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Canal Integrated Monitoring System Based on Multidimensional Detection

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Abstract: *This article focuses on the ecological protection of canals within cities and designs a multi-level and holistic intelligent monitoring system for water quality and environment. This system integrates monitoring technologies from three dimensions: air above water, water surface, and underwater, achieving real-time and refined monitoring of the canal environment. Above the canal, the system monitors atmospheric environmental parameters in real-time, evaluates the air quality around the canal; On the water surface, the system continuously observes real-time images to assist in identifying abnormal phenomena and provide intuitive visual data for canal management; Underwater, the system accurately measures the turbidity of water and the concentration of dissolved solids, providing precise data support for preventing water pollution. Through mobile terminals, the system integrates the function of tourists actively reporting anomalies, and forms a closed loop of canal monitoring and protection through societal participation. This system addresses the shortcomings of traditional water quality detection mode being single and inefficient. Through integrated monitoring, it effectively collects and analyzes environmental data, which plays an important role in protecting the unique ecological and landscape value of canals within cities.*

Keywords: *Canal Ecological Protection; Integrated Monitoring; Water Surface Observation; Dissolved Solids; Society Participation*

1. Introduction

Canals within cities play an important role in urban construction planning, economic development, and have a profound impact on cities. For example, the Grand Canal, spanning across the north and south of China with a history of over 2500 years, is a world cultural heritage site that plays an important role in the economic and social development of multiple cities it passes through. The Grand Canal starts from Zhejiang and flows through multiple cities such as Hangzhou and Huzhou.

The core of canal ecological environment protection lies in the protection of canal water quality and surrounding environment. The Hangzhou section of the Grand Canal, for example, is characterized by its long length, numerous branches, and dense coastal population. Although the existing protective measures such as regular patrols by dedicated personnel and fixed-point detection of water pollution have played a certain role, there are still many problems. Taking the Hangzhou section of the Grand Canal as an example, we found that some problems are more prominent:

(1) Floating garbage. Large areas of fallen leaves, plastic bottles, packaging bags, and other common household waste often float on the surface of the canal. In certain seasons, fish may also float after dying due to lack of oxygen. Although there are staff members from relevant departments patrolling the canal every day, it is difficult to handle it in a timely manner due to labor and time costs, which affects the landscape value of the canal.

(2) Turbid water. The reason for this problem is that there are problems with the interception pipe network of some sewage outlets that enter the canal, which fails to block sediment before the tributaries flow into the main canal channel. Due to the large number of sewage outlets in the Hangzhou section of the Grand Canal, traditional inspection methods require targeted inspections one by one, which is inefficient and cannot detect problems in a timely manner.

(3) Illegal discharge of sewage. In recent years, there have been incidents of excessive sewage being discharged into canals. However, the discharge of excessive sewage is covert, and traditional water quality testing requires manual sampling and testing, which is slow and not conducive to timely

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elimination of adverse effects on water quality.

In summary, for the common problems faced in canal protection, although traditional protection methods have some ability to solve them, there are still problems such as single focus, scattered protection forces, high manpower consumption, and lagging problem discovery and processing. The canal integrated monitoring system based on multidimensional detection proposed in this paper has important application value in solving the practical problems faced by canal ecological protection.

2. The Research Status of Related Study

In recent years, some studies have focused on the research of water quality monitoring systems within a limited scope. An online monitoring system based on Modbus protocol and embedded technology was designed [1]. To achieve interconnection with the computer, RS485 bus was used to upload environmental data, but the wired transmission method has significant limitations. Faustine A et al. designed water quality collection points for monitoring basic data such as temperature and pH value, based on the combination of Zigbee and GPRS gateway. The disadvantage is that the data transmission speed is slow [2]. Bu et al. used wireless sensor (WSN) technology to monitor pH, temperature, and water level in aquaculture environments, which significantly improved data transmission speed [3]. The disadvantage of these water quality detection systems is that most of the environmental data they focus on is simple and cannot be transmitted over long distances. They can only achieve limited water quality monitoring in a small area and have weak scalability. They are not suitable for ecological environment monitoring scenarios such as the Grand Canal, which has numerous watersheds.

