Design of a Digital Laboratory Management System Based on the Internet of Things

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Abstract. In the context of the rapid development of information technology in the current era, there exist some problems in college laboratory management such as high difficulty in maintenance and low management efficiency. To address this issue, this paper designs a digital laboratory management system that uses both wired and wireless networks, servers, sensor devices, and IoT control equipment, which can achieve real-time monitoring and remote management of the laboratory, reduce workload and difficulty in practical teaching management, and provide some technical support and reference methods for college practical teaching management.

Keywords: digital laboratory management system, practical management, digital twin, IoT.

1 Introduction

In the context of the rapid development of information technology in today's society, universities have increasingly higher requirements for using laboratories [1], but traditional laboratory management methods cannot keep up with the rapid changes in demand, resulting in a series of problems and challenges, such as difficult laboratory maintenance, difficulties in reserving laboratory space, low utilization rate of laboratories, etc. These issues result in poor efficiency in practical teaching management, inadequate protection of teaching quality, and hinder the cultivation of students' practical ability and comprehensive qualities [2].

In terms of research and application of laboratory management systems, many scholars have conducted a series of studies and explorations. Hua, N., Han, J., and Tian, H. discussed how to design and implement a laboratory instrument management system based on B/S architecture [3]. Zhang, W. studied the application of big data technologies in laboratory management and provided a reference construction plan for a big data technology laboratory [4]. Le, SK, Adi, NH, and Kusuma developed a Web-Based Computer Laboratory Management Information System using Codeigniter to improve the efficiency of computer laboratory management [5]. In digital twin technology, Förster, D. researched its application in the construction and building industry [6]. Yang, Y., Zou, J., et al. summarized the basic concepts, technical characteristics, application prospects, and development trends of digital twin technology, analyzed and classified its common core concepts, key technologies, and application prospects in different application fields, as well as its relationship with other corresponding Internet of Things technologies such as artificial intelligence, industrial big data, etc. [7].

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This article hopes to provide powerful technical support and methodological reference for university practical teaching management through the design of digital laboratory management.

2 Overall architecture

2.1 Technical introduction

The system adopts both wired and wireless network transmission technologies to ensure the stability of system communication. The wired network uses traditional Ethernet technology that can adapt to existing network equipment, reducing the system's investment cost and ensuring system compatibility and stability. The wireless network uses both 4G and WiFi technologies to support more connected devices and a wider coverage range.

The Internet of Things (IoT) technology can connect various physical devices, sensors, and intelligent terminals to the Internet, thereby achieving data exchange and sharing between devices, thus realizing intelligent control and management.

Digital twin technology is an emerging technology that works by collecting various data from physical entities, such as temperature, pressure, speed, and so on, establishing a digital model of the physical entity, and simulating and predicting its behavior and state through simulation and prediction.

2.2 Systematic architecture design

The system adopts a star topology network topology, which connects to the existing campus network using traditional Ethernet technology, and supports terminal devices such as mobile phones and computers to access the internet via the external network. The control host transmits the information collected by the sensors to the server through a POE switch, while the relevant data is displayed on the display terminal in real time. The system converts the collected data into a digital model in real-time using digital twin technology. The administrator can remotely control the equipment in the laboratory through the network. As shown in the figure 1.

The components of the system are described as follows:

1) Data collection. The laboratory collects various types of information, including temperature and humidity, PM values, and other data through various sensors. The control host verifies the information collected by the sensors and transmits it to the server via the Ethernet network.

2) Data processing and modeling. The server analyzes and processes the collected information and generates a digital model. It then performs trend analysis and prediction in the laboratory environment.

3) Remote management. The system can automatically control devices based on pre-set thresholds. Additionally, the administrator can remotely control the devices through the network based on actual needs.

