reduces the workload of manual maintenance while ensuring stable water quality. Flow chart of water replacement is shown in Figure 11(a).



(a) Water Replacement Module



(b) Filter module

Figure 11 Flow chart of water replacement and filter modules

Metabolic waste and microbial growth in fish tanks can contaminate water quality and pose a threat to fish health. This system adopts physical chemical composite filtration technology, which efficiently removes harmful substances such as ammonia and nitrite through the synergistic effect of filter cotton and activated carbon, maintaining water cleanliness. The filtration system not only purifies water quality, but also promotes uniform distribution of dissolved oxygen through circulating water flow, stabilizes water temperature and pH value, thereby creating a healthy living environment for fish and effectively preventing disease occurrence. This system accurately measures the turbidity of fish tank water through a turbidity sensor and automatically determines whether to activate the filtration device based on this. The system compares sensor data with a preset threshold, and immediately starts filtering once the turbidity exceeds the standard; After the turbidity returns to normal, it will automatically stop. This design effectively achieves automatic filtration of the fish tank, greatly reducing the need for manual cleaning. Flow chart of filter module is shown in Figure 11(b).

C. *Remote monitoring system*

The smart fish tank needs to establish communication with the mobile terminal. In order to establish stable and secure uplink and downlink data communication. This section mainly provides a detailed description of the Alibaba Cloud IoT platform, MQTT data communication protocol, and the process of integrating smart fish tanks into the cloud platform.

The mobile end uploads control instructions to the IoT platform, and the cloud platform receives them and issues them to the smart fish tank through the rule engine, enabling remote operation of the smart fish tank. The cloud platform is mainly responsible for data reception and forwarding functions. A lightweight protocol is that the significant advantage of MQTT protocol is that it has less code and occupies less bandwidth, and provides stable and instant connection services for devices, which is more suitable in unstable network environments.

D. *Mobile Client Design*

The manual control interface of the smart fish tank control system mainly consists of data monitoring, feeding, water change, and other switch devices. When the main control chip is powered on, it will automatically initialize various devices. After the software APP is opened, it will automatically connect to the user hotspot set in the program and obtain the detection data from the data collection end, thus realizing the uploading of monitoring data to the cloud. In manual mode, the system supports feeding, water changing, and on/ off light control interfaces based on the device's functions, as well as downstream control of devices with various switch values; In automatic mode, set the corresponding feeding time interval, water change time interval, and heating threshold, and the system will automatically run to achieve intelligent control. APP interactive interface is shown in Figure 12.

(a) APP interactive interface (b) Overall system

Figure 12 APP interactive interface of overall system

V. Experimental Results

A. *Results of turbidity module testing*

When the turbidity of the water in the fish tank exceeds the set value, the filtering device will start working, and will stop working when the turbidity reaches the set value**.**

B. *Results of heating module testing*

Heating starts when the temperature is below the minimum temperature threshold, and stops when the temperature is above the maximum temperature threshold**.** The temperature threshold can be set through the mobile app or by pressing a button**.**

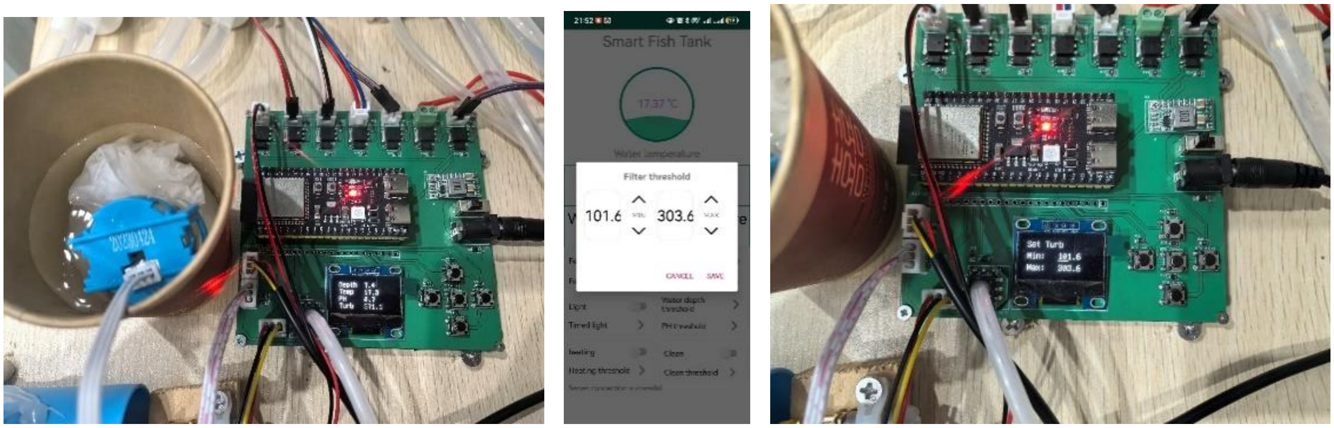
C. *Results of pH module testing and water replenishment module.*