With the great progress of IoT technology, including wireless communication technology, some studies have focused on the development of integrated water quality monitoring systems. Spandana et al. [4] designed an intelligent water environment system that uses multiple nodes to monitor water quality parameters, including temperature, pH, and water level. The collected data is remotely connected to the CPU through the WIFI protocol and transmitted and stored through a web server, but the WIFI transmission solution has poor adaptability to outdoor environments. Imran et al. [5] proposed a river water quality monitoring node design based on LoRa technology. In the same year, Qiu et al. [6] proposed a similar solution, but the latter used solar or lithium batteries in the power supply module to improve the system's endurance. Alam A U et al. [7] designed a multi-parameter water quality monitoring system (MWQMS) that can be used to monitor parameters such as pH, free chlorine, and temperature in water bodies, and transmit the data to an Android application, achieving convenient real-time monitoring. Jamroen C et al. [8] designed and implemented an aquaculture water quality monitoring system based on narrowband IoT NB-IOT technology. The system is powered by an independent photovoltaic power source, with monitoring parameters including dissolved oxygen, hydrogen potential, and temperature. By integrating the monitored water quality parameters, it further achieves water pollution warning function. Although this type of research has significantly improved in terms of data transmission distance, it is still limited to the single issue of water quality testing and cannot effectively address other problems found by us in field investigations of urban canals.

3. System Design

3.1. Design Scheme for Monitoring System

The system framework is shown in Figure 1, mainly including the air environment monitoring module (environmental temperature and humidity detection, PM2.5 air quality detection), water quality monitoring module (conductivity detection, turbidity detection, TDS (Total Dissolved Solids) detection, and water temperature detection), surface ecological monitoring module (camera monitoring), human-computer interaction module (display screen display, button interaction), communication module, CPU main control board module, and power module. We integrated all the designed functions and created a physical model of a multi-dimensional canal integrated monitoring system, as shown in Figure 2.

3.1.1. Technical Scheme for Air Environment Monitoring

This module collects real-time air quality and environmental temperature and humidity information through a GP2Y1010AU0F PM2.5 sensor and a DHT11 temperature and humidity sensor, sends it to the STM32 microcontroller for processing, displays the data on the display screen, and sends the water environment data to the remote end through a wireless module.

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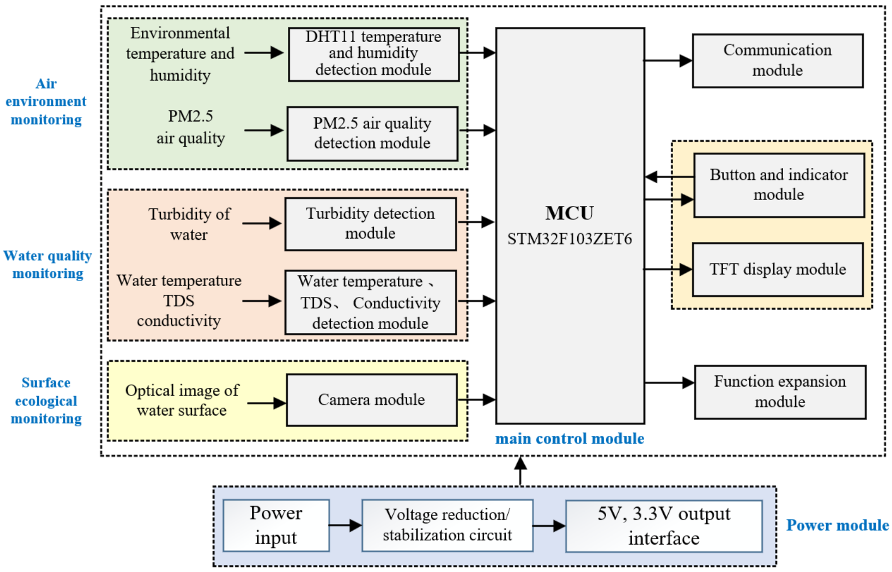

Figure 1: Block Diagram of the Canal Integrated Monitoring System

Figure 2: System physical model of the Canal Integrated Monitoring System

3.1.2. Technical Scheme for Water Quality Monitoring

This module is embedded with turbidity sensors, conductivity sensors, TDS sensors, and water temperature sensors to collect real-time data on water turbidity, conductivity, TDS values, and water temperature. After processing by the STM32 microcontroller, the data is displayed on the screen, and the underwater water quality data is sent to the remote end through a wireless module.

3.1.3. Technical Scheme for Water Surface Ecological Monitoring

This module installs a camera module to collect real-time optical images of the water surface. After processing by the STM32 microcontroller, the captured images are displayed on the screen and the real-time monitoring images are synchronized to the remote end.

