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Research on Intelligent Environment Monitoring and Early Warning Technology Based on Embedded System

Zhenning Zhu

School of Innovation Engineering, Macau University of Science and Technology, Macau, 999078, China

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Abstract: The purpose of this study is to develop a system that can monitor various environmental parameters in real time, process data efficiently and warn abnormal situations in time. The system integrates high-precision DHT22 temperature and humidity sensors, MQ series harmful gas sensors and photoresistors, and is equipped with low-power STM32 series microcontrollers to realize comprehensive monitoring of environmental parameters. Modular software architecture is designed for the system, including data acquisition, processing, storage, early warning and communication modules, to ensure the expansibility and maintainability of the system. The early warning mechanism combines static and dynamic threshold setting, multi-parameter combination trigger conditions and hierarchical notification process, which improves the sensitivity and accuracy of early warning. The experimental results show that the system has good monitoring accuracy and stability under different environmental conditions.

1. Introduction

Environmental monitoring can not only reflect the environmental situation in time, provide data support for environmental protection, but also warn potential environmental risks and ensure public health and safety. However, traditional environmental monitoring methods are often limited by equipment cost, monitoring scope and real-time data processing, and it is difficult to meet the high standard requirements of modern society for environmental monitoring.

Embedded system has shown great application potential in the field of environmental monitoring because of its miniaturization, low power consumption, high integration and strong real-time performance [1]. By carrying a variety of sensors, the embedded system can realize comprehensive and accurate monitoring of environmental parameters and real-time analysis through the built-in data processing unit, thus providing scientific basis for environmental management and decision-making. In addition, the portability and flexibility of the embedded system also enable it to adapt to various complex and changeable monitoring scenarios, greatly improving the efficiency and coverage of environmental monitoring [2].

The purpose of this study is to develop an intelligent environmental monitoring and early warning technology based on embedded system, which can realize real-time monitoring of various environmental parameters, efficient data processing and abnormal early warning. Through this study, the problems existing in traditional environmental monitoring methods are solved, the accuracy and timeliness of environmental monitoring are improved, and the contribution to environmental protection and sustainable development is made.

2. System design and implementation

2.1. Hardware design

The system integrates a variety of environmental monitoring sensors, including DHT22 high-precision sensor for detecting temperature and humidity, which is characterized by rapid and stable response; MQ series sensors for monitoring harmful gases including carbon dioxide (CO_2) and PM2.5, which have good detection performance for various gas concentrations and excellent sensitivity and selectivity; And photoresistors or illuminance sensors for measuring the ambient light intensity, which can output corresponding electrical signals according to the change of light intensity [3]. All these sensors are connected with the embedded development board through specially designed interface circuits, which ensures the accurate transmission of monitoring data.

As the core component of the system, the embedded development board adopts STM32 series microcontroller with stable performance and low power consumption to be responsible for data acquisition, processing and transmission. The design of the development board includes power supply circuit, which can use lithium battery or solar power supply system to provide reliable power support for field environmental monitoring [4]; The sensor interface circuit adapts to various sensors and converts their analog or digital signals into a format that can be processed by the microcontroller; In addition, the storage circuit is also configured to ensure that there is enough space to temporarily store environmental data to prevent data loss caused by unexpected circumstances; Finally, the Wi-Fi/4G communication module is integrated, which makes wireless data transmission and remote monitoring possible.

In order to improve the practicability and flexibility of the system, several peripherals and extended functions are added, including a small LCD screen, which is used to display environmental monitoring data in real time for users to read directly; Alarm devices, such as buzzer or LED lights, will trigger an alarm when abnormal environmental parameters are detected, prompting users to respond quickly; At the same time, the system has reserved extended interfaces, such as GPIO port and I2C interface, which provides convenience for adding more sensors or functional modules in the future [5-6].

2.2. Software design

The overall architecture of the software adopts modular design to facilitate the expansion and maintenance of the system. The main modules include data acquisition module, data processing module, data storage module, early warning module and communication module. The modules communicate with each other through defined interfaces to ensure the loose coupling of the system. The schematic diagram of modular design of the system is shown in Figure 1.