When the pH value of the water in the fish tank exceeds the set threshold, the water pump will start working, extracting water from the main tank and injecting water from the secondary tank into the main tank**.** When the water level reaches the set value, it will stop working**.** The pH module testing and mobile setting interface are shown in Figure 15**(**a**)**-15**(**b**).**

Table II

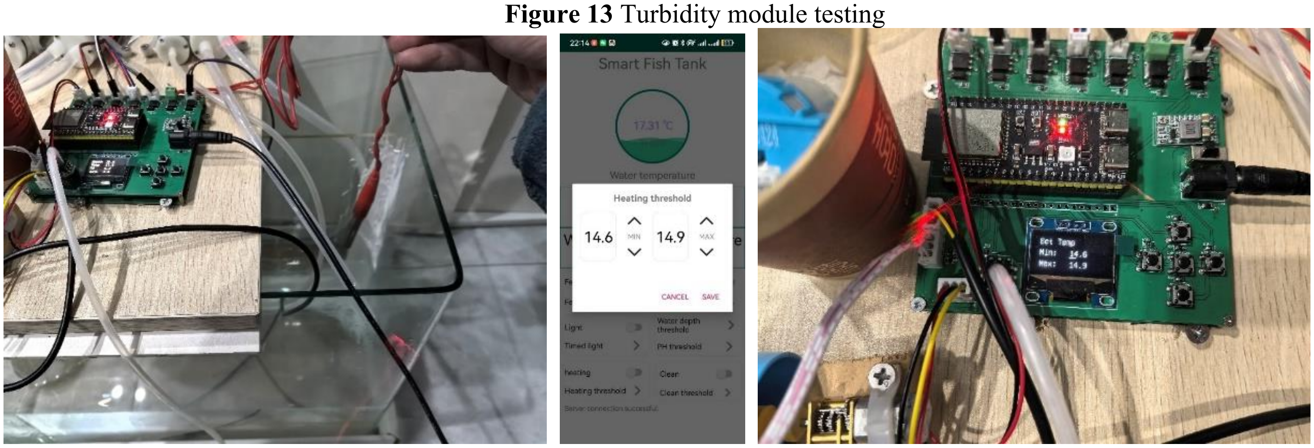
Automatic heating, indoor temperature is 18.0 °C, initial water temperature is 17.8 °C. Set the temperature threshold to 26-30 °C through the application.

Time (hr:min)	Threshold	Fish tank temperature	yes/no heated
9:45	26-30℃	17.8	yes
9:55	26-30℃	25.6	yes
10:02	26-30℃	30.1	no
10:18	26-30℃	27.5	no
10:30	26-30℃	25.9	yes
10:38	26-30℃	30.1	no
10:45	26-30℃	28.0	no
11:01	26-30℃	25.9	yes
11:05	26-30℃	28.2	yes
11:09	26-30℃	30.0	no
11:15	26-30℃	28.5	no
11:34	26-30℃	25.9	yes



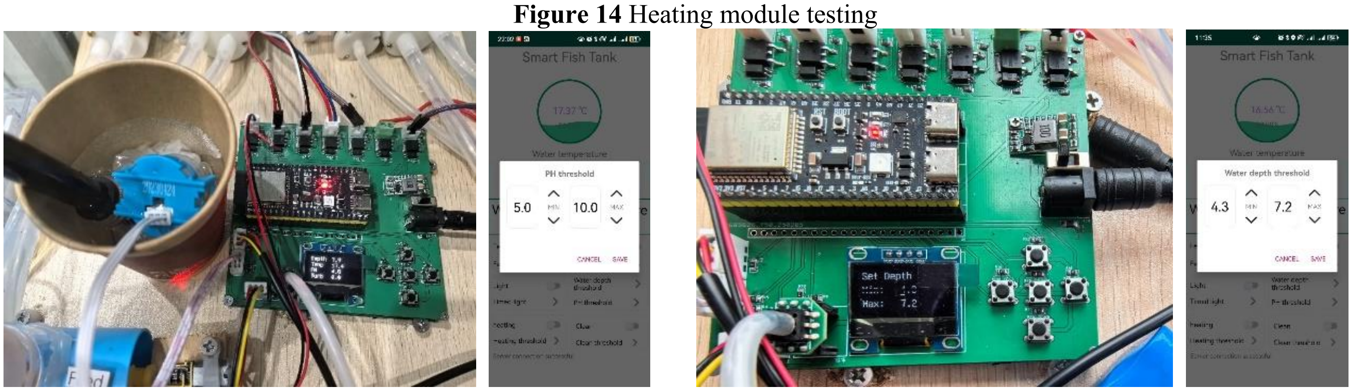
(a) Turbidity module test **(b)** turbidity setting interface **(c)** Turbidity button setting interface