3.1.4. Technical Scheme for Remote Data Transmission and Display

In the human-machine interaction module, an ILI9806 TFTLCD display screen and button module are installed. The display screen displays real-time environmental monitoring values and monitoring shooting images, and displays a QR code for the public to report abnormalities. The button module adjusts the lighting mode, contrast, brightness, and saturation of the camera's captured image by pressing different buttons.

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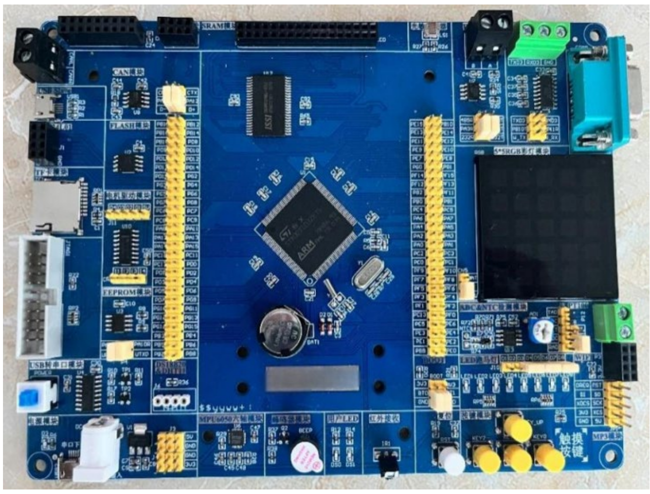

Figure 3: Xuanwu STM32F103ZET6 development board

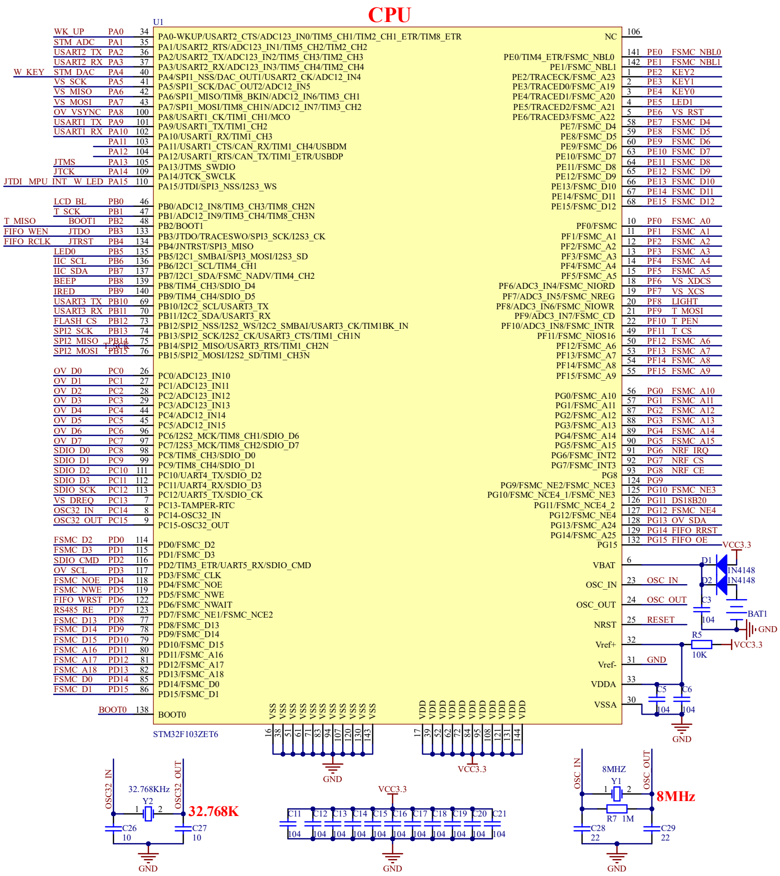

Figure 4: The main control circuit of STM32F103ZET6

3.1.5. Technical Scheme for Human Computer Interaction

To ensure that the real-time data collected by each module can be sent to the remote end in a timely manner for canal management personnel to view and make corresponding decisions based on the situation, this system embeds a mobile communication module. After considering communication distance, cost, and stability, the 4G LTE communication module is selected. The STM32 microcontroller is connected to the 4G module through a serial port to control data transmission to a remote server. The server runs the visualization platform of this system, collects received data, classifies and integrates it, and presents the data in real-time on the screen.

3.1.6. Technical Scheme for Public Proactive Reporting of Abnormal

To achieve a closed-loop monitoring process for the canal, this system is designed to enable the public

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to proactively report any abnormalities in the canal environment. Considering the convenience of users' mobile terminals, this system displays a dedicated QR code on the device screen, and the public can quickly access the reporting function by scanning the code after discovering abnormalities. After the relevant information is transmitted to the backend, it is received and viewed by a dedicated person, and corresponding practical processing is carried out according to the situation.