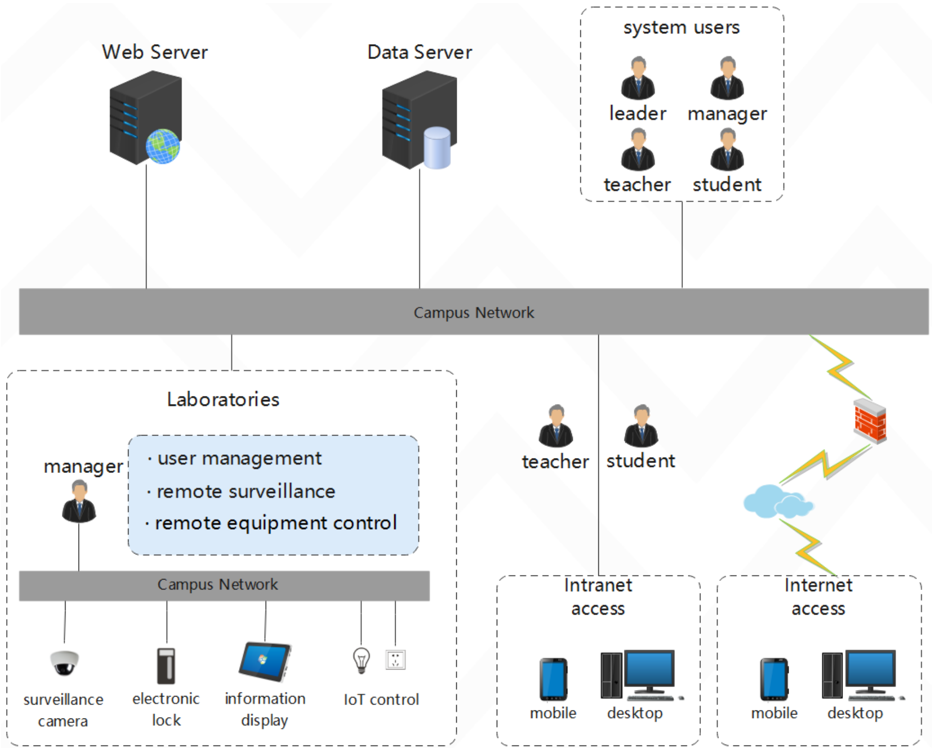

Fig. 1. Systematic architecture design.

2.3 System automatic management

The system can analyze and process the information collected by the server and automatically control the devices based on pre-set thresholds. For example, in the case of a fire warning, the specific detection process and automatic control method are as follows.

1) If the smoke detector in the laboratory detects abnormal values, the system will automatically prompt the user to check the indoor situation promptly.

2) If the temperature sensor in the laboratory detects abnormal values, the system will automatically prompt the user to check the indoor situation promptly.

3) If both the smoke detector and temperature sensor in the laboratory detect abnormal values simultaneously, the system will issue an alarm and automatically open the laboratory doors and windows, reminding the user to promptly report the situation and avoid personnel casualties.

3 Hardware design

The system hardware includes five categories of hardware devices: servers, sensors, network devices, remote control devices, and security management devices. In the system, the control host transmits the information collected by the sensors to the server via the network device.

Terminal devices can access the system to control the remote control devices and security management devices through applications or web pages. The communication process between the sensor and the server is achieved through a wired Ethernet connection, and in addition, the terminal device and the server can be connected through 4G and WiFi technologies. As shown in the figure 2.