Figure 13 Turbidity module testing



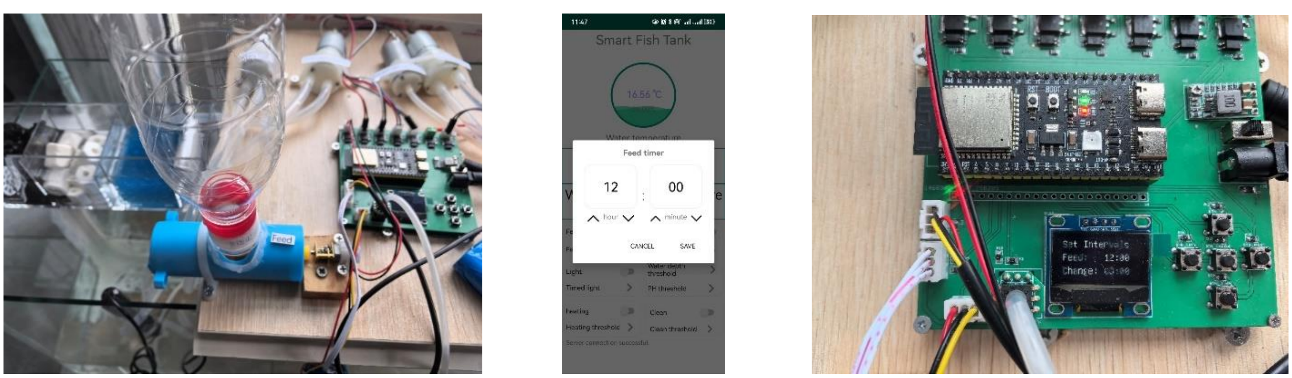
(a)Heating module test (b) heating setting interface (c) heating button setting interface

Figure 14 Heating module testing



(a)pH module test **(b)** mobile pH setting interface **(c)** water level module **(d)** water interface

Figure 15 pH module and water replenishment testing



(a) Feeding module testing (b) mobile feeding setting (c) automatic feeding setting interface

Figure 16 Automatic feeding module

When the water level is below the standard level, start adding water, and stop adding water when it exceeds the standard level to prevent the fish tank water from being too low. When the water level is higher than the maximum water level (standard water level+ 5cm), drainage begins, and when it is lower than the maximum water level (standard water level+ 5cm), drainage stops to prevent the fish tank water from being too high. The water level module testing and mobile setting interface are shown in Figure 15(c)-15(d).

Table III

Automatic water change (Set the water change threshold through the application. for testing, change water every 2 mins)

No.	pH value	Start water change time (min:sec.ms)	End time of water change (min:sec.ms)
1	6.8	02:00.38	02:52.71
2	6.8	04:53.50	05:46.12
3	6.7	07:46.73	08:39.37
4	6.9	10:39.37	11:33.39

D. Results of feeding module testing

The feeding module is divided into automatic feeding and manual feeding. During manual feeding, the feeding button is pressed and the motor runs once. For automatic feeding, the feeding interval can be set by pressing the button or using the app, which can be minutes, hours, or days. Activate automatic feeding once every time the threshold is reached. The amount of food fed each time is determined by the number of revolutions of the motor, which can rotate half a circle, one circle, or more.

Table IV

Automatic feeding (Set feeding thresholds through the application.for testing, feed once every 2 mins, set the feeding amount to 10g, i.e. the motor rotates a circle every 2 mins).

No.	Feeding interval time (min:sec.ms)	Time (min:sec.ms)	Feed amount (Unit: g)
1	2:00.54	2:00.54	10
2	02:03.85	04:04.40	10
3	02:03.25	06:07.65	10
4	02:04.18	08:11.83	10
5	02:03.94	10:15.77	10
6	02:06.38	12:22.15	10
7	02:01.12	14:23.27	10
8	02:03.27	16:26.54	10
9	02:03.36	18:29.91	10

VI Conclusion

This study designed and implemented a multifunctional smart fish tank system based on a microcontroller. Through sensors such as temperature, turbidity, and pH value, real-time monitoring and automated management of the fish tank environment were achieved, with functions such as automatic water change, replenishment, heating, and feeding. The system is equipped with a backup power supply to ensure stable operation in case of power outages and other emergencies. At the same time, a mobile application has been developed to support users in remotely monitoring and controlling the fish tank environment. The test results show that the system runs stably and reliably, significantly improving the intelligence and convenience of fish farming, and can effectively meet the practical needs of modern fish farming.

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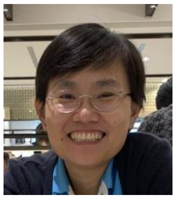
Li Fei graduated from Chongqing University of Arts and Sciences in China and works at ChongQing Water Resources And Electric Engineering College. He is currently pursuing a Master's degree in Electrical Engineering at Mahanakorn University of Technology in Thailand. His research interests include smart homes, smart grids, and power system monitoring.



Suchada Sitjongsataporn received her B.Eng. (first-class honors) and D.Eng. degrees in Electronic Engineering from the Mahanakorn University of Technology, Bangkok, Thailand in 2002 and 2009, respectively. She has worked as a lecturer at the department of electronic engineering, Mahanakorn University of Technology since 2002. Currently, she is an Associate Professor in electronic engineering, the Assistant President for Research and Dean of Graduate College in the Mahanakorn University of Technology. Her research interests are in mathematical and statistical models in the area of adaptive signal processing for communications, networking, embedded system, image and video processing, deep learning and semiconductor technology.