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Research on the Intelligent Design and Management of Buildings Based on the Internet of Things Engineering

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Abstract: The Internet of Things (IoT) technology provides new impetus for the development of building intelligence. This research focuses on the intelligent design and management of buildings based on IoT engineering. It expounds on the system design principles such as sensor technology, communication network technology, and data storage and analysis, and analyzes the key points of design, including design requirement analysis, equipment layout, and system integration. Through specific cases, it demonstrates the application practice of the system in buildings, and presents the application effect of intelligent system management with multi-parameter values, providing theoretical and practical references for the development of building intelligence and helping to achieve efficient, energy-saving, and safe building operation.

Keywords: Internet of Things; Building intelligence; System design; Sensor technology; Data management

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1. Introduction

With the continuous progress of science and technology, the construction industry has ushered in new development opportunities. The traditional building management model has many problems, such as resource waste, low management efficiency, and difficulty in timely detection of potential safety hazards. It is increasingly difficult to meet the high requirements of modern society for building functions and performance [1]. IoT engineering, with its unique advantages, realizes the interconnection of devices and real-time data interaction through technologies such as sensors and communication networks, providing crucial support for the intelligent transformation of buildings [2]. Applying IoT engineering to the intelligent design and management of buildings can achieve precise monitoring and intelligent control of various aspects of buildings, such as internal equipment, environment, and energy consumption [3]. This can effectively improve building operation efficiency, reduce energy consumption costs, and enhance safety. Currently, building intelligence has become an important trend in the industry. In-depth research on the intelligent design and management of buildings based on IoT engineering is of great practical significance for promoting technological innovation in the construction industry and enhancing the comprehensive competitiveness of buildings.

2. System design principles

2.1. Sensor technology

Sensors, as key devices for obtaining information in IoT systems, play a sensing role in intelligent building systems. Different types of sensors can collect multi-dimensional information within buildings. Temperature sensors use thermosensitive elements to sense changes in environmental temperature and convert temperature signals into electrical signals for output, with an accuracy of up to ± 0.5°C, enabling real-time monitoring of indoor and outdoor temperature changes [4]. Humidity sensors utilize the capacitance characteristics of polymer films to measure air humidity, with a resolution of up to 1% RH, providing a data basis for indoor humidity control. Smoke sensors can respond rapidly when the smoke concentration reaches 0.01mg/m³ through photoelectric or ion-sensing principles, achieving early-warning of fires [5]. Pressure sensors, based on the piezoresistive effect, can accurately measure information such as pipeline pressure and equipment stress, with an error of no more than ± 0.2% FS. Multiple sensors work together to construct a comprehensive information collection network, providing rich and accurate data for intelligent building systems.

2.2. Communication network technology

Communication network technology serves as a bridge for the interconnection of devices within buildings. Among wireless communication technologies, Bluetooth technology is suitable for short-distance data transmission between devices, such as the connection between smart locks and mobile phones. Its transmission distance is generally within 10 meters, and the transmission rate can reach 1Mbps [6]. ZigBee technology has the characteristics of low power consumption and self-networking, enabling wireless connection of multi-node devices within buildings. The communication distance ranges from 10 to 75 meters, and it supports multiple network topologies such as star-shaped and mesh–shaped [7]. Wi-Fi technology, with its high-speed transmission advantage, has a maximum transmission rate of up to 1Gbps and is widely used in high-speed data transmission scenarios within buildings, such as the real-time transmission of surveillance videos. In terms of wired communication technology, Ethernet uses the TCP/IP protocol, featuring stable transmission and high bandwidth [8]. It is often used for connecting core devices within buildings, with a transmission distance of up to 100 meters. Different communication technologies complement each other. According to the distribution and functional requirements of devices within buildings, a stable and efficient communication network is constructed to ensure reliable data transmission.

2.3. Data storage and analysis

Data storage and analysis are the core links for mining the value of building operation data. In terms of data storage, distributed storage technology is adopted, which distributes data across multiple nodes, improving the reliability and scalability of data storage. For example, the Ceph distributed storage system can dynamically expand the storage capacity according to the building scale and also has a data redundancy protection function to ensure data security. At the data analysis level, big data analysis technology is used to clean, transform, and analyze the collected massive data [9]. Cluster analysis can classify building energy consumption patterns, identify high energy consumption periods and areas. Correlation analysis can discover potential relationships between device operation parameters, such as the correlation between the operating temperature of air conditioners and the indoor population density. Machine learning algorithms can be used to predict device failures. By learning from the historical operation data of devices, a failure prediction model is established to identify device abnormalities in advance, providing a scientific basis for device maintenance.