3.2. Detailed Design

3.2.1. Design of Main Control Module

We use the Xuanwu F103 development board with M3 core, which has abundant onboard resources and high cost-effectiveness. The physical development board is shown in Figure 3. We mainly utilize onboard hardware resources such as STM32F103ZET6 main chip, DS18B20&DHT11 module, camera module interface, LCD touch screen interface, LED module, button module, WIFI/Bluetooth/GPS module interface, power module, NRF24L01 module interface, USB to TTL module, etc. The main control circuit of STM32F103ZET6 is shown in Figure 4.

The power circuit, as shown in Figure 5, is a development board resource. The system is powered by USB 5V. After pressing the power switch POWER, the 5V input voltage is stabilized by the 1117-3.3 voltage regulator circuit to output a stable 3.3V voltage to supply power to various modules of the system. J3 and J4 provide 5V and 3.3V power interfaces for external modules and circuits.

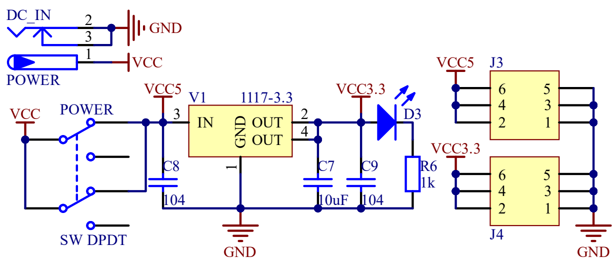

Figure 5: The power circuit

3.2.2. Design of Air Environment Monitoring Circuit

The air environment monitoring circuit module includes DTT11 temperature and humidity detection circuit, PM2.5 air quality detection circuit, and the complete circuit is shown in Figure 6.

In the temperature and humidity detection circuit, the digital temperature and humidity sensor DTT11 collects environmental temperature and humidity information, converts it into digital signals, and sends them to the PG11 port of STM32. The microcontroller completes the signal operation, logic control, and other functions, and the measurement results are sent to the display screen for display.

The air quality detection circuit uses a GP2Y1010AU0F air quality sensor to collect PM2.5 particles in the air. The PA7 port of STM32 drives the LED inside the sensor to emit infrared signals in a directional manner through transistor Q201. The infrared receiving tube inside the sensor converts the light signal containing PM2.5 information into an analog voltage, amplifies the output analog signal, and sends it to the PA5 port of STM32. The microcontroller completes the signal calculation and processing, and the measurement results are displayed on the screen.

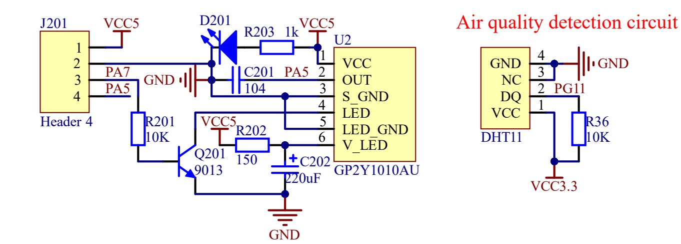

Figure 6: Environmental temperature and humidity, air quality detection circuit

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3.2.3. Design of Water Quality Monitoring Circuit

The water temperature and TDS detection circuit is shown in Figure 7. NTC probe is used to collect water temperature data, and TDS probe is used to detect the conductivity of water. After temperature compensation of TDS value by BA111, the TDS value at the current temperature is calculated through conductivity conversion algorithm and temperature correction algorithm. The TDS value and water temperature value are communicated with PB11 and PB10 ports of STM32 through TXD and RXD. After processing by the microcontroller, the water temperature and TDS value are displayed on the screen.