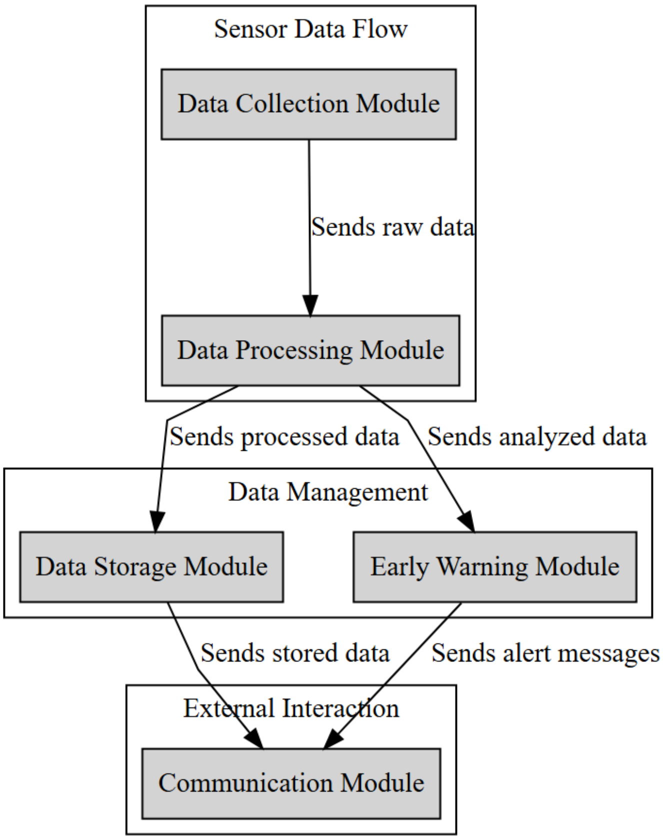

Figure 1: Schematic diagram of system modular design

The data acquisition module is responsible for communicating with the sensor to obtain environmental parameter data. The module needs to poll all sensors regularly, read their values, and pass the read raw data to the data processing module. In order to ensure the accuracy and real-time performance of the data, the interrupt-driven method is adopted, and when the sensor data changes, the data acquisition operation is triggered immediately.

The data processing module is responsible for processing and analyzing the collected original data. Firstly, the data is preprocessed, such as denoising and filtering, to improve the data quality. Then, according to the preset algorithm, the data is further analyzed, such as calculating statistics such as average value, maximum value and minimum value, or forecasting the trend. The processed data will be transmitted to the data storage module and the early warning module.

The data storage module is responsible for saving the processed environmental parameter data for subsequent query and analysis. The lightweight database system SQLite is used to store data, which can ensure the persistence and quick query of data. At the same time, the data backup and recovery mechanism is designed to prevent data loss [7].

Early warning module is one of the core functions of the system, which judges whether the environmental conditions are abnormal according to the preset threshold and environmental parameter data. When the environmental parameters exceed the threshold, the early warning module will immediately trigger the alarm and send the alarm information to the relevant personnel through the communication module. Alarm information includes detailed information such as the type, value and occurrence time of abnormal parameters, so that relevant personnel can take timely measures to deal with them.

The communication module is responsible for data exchange and remote control with external systems. The HTTP/HTTPS protocol is adopted to communicate with the cloud server, and the functions of uploading and downloading data are realized. At the same time, it also supports Internet of Things communication protocols such as MQTT, so as to communicate with other smart devices. In order to ensure the security and stability of communication, encryption transmission and error retransmission mechanism are adopted. The main program flow of communication module is shown in Figure 2.