3. Design of intelligent building management system

3.1. Design requirement analysis

The intelligent building management system needs to meet the requirements of the entire building life-cycle management. During the operation and maintenance stage, managers expect to have real-time access to device operation status, promptly detect potential failures, and arrange maintenance to reduce the risk of unplanned downtime [10]. In terms of energy conservation, through in-depth analysis of energy consumption data, the potential for energy savings is explored to achieve refined management of building energy and reduce operating costs. Different types of buildings have significant differences in requirements. Hospital buildings need to ensure the continuous power supply of medical equipment and environmental stability to ensure the normal operation of medical services. School buildings focus on the management of personnel evacuation safety and the control of environmental comfort in teaching areas. In addition, the system needs to have good compatibility, be able to connect devices of different brands and from different periods, and at the same time meet the requirements of data security and privacy protection to prevent data leakage and illegal access, building a solid security line for intelligent building management.

3.2. System architecture

The architecture of the intelligent building management system adopts a hierarchical design concept (refer to **Figure 1**). The perception layer consists of various sensors and intelligent terminals, responsible for collecting basic data such as device operation data, environmental parameters, and personnel activity information within the building, such as temperature-humidity sensors and current-voltage sensors. The network layer relies on wired and wireless communication networks to achieve efficient data transmission, accurately transmitting the data collected by the perception layer to the platform layer, and at the same time transmitting the control instructions of the platform layer to the execution devices [11]. The platform layer is the core of the system, undertaking data storage, processing, and analysis functions. It uses big data technology to clean and mine massive data, and through algorithm models, functions such as device failure prediction and energy consumption optimization are realized [12]. It also provides a unified management interface for managers to facilitate device management and strategy configuration. The application layer, based on the data and functions of the platform layer, develops diverse applications such as intelligent operation and maintenance, energy-saving management, and security monitoring to meet the needs of different users and achieve

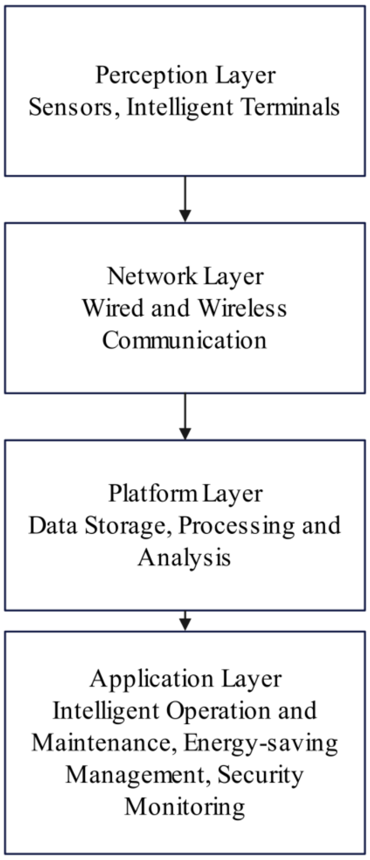

Figure 1. System architecture diagram

efficient operation and precise decision-making in intelligent building management.

4. Realization of intelligent building management functions

4.1. Communication control system integration

The integration of the communication control system realizes the interconnection of heterogeneous devices through standardized protocols and interfaces. Industrial-grade communication protocols, such as the MQTT protocol, are used to achieve lightweight communication between devices and the platform, reducing network load. The OPC UA protocol is used to achieve data semantic interoperability between devices of different manufacturers, eliminating information silos [13]. A distributed communication architecture is constructed, dividing the building into multiple communication sub-networks. Each sub-network realizes data aggregation and protocol conversion through gateways, enhancing the system's anti-interference ability and stability. At the control level, a hierarchical control mechanism is established. The underlying devices achieve autonomous logic control, the middle layer realizes device collaboration through regional controllers, and the top-level central control system conducts global strategy allocation to achieve the linkage control of lighting, air-conditioning, elevators, and other devices, improving building operation efficiency [14].

4.2. Real-time monitoring of buildings

The real-time monitoring system is based on the integration of multi-source data to construct a comprehensive monitoring system. It uses IoT sensors to collect device operation parameters, environmental indicators, and personnel activity information in real-time, and combines video surveillance and RFID positioning technology to achieve a three-dimensional perception of the building's physical space and personnel behavior. In terms of device monitoring, vibration sensors, infrared thermal imagers, and other devices are used to conduct non-invasive monitoring of key devices, obtaining data such as device vibration frequency and surface temperature, and the device health status is diagnosed in real-time through a state evaluation model. In environmental monitoring, air quality sensors, noise monitors, and other devices are deployed to draw a real-time distribution map of building environmental parameters, providing data support for environmental regulation [15]. Personnel monitoring uses access control systems and video analysis technology to keep track of personnel flow trajectories and gathering situations in real-time, ensuring the safe and orderly operation of the building.

4.3. Remote control of equipment

The remote control function of equipment is realized through a secure and reliable network channel and a permission management mechanism. Virtual Private Network (VPN) technology is used to establish an encrypted communication tunnel to ensure the secure transmission of remote control commands. A multi-role permission management system is designed to assign device operation permissions according to user responsibilities to prevent unauthorized operations. A cross-platform control application is developed, supporting access from multiple terminals such as PCs and mobile devices. Users can remotely start, stop, and adjust the operation parameters of equipment through a visual operation interface. In the remote control of air - conditioning systems, users can remotely set the operation mode and temperature value according to indoor and outdoor temperatures and population density. In elevator management, maintenance personnel can remotely view the elevator operation status, conduct fault diagnosis, and perform program upgrades, reducing on-site maintenance costs and enhancing equipment management flexibility [16].

4.4. Alarm and early-warning functions

The alarm and early-warning functions achieve intelligent early-warning through data mining and machine learning algorithms [17]. An abnormal data detection model is established, and threshold models and pattern recognition algorithms are trained based on historical data. When real-time data exceeds the normal range or an abnormal pattern appears, an immediate alarm is triggered, and relevant personnel are notified through multiple methods such as sound and light, text messages, and APP push notifications. Early-warning uses time-series analysis and fault prediction algorithms to analyze the trend of device operation data and predict the probability and time of device failures. For example, by analyzing the flow, pressure, and vibration data of water pumps, the LSTM neural network is used to predict the wear degree of water pump bearings, and maintenance plans are made in advance to eliminate potential failures, reduce equipment downtime losses, and ensure the stable operation of the building.

4.5. Data analysis and statistics

Data analysis and statistics focus on building operation data and use big data analysis technology to mine data value. A data warehouse is constructed to integrate multi-dimensional data, such as device operation, energy consumption, environment, and personnel. ETL technology is used for data cleaning, transformation, and loading. Data visualization tools are used to convert complex data into intuitive charts and dashboards, showing key indicators such as building energy consumption distribution, equipment utilization rate, and environmental quality changes. Algorithms such as cluster analysis and association rule mining are used to discover building operation laws and potential problems. For example, by analyzing the correlation between lighting energy consumption and personnel activity time, the lighting control strategy is optimized. By clustering the energy consumption patterns of different areas of the building, high energy consumption areas are identified, and energy-saving renovation plans are developed. At the same time, statistical reports and analysis reports are generated regularly to provide a scientific basis for building managers to promote the continuous improvement of intelligent building management levels.

5. Application case

5.1. Case background

A large-scale commercial complex is selected as a case. The complex has a total construction area of 250,000 square meters and consists of a shopping mall, Grade A office buildings, a five-star hotel, and an underground parking lot. The average daily footfall exceeds 50,000 people, and there are more than 2,000 pieces of equipment in the building, such as central air-conditioning systems, elevator group control systems, and intelligent lighting systems. Under the traditional management model, equipment operation and maintenance rely on manual inspections, resulting in serious energy waste and blind spots in safety monitoring. To solve these problems, the commercial complex introduced an intelligent building management system based on IoT engineering, aiming to create an efficient, energy-saving, and safe building operation environment and enhance the overall operation efficiency and user experience.

5.2. Application effect

Six months after the intelligent system was put into use, significant improvements were achieved in multiple key indicators of building operation. The specific data are shown in **Table 1**. From the data, it can be seen that the intelligent system has greatly reduced the daily total energy consumption through precise energy management strategies. The decrease in the energy consumption proportion of the air-conditioning system reflects the energy-saving advantages of intelligent control. The number of elevator failures has decreased significantly, improving equipment reliability and operational safety. The intelligent adjustment response time of the lighting system is controlled within 3 seconds, achieving timely and precise lighting control. The shortening of the response time for security incidents effectively guarantees the safety of personnel and property in the building. In addition, the improvement of indoor air quality and the increase in user satisfaction fully demonstrate the excellent results of the intelligent system in optimizing the user experience.

Table 1. Application effect of intelligent system management

Evaluation index	Before application	After application	Improvement rate
Daily total energy consumption (kWh)	12500	9200	26.4%
Energy consumption proportion of air-conditioning system (%)	45	38	15.6%
Intelligent adjustment response time of lighting system (s)	5	≤ 3	-
Average response time for security incidents (min)	15	5	66.7%
Number of elevator failures (times/month)	8	2	75%

6. Conclusion

The intelligent design and management of buildings based on IoT engineering realize the intelligent operation and efficient management of buildings through advanced sensor technology, communication network technology, and data processing technology. This research starts from the system design principles, elaborates on the key points of intelligent building design, and verifies its application effect through practical cases. The research shows that this technology can effectively improve the energy utilization efficiency, management level, and safety of buildings.

Disclosure statement

The author declares no conflict of interest.

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