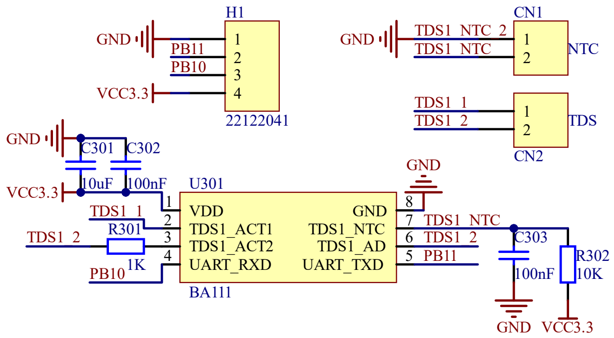

Figure 7: Water temperature and TDS detection circuit

The turbidity detection circuit is shown in Figure 8. The TSW-30 turbidity sensor is used to collect the transparency of suspended solids in water and output analog and digital signals. The analog signal is sent to the PA6 port of STM32, and the microcontroller completes A/D conversion, signal operation, and processing. The measurement results are displayed on the screen. The digital DOUT can be triggered by adjusting the threshold through the potentiometer on the module. When the turbidity reaches the set threshold, the D402 indicator light will be turned on, and the sensor module output will change from high level to low level. The microcontroller monitors the change in level to determine whether the turbidity of the water exceeds the standard, thereby warning or linking with other devices.

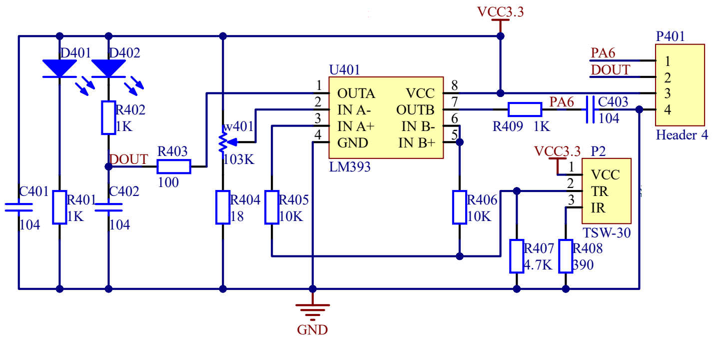

Figure 8: The turbidity detection circuit

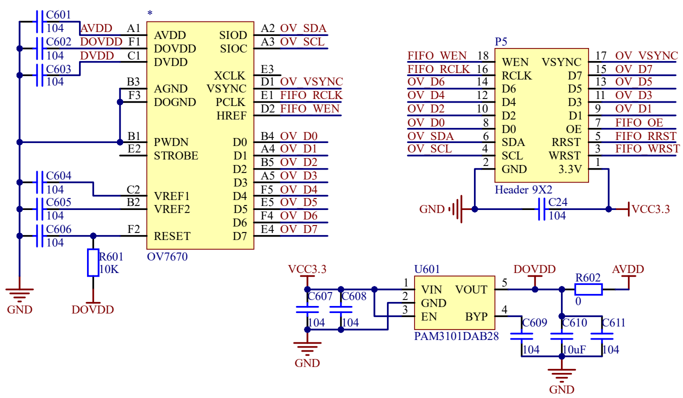

Figure 9: The water surface monitoring circuit

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3.2.4. Design of Water Surface Monitoring Circuit

The water surface monitoring circuit is shown in Figure 9. This module is mainly composed of a camera module, which transmits the captured images to STM32 through OV-D0 to OV-D7. The microcontroller processes the data and displays the captured images on the display screen.

3.2.5. Design of Human-Machine Interaction Circuit

The human-machine interaction module circuit is shown in Figure 10, mainly composed of an ILI9806 LCD TFTLCD display screen, LED indicator, and button circuit. The four independent buttons function as follows: KEY-UP is the lighting mode setting button, used to switch the lighting mode of the captured image. By continuously clicking on "Auto", "Sunny", "Cloudy", "Office", "Home" (automatic mode, sunny mode, rainy mode, office mode, home mode), it can be switched; KEY0, KEY1, and KEY2 are respectively the contrast setting key, brightness setting key, and saturation setting key. By continuously clicking, the contrast, brightness, and saturation of the captured image can be switched within the range of -2 to 2.

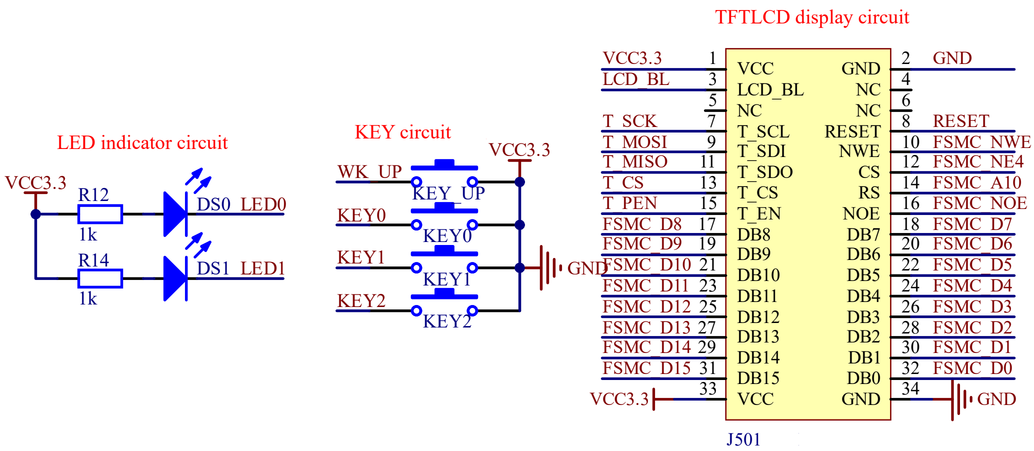

Figure 10: The human-machine interaction module circuit

3.2.6. Design of Remote Data Transmission and Display

We use Air724 4G LTE module for remote data transmission. This module is a small communication module with superior communication performance, complying with the LTE Cat.1 communication standard, and capable of supporting data transmission at a maximum downlink rate of 10Mbps and a maximum uplink rate of 5Mbps. It has the characteristics of high sensitivity, reliable communication, strong anti-interference ability, and long communication distance. This module uses a TTL level serial port to communicate with the MCU, and can be widely used in fields such as smart homes, smart transportation, and smart city IoT. This module has high stability. Ordinary commercial SIM Nano cards can be inserted and automatically search for access to commercial mobile communication networks after power on. When setting up transmission, the MCU program configures the target server's public IP address to complete data transmission.

After receiving the data, the server needs to perform data processing on the backend, using Java to build the service backend. MySQL database creates databases by module and data tables by date to store detection data. We use Java Swing to write the monitoring system interface, and the program reads the data and arranges it in order to provide monitoring panel services for canal management personnel.

3.2.7. Design of Function for The Public to Proactively Report Abnormal Conditions

The core idea of this feature design is that public roles such as tourists and residents along the canal have a fast and convenient reporting channel when they discover abnormal conditions (such as floating garbage, chemical pollution, etc.) on the canal, and can timely transmit relevant information to the management department. Therefore, we have decided to use mobile terminals as carriers and leverage the convenience of scanning codes on mobile phones to achieve the transmission of relevant information.

WenJuanXing is a well-known professional survey information collection platform in China, focusing on providing users with powerful and user-friendly online survey filling and other services. We utilize its already launched QR code access service function to build a dedicated information collection channel, leveraging its obvious advantages of speed, ease of use, low cost, and stability.

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The main device of this system displays a dedicated QR code, and the public can quickly access the reporting function by scanning the code after discovering abnormal situations. Users fill in information such as location and situation, and the relevant information is transmitted to the backend for receiving and viewing by a dedicated person, and corresponding actual processing is carried out according to the situation. The service page after scanning the code is shown in Figure 11.

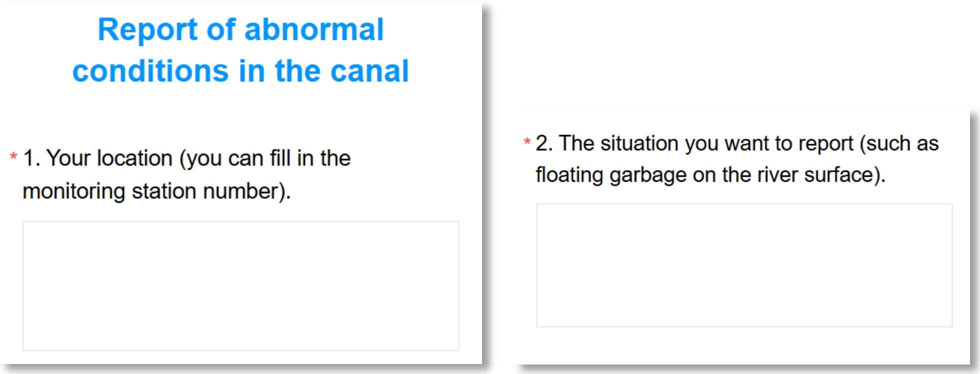

Figure 11: Abnormal conditions reporting page

4. System Testing

The physical model of this system is shown in the following figure 12.

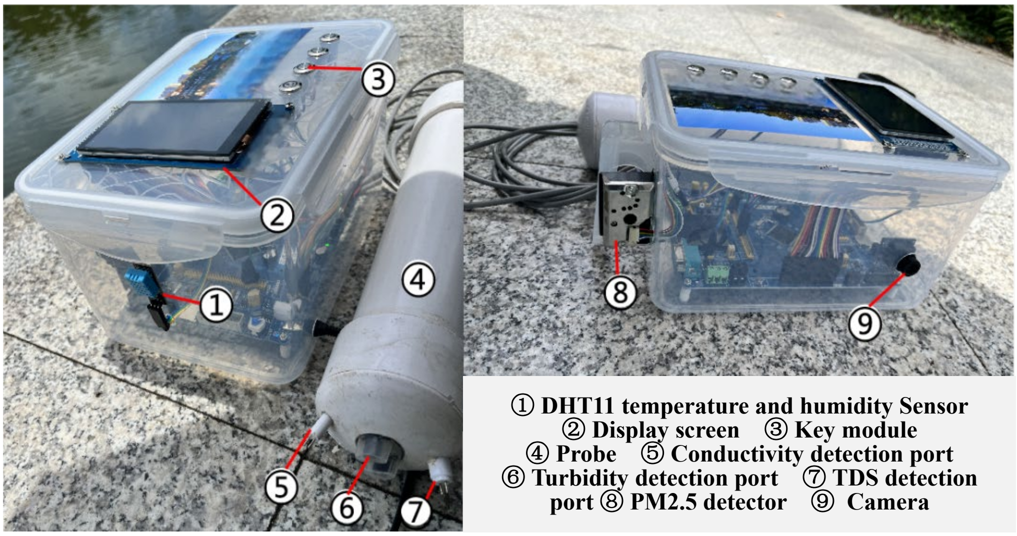

Figure 12: Physical model of canal integrated monitoring system

After booting up, the system will first scan and verify the functions of each module. When each module is not connected or abnormal, an ERROR prompt will be displayed on the screen. After all modules have no abnormalities, the system enters environmental monitoring mode. In monitoring mode, the upper right corner of the display screen will show the real-time image captured by the camera, and the left side of the screen will display the current camera's sampled light mode, saturation, brightness, and contrast.

The four buttons in the interactive area are the light mode setting button, saturation setting button, brightness setting button, and contrast setting button. On the corresponding module display position on the screen, sequentially display the current environment's temperature, humidity, PM2.5 value, water quality conductivity, turbidity detection value, TDS detection value, and water temperature. In the bottom right corner of the screen, a QR code is displayed for exchanging information with the public. The public can report abnormal conditions by scanning the QR code.

4.1. Field Testing

To verify the effectiveness of the system, we conducted field tests at multiple locations along the

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Hangzhou section of the Grand Canal, including Gongchen Bridge, Wulinmen Wharf, and Pujia Wharf. The test results are shown in Table 1 below.

Table 1: System monitoring results at different locations.

Items	Gongchen Bridge	Wulinmen Wharf	Pujia Wharf
PM2.5 (μg/m^3)	33	26	37
Temperature (℃)	40	39	40
Humidity (%)	43	47	45
Turbidity (mg/L)	36	53	327
Conductivity (μS/L)	592	490	538
TDS (mg/L)	204	167	182

Observing the data in the table, it can be found that the air quality at all three test points is normal, which is consistent with the good weather conditions on the day of the test (sunny summer afternoon). Analyzing the water quality testing results, it can be found that the turbidity values, conductivity, and TDS of the Gongchen Bridge testing point and the Wulinmen Port testing point are all at a low level, indicating that the water quality at these two locations is good. However, the turbidity value at the Pujia Wharf testing point is relatively high, and visible turbidity can also be found in the canal water at that location, indicating slightly poor water quality. Based on comprehensive analysis, the Gongchen Bridge section of the Grand Canal and the Wulinmen Wharf are both famous scenic spots in Hangzhou, which have received key treatment and strong protection efforts, resulting in good water quality conditions. There are many residential areas along the Pujia Wharf section of the Grand Canal, and there are also some production-oriented enterprises, which have multiple potential environmental factors affecting the Grand Canal.

Figure 13: Simulate adverse air conditions

4.2. Indoor Simulation Experiment

This system already has the function of monitoring actual canal scenes, but considering the requirements of green environmental protection, it is not possible to conduct pollution testing in the actual environment of the canal. We conducted simulation experiments indoors to fully verify the effectiveness of the system.

4.2.1. Air Environment Detection Experiment

To test the effectiveness of the system in detecting changes in the air environment, we designed the following experiment: first, the system detects the conventional indoor environment as a control and records the values of various parameters. Then ignite a stick near the temperature and humidity detection module, as shown in Figure 13. The burning stick produces a large amount of dust particles to simulate changes in air conditions and record various parameter values. Verify the system's ability to detect changes in air quality by comparing the changes in corresponding parameters of normal indoor air and indoor air after lighting with fragrance. The experimental test results are shown in Table 2.

Table 2: Monitoring results of air environment in different scenarios.

Scenarios	PM2.5 (μg/m^3)	Temperature (℃)	Humidity (%)
Normal indoor environment	29	29	64
Indoor environment after igniting a stick	450	29.1	64

From the table data, it can be seen that when the wooden stick ignites and causes a decrease in air quality, it can be detected by the system after a certain period of time, reflected in the PM2.5 value index, which has significantly increased from 29 μg/m^3 to 450 μg/m^3. At the same time, the system's temperature and humidity detection is working normally. Should air quality change in the canal's actual environment, the system would detect such alterations promptly. Managers can identify and respond to abnormal changes in corresponding indicators.

4.2.2. Water Quality Change Detection Experiment

To test the effectiveness of our system in monitoring water quality changes, we prepared five containers and added different substances, as shown in Figure 14.

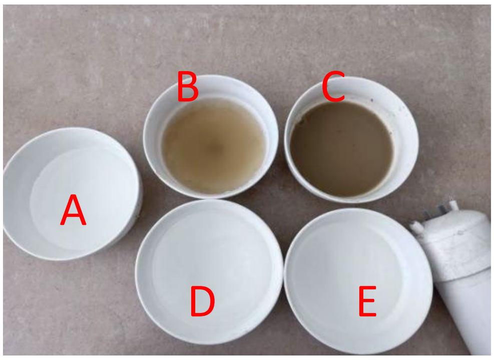

Figure 14: Simulate different canal water conditions

Table 3: Monitoring results of air environment in different scenarios.

Scenarios	Turbidity (mg/L)	Conductivity (μS/L)	TDS (mg/L)
Container A	67	153	62
Container B	1074	247	108
Container C	3008	470	176
Container D	90	4843	2769
Container E	82	4741	7762

First, add an equal amount of purified water to all containers. Container A is the control group, without adding any other substances; Add a small amount of soil to container B to simulate ordinary turbid canal water; Add a large amount of soil to container C to simulate highly turbid canal water; Add a small amount of edible salt to container D, and a large amount of edible salt to container E to form low and high concentration saltwater, respectively, simulating the discharge of wastewater containing metal ions of different concentrations into the canal. After thoroughly stirring the above solutions, experiments were conducted separately, and the turbidity values, conductivity, and TDS of each solution were recorded. The results are shown in Table 3.

According to common sense, the turbidity value can reflect the number of insoluble particles in water, and the larger it is, the more turbid the water is; The size of conductivity and TDS reflects the amount of water-soluble substances. From the results in the table above, it can be seen that the turbidity of solutions B and C with added soil has significantly increased compared to the control group, and the solution with more mud has a higher C index. This is because there are many insoluble substances in the soil; the conductivity of solutions B and C also showed a significant increase compared to the TDS control group, indicating that the soluble solids in the soil dissolved in water led to an increase in ion concentration. Compared to the control group, there was no significant change in turbidity values between solution D and solution E, as the edible salt was completely soluble and did not cause water turbidity. The significant increase in conductivity and TDS of solutions D and E is due to the increase in sodium and chloride ion concentrations after the dissolution of edible salt, which is positively correlated with the amount of edible salt dissolved. From this, it can be seen that corresponding to the actual canal environment, if there are problems such as damage to the sewage interception port causing mud water to be discharged into the canal, resulting in canal water mixing, and excessive sewage discharged into the canal causing an increase in heavy metal ion concentration in the canal water, the monitoring indicators of this system can reflect the actual situation and help managers take action.

In summary, this section simulated relevant scenarios indoors to verify the effectiveness of the system's functions. Corresponding to real canal application scenarios, each level of this system can also work normally according to its design functions and monitor the canal environment.

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5. Conclusions

This system creatively proposes the concept of integrated monitoring, which comprehensively arranges detection modules in the three dimensions of air, water surface, and underwater to ensure seamless monitoring of the entire canal environment, greatly enhancing the protection effect of the canal ecological environment. In addition, the system innovatively introduces a mechanism to encourage public participation in canal protection. Through spontaneous supervision and abnormal reporting by the public, a closed loop of environmental supervision involving both the government and the public has been formed, enhancing the social influence and effectiveness of the monitoring system.

Acknowledgements

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