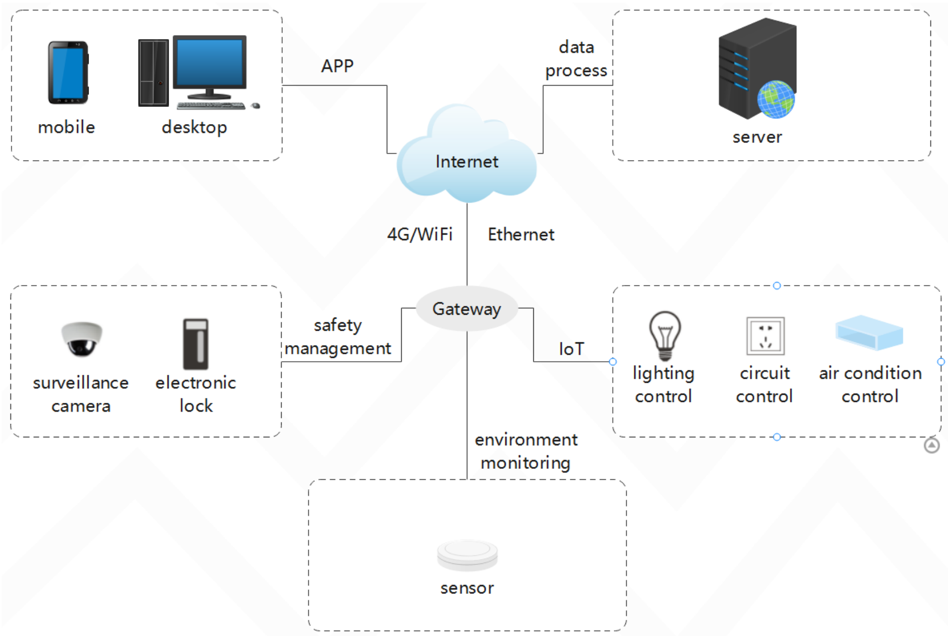

Fig. 2. System hardware design

4 Software design

The digital experiment management system consists of four subsystems: environmental monitoring nodes, data transmission nodes, data processing nodes, and interactive software, as shown in Figure 3.

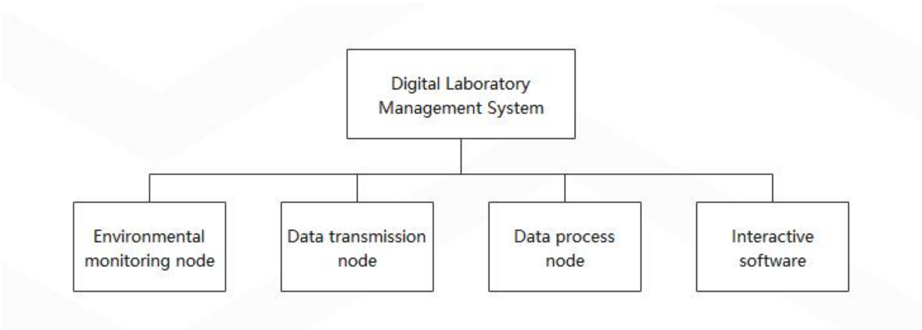

Fig. 3. System software design

4.1 Environmental monitoring node

The environmental monitoring node includes initialization programs for the control host and various collection modules, as well as data-checking programs for the control host. The system first performs initialization operations and then conducts data collection. The collected data is analyzed, processed, corrected, and calculated by the control host to obtain the actual result value. The flowchart of the program is shown in Figure 4.

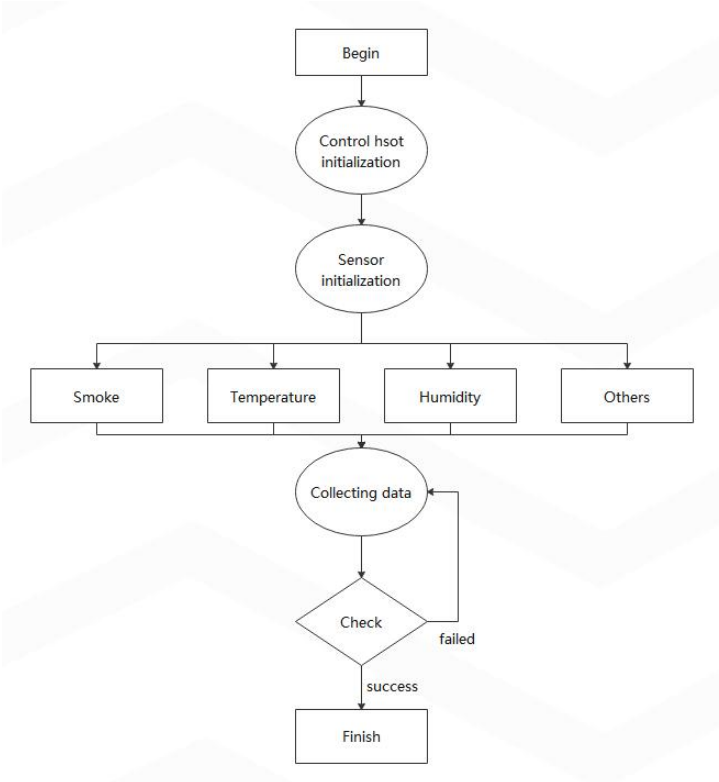

Fig. 4. Flowchart of the environmental monitoring node

4.2 Data transfer node

The data transfer node mainly refers to the communication protocol between different devices. The data sent by the control host is transmitted through the ethernet, and after receiving the data, the server performs verification and processing, as shown in Figure 5.

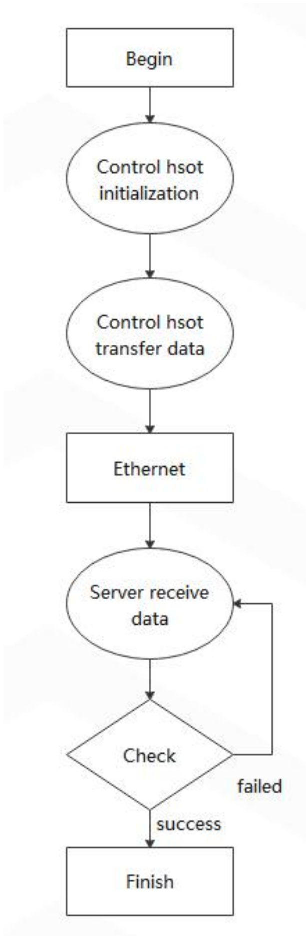

Fig. 5. Flowchart of the data transfer node

4.3 Data processing node

The data processing node includes the data storage and data analysis modules. The data storage module is used to store the collected data, including timestamps, sensor information, and other data. The data analysis module processes and analyzes the stored data using digital twin technology to generate a real-time laboratory model.

4.4 Interactive software

The interactive software of the system adopts a B/S architecture based on Java as a solution, compared with the C/S architecture, the B/S architecture centralizes the core part of the system function implementation on the server, simplifies system development, maintenance, and use, reduces the client's load, and reduces system maintenance and update costs. The platform's data uses Microsoft Corporation's SQL Server relational database to provide services for data sharing and management for all clients, ensuring the accuracy and completeness of the data, and enabling the system to have good performance and scalability. The interactive software of the entire system mainly consists of three parts: the user management module, the data visualization display module, and the remote management module. The specific functions of each module are shown in Figure 6.

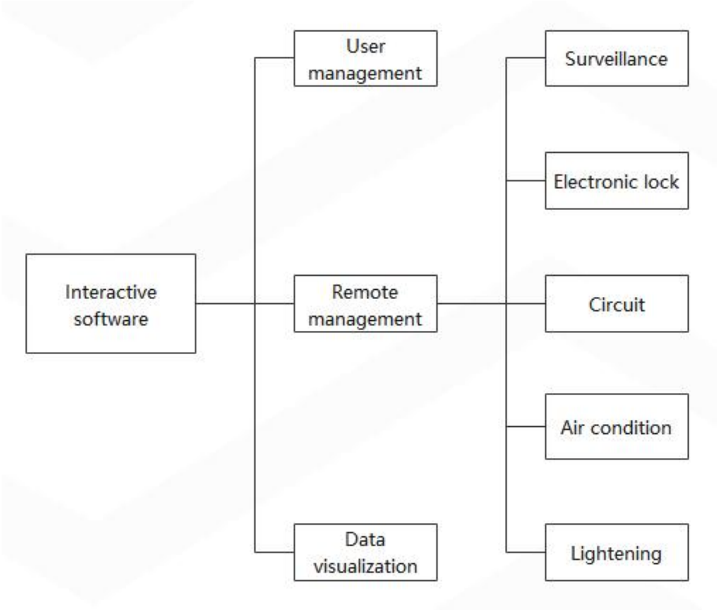

Fig. 6. The specific functions of each module.

5 Conclusion

In response to the current challenges faced by universities in maintaining their laboratories, such as low efficiency and outdated information technology levels, this paper proposes a digital laboratory management system that utilizes existing Ethernet infrastructure. The system consists of coexisting wired and wireless networks, servers, sensors, IoT-enabled control devices, and security management devices. The digital laboratory management system is designed to have excellent compatibility, stability, and scalability, and can meet the remote monitoring needs of laboratories, thereby improving the level of laboratory management information. Additionally, with sufficient funding, universities can consider increasing the number and accuracy of sensors and cameras to achieve more comprehensive and precise data collection and monitoring, further improving the efficiency and quality of laboratory management and achieving continuous optimization and development of the system.

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