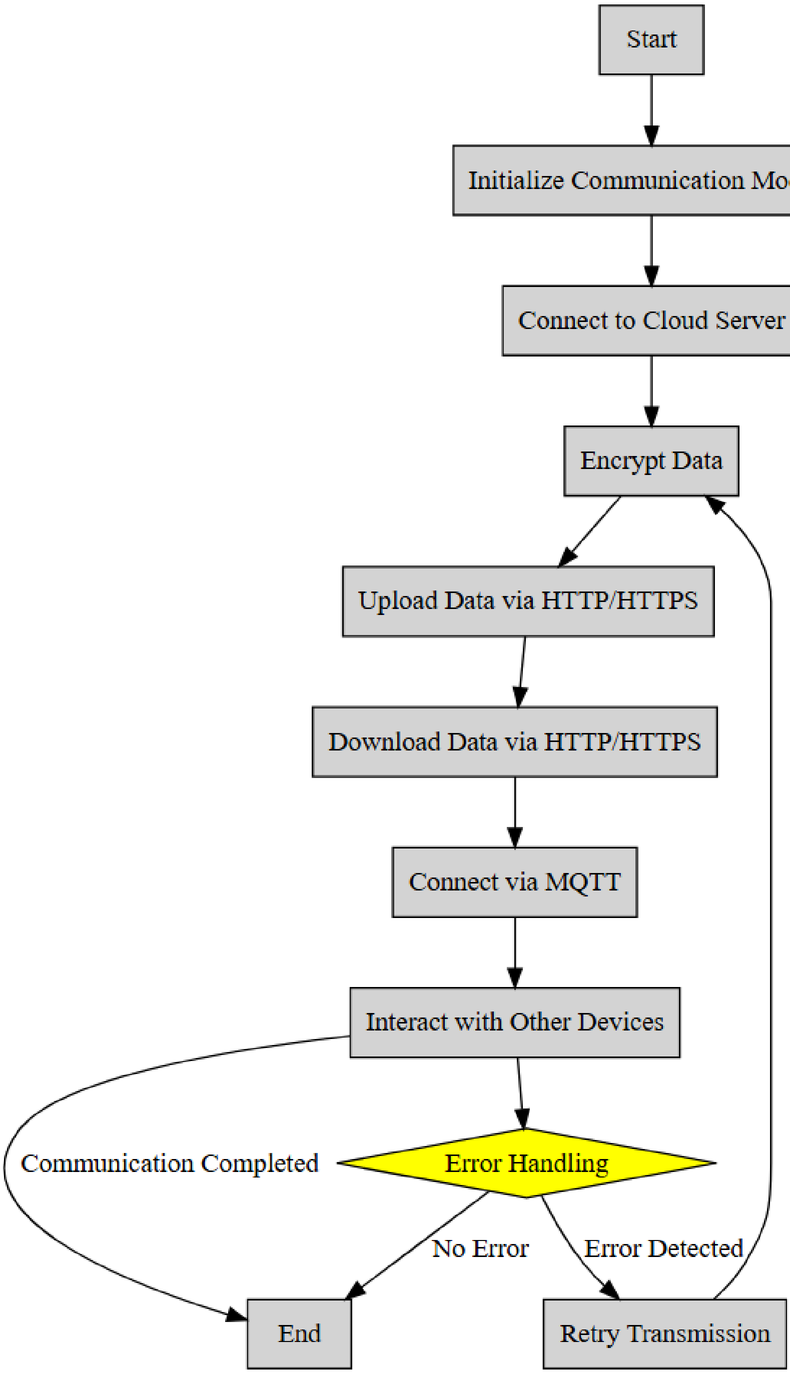

Figure 2: Main program flow of communication module

2.3. Early warning mechanism design

The core goal of the early warning mechanism is to monitor the environmental parameters in real time, and when the parameters exceed the preset safety range, the alarm will be triggered quickly to inform relevant personnel to take countermeasures. The mechanism should have high sensitivity, low false alarm rate and powerful notification function to ensure the effectiveness of the system. This early warning mechanism design method combines static and dynamic threshold setting, multi-parameter combination trigger conditions, hierarchical notification process, early warning cancellation and post-processing.

Static Threshold According to historical data and expert advice, a static safety range is set for each environmental parameter. The temperature is set at 20-25℃ and the humidity is set at 40%-60% [8]. Dynamic threshold uses machine learning algorithm to analyze historical data, and dynamically adjusts the early warning threshold according to the changing trend and seasonal characteristics of environmental parameters. This will help to improve the flexibility and accuracy of the early warning mechanism. When the real-time value of an environmental parameter exceeds its static or dynamic threshold, an early warning is triggered immediately. Multiple parameters are abnormal at the same time or successively, which may indicate that there are more complex environmental problems. This kind of situation can be identified by setting the combined trigger conditions, such as temperature and humidity exceeding the standard at the same time.

The early warning notification process includes the division of early warning levels, which are divided into low, medium and high according to the severity of environmental anomalies; Choose different notification methods according to the level. Low-level early warning uses system prompt or email, while high-level early warning is notified by SMS, telephone or instant messaging tools. Clearly notify the target to ensure that the system administrator, monitoring personnel and emergency team can be contacted quickly when the early warning is triggered. The early warning can be lifted automatically or manually after the environmental parameters return to normal and last for a certain period of time. After each warning, the system generates a record report for data analysis and optimization.

3. Experiment and result analysis

In order to comprehensively evaluate the performance of intelligent environmental monitoring and early warning technology based on embedded system, a variety of experimental environments are constructed to simulate different conditions for testing, including adjusting temperature, humidity and illumination in the laboratory to simulate daily home or office environment; Set up experimental points in open areas such as industrial parks to test the stability and accuracy of the system under natural conditions; And through the use of temperature control box, humidifier and other equipment to create high temperature, low temperature, high humidity and other extreme environments, to test the reliability and responsiveness of the system under extreme conditions.

During the experiment, the system continuously collects real-time environmental data such as temperature, humidity and light every minute, and records the time, parameters, level and notification of early warning trigger; At the same time, record the key operation events of the system, such as start-up, stop and abnormal conditions, so as to analyze the system performance.

The monitoring accuracy of the system varies under different environmental conditions (see Figure 3). Specifically, temperature monitoring is more accurate indoors, but the accuracy decreases under extreme high temperature; Humidity monitoring is acceptable in ordinary environment, but the accuracy is poor in high humidity; The overall accuracy of illumination monitoring is high, with slight deviation in outdoor environment. This shows that the monitoring accuracy of the system needs to be improved under extreme conditions, which provides a direction for optimizing sensor selection and calibration algorithm.

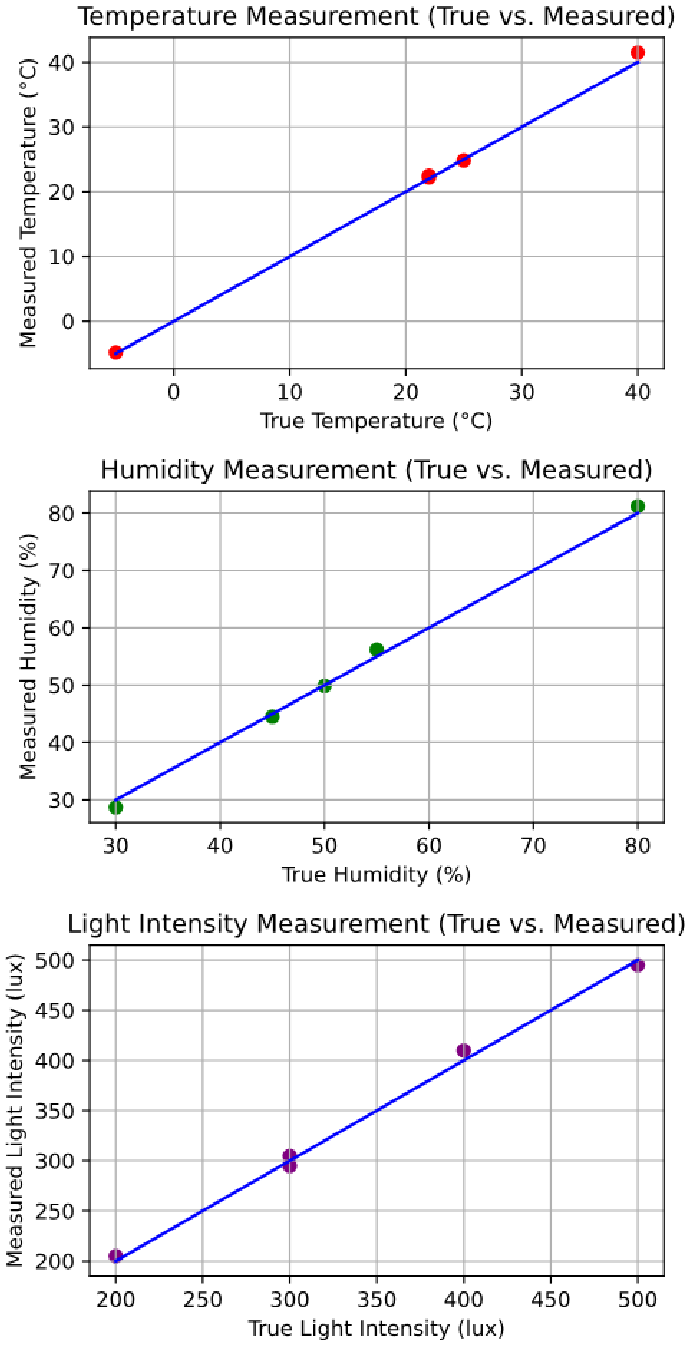

Figure 3: System monitoring value and real value under different environmental conditions

As can be seen from Table 1, the response speed of the system is faster at normal indoor temperature and normal outdoor temperature, and the response time is 0.5s and 0.6s respectively. However, under indoor and outdoor high temperature conditions, the response time of the system increased to 0.8s and 1.2s respectively, especially under extreme high temperature conditions, the response time reached 1.5s. This shows that the response speed of the system has decreased in high temperature environment, which may be related to the limited performance of hardware equipment.

In terms of stability, the system shows good long-term running ability, and there is no serious failure or abnormality. However, in high humidity environment, the reliability of some hardware components is challenged, so it is necessary to strengthen moisture-proof measures or choose more moisture-resistant materials.

Table 1: Response speed of the system

environmental conditions	Response time (s)	Early warning trigger times
Normal indoor temperature	0.5	10
Indoor high temperature	0.8	8
Normal outdoor temperature	0.6	12
Outdoor high temperature	1.2	7
Extreme low temperature	0.7	9
Extreme high temperature	1.5	5
High humidity	0.9	11

Based on the experimental results, it is suggested to improve the monitoring accuracy under outdoor and extreme conditions by adopting higher-level sensors or introducing data fusion algorithms. Optimize the hardware design, choose a microcontroller with low power consumption and high frequency, and optimize the software algorithm to reduce the calculation delay, thus improving the response speed of the system; Moistureproof hardware or materials with higher moistureproof performance are selected to enhance the stability in high humidity environment, and strengthen the ability of fault detection and recovery, so as to ensure that the system can quickly resume normal operation when it is abnormal.

4. Conclusion

A system integrating temperature, humidity, CO2, PM2.5 and light intensity is developed. With STM32 series microcontroller as the core, accurate real-time data acquisition and processing are realized, and it has the function of abnormal early warning. The system design is modular, supports expansion, and can transmit data wirelessly to support remote monitoring. Experiments show that the system performs well in normal indoor and outdoor environment, but the response speed decreases at high temperature, and the stability in high humidity environment is affected, suggesting that hardware performance should be optimized, software algorithms should be adjusted and moisture-proof measures should be strengthened. Generally speaking, the system improves the efficiency and accuracy of environmental monitoring, contributes to environmental protection and sustainable development, and will further improve the performance and reliability under extreme conditions in the future.

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