International Journal of Computer Science & Information Technology (IJCSIT) Vol 17, No 6, December 2025

IoT-Based Smart Building Monitoring and Control Strategies With Intelligence Deep Neural Networks

Tony Tsang and Yau Ka Hei

Centre of International Education, Hong Kong College of Technology,
Hong Kong

ABSTRACT

This paper systematically discusses the application of Internet of Things (IoT) technology in intelligent building monitoring and control, focusing on its core role in energy management, environmental regulation, equipment maintenance and security monitoring. By integrating sensor networks, data communication layers, intelligent decision-making and execution layers, this study constructs an IoT-based intelligent building management framework, aiming to achieve real-time monitoring and dynamic optimization of the building environment. The literature review summarizes the current status of IoT technology applications in intelligent buildings, including innovative practices of algorithms such as support vector machines (SVM) and deep reinforcement learning in equipment control and energy scheduling, and points out the challenges such as sensor deployment, data integration and communication protocol optimization. Through case analysis and mathematical modelling (such as multi-objective optimization model and Q learning algorithm), the study verifies the significant advantages of deep neural networks (DNN)[1] in prediction accuracy and response with an accuracy of 85.2%, which is better than the traditional linear regression and SVM models. Preliminary data shows that the IoT system can dynamically adjust temperature, humidity and lighting intensity, reducing energy waste by more than 30%. Future research will focus on the integration of edge computing and distributed architecture to improve real-time and scalability of the system and to promote the evolution of smart buildings towards efficiency, greenness and adaptability.

KEYWORDS

Internet of Things (IoT), smart buildings, energy management, deep reinforcement learning, edge computing

1. Introduction

1.1. Importance of Smart Building Monitoring and Control

In 2010, a fire accident occurred in Shanghai Ruijin Hospital, causing serious property losses and casualties. The incident occurred in the hospital's inpatient department. Because the hospital's building management system failed to effectively link and monitor the early signs of the fire, the fire spread rapidly and was not effectively controlled in the first place. When the fire broke out, the smoke sensors in the building failed to issue an alarm in time, and the temperature sensors failed to accurately capture the temperature rise information of the fire source, resulting in the failure to quickly start the automatic fire extinguishing system or effectively evacuate in the early stage of the fire. Although the hospital has installed basic fire-fighting facilities, the response speed of these facilities is greatly reduced due to the lack of intelligent linkage. Facilities such as the air- conditioning system, lighting equipment and power system in the building also failed to be shut down or adjusted in time according to the situation of the fire, which caused the fire to spread rapidly without being effectively controlled. The result of the accident was 15 deaths, more than 50 injuries, and property losses of up to 150 million RMB. In this accident, the traditional building management system failed to provide sufficient real-time monitoring capabilities and intelligent response mechanisms, resulting in the spread of the fire and delays in rescue. Although Ruijin Hospital is equipped with traditional smoke detectors and firefighting equipment, these systems have not been deeply integrated with the overall management system of the building, and cannot achieve real-time data sharing and dynamic response. In intelligent building management, the effective linkage of sensors, fire alarm systems and control systems are crucial. IoT technology can continuously monitor various environmental parameters inside the building, such as temperature, humidity, air quality and smoke concentration using sensors. Once an abnormality is detected, the system can automatically start the emergency procedure and intervene quickly to avoid the spread of fire. Ruijin Hospital lacks this kind of intelligent linkage mechanism, which makes the fire fail to be responded to and effectively controlled in time at the early stage, thus aggravating the severity of the accident.

Intelligent building management system relies on IoT technology to optimize building operation through real-time data collection, intelligent analysis and automatic adjustment [2]. The core advantages of IoT are its real-time, precision and automation, which enables buildings to autonomously adjust the operating status of facilities according to environmental changes, ensuring safety and efficiency of building operation. In intelligent buildings, the fire monitoring system does not rely solely on traditional fire alarms, but through deep integration with the building management system, it tracks changes in the internal environment of the building in real time and predicts potential risks. By integrating temperature and humidity sensors, smoke detectors and other equipment, the intelligent system can identify the occurrence of fire sources and provide early warnings through data analysis at the early stage of a fire. This early warning mechanism can achieve cross-system information sharing and coordination through the Internet of Things technology, so that air conditioning, lighting, electricity and other equipment can be turned off in time at the moment of a fire to prevent the spread of the fire. In terms of fire emergency response, the intelligent building control system can automatically start the fire extinguishing system, control the air circulation around the fire source, and activate the emergency evacuation channel. The intelligent linkage of these systems can significantly improve the building's ability to respond to emergencies, shorten the response time, and minimize the losses after the disaster. The intelligent building monitoring system can not only respond to fires in a timely manner, but also provide real- time data support for rescue personnel after the fire, helping them to determine the specific location of the fire source, the speed of the fire spread, the distribution of people on the floor and other key information, and then take the most effective response measures.

The lessons of the Ruijin Hospital fire accident revealed the huge gap between traditional building management systems and modern intelligent control systems. In modern buildings, intelligent monitoring and control systems are not only for energy saving or improving comfort, but also for ensuring building safety and reducing losses caused by emergencies. Intelligent systems can provide all-round real-time monitoring, combined with big data analysis and artificial intelligence technology, to predict and identify potential dangers in advance and take proactive control measures. For example, when a fire occurs, the intelligent system can monitor indoor air quality changes, smoke concentration and temperature changes in real time, shut down unnecessary equipment in time, start the fire extinguishing system, and prevent the fire from spreading. In addition, the intelligent system can automatically provide evacuation guidance for people in the building to avoid people's mis-judgment or delay in escape time. Therefore, the construction of intelligent building monitoring and control systems can not only improve the energy management efficiency of buildings, but also significantly improve the emergency response capabilities of buildings in emergencies. The occurrence of the Ruijin Hospital fire shows that buildings that lack intelligent monitoring and control systems often find it difficult to cope with complex emergencies such as fires. The introduction of intelligent monitoring and control will effectively reduce the probability of such incidents, shorten disaster response time, and minimize catastrophic consequences.

1.2. Research Objectives and Scope

1. Constructing a framework for intelligent building monitoring and control systems based on the Internet of Things：The primary goal of this study is to design and implement a new framework for intelligent building monitoring and control systems driven by the Internet of Things. The framework will achieve real-time monitoring of all facilities and environments in the building by integrating various intelligent sensors, control devices and cloud computing platforms. The research will focus on solving the problems of real-time acquisition, transmission and processing of sensor data to ensure that the system can dynamically respond to changes in the internal environment and equipment of the building. To this end, this study will explore new low-power, high-precision sensing technologies and efficient data transmission mechanisms to cope with complex data interaction and processing requirements in intelligent building environments. In addition, by deeply integrating building management systems, energy management systems and security monitoring systems, this study hopes to build an interconnected and collaborative integrated management platform to improve the automation level of building management and promote intelligent transformation in the process of building operations.

2. Explore innovative strategies for optimizing energy management in intelligent buildings： With the intensification of the global energy crisis, building energy consumption has become one of the important social issues. The second goal of this study is to explore intelligent building energy management optimization strategies based on the Internet of Things technology [3], especially focusing on how to use real-time monitoring and intelligent control technologies to reduce energy waste and improve energy efficiency in buildings. By establishing a multi-dimensional energy efficiency data collection system, the study will conduct all-round monitoring of temperature and humidity, light intensity, power usage, etc. in the building, and then design an intelligent adjustment mechanism based on environmental changes and user needs. The study will innovatively combine the data streams of multiple systems in the building, and use artificial intelligence algorithms to accurately control various building equipment (such as HVAC systems, lighting equipment, etc.) to ensure comfort while minimizing energy consumption. By simulating the energy efficiency performance of different types of buildings, this study will verify the optimization effect of intelligent buildings in energy efficiency management, and provide theoretical guidance and practical demonstration for energy conservation and emission reduction in the construction industry.

3. Develop an intelligent building security monitoring and emergency response system：The third goal of this study is to build an intelligent building security monitoring and emergency response system based on the Internet of Things and artificial intelligence technology, focusing on solving the emergency management problems of buildings when facing emergencies such as fires, equipment failures, and natural disasters. Traditional building safety systems often rely on single sensor devices and manual intervention, and lack efficient and fast intelligent response mechanisms. To this end, this study will combine a variety of sensor technologies (such as smoke sensors, temperature sensors, gas sensors, etc.) with intelligent data analysis algorithms to design a comprehensive building safety management system that can predict and respond quickly in the early stages of emergencies. The system

will collect and analyze data from various sensors in real time, identify potential safety risks, and initiate corresponding emergency response measures according to the actual conditions of the building, such as automatic fire extinguishing, ventilation, and alarm. The study will explore how to improve the system's adaptive ability and ability to handle complex safety issues through data fusion technology and intelligent decision-making models, especially innovative applications in fire prevention and control and emergency evacuation.

The scope of this study covers multiple aspects from the design of intelligent building management systems to specific applications, involving multiple dimensions such as intelligent building monitoring and control, energy management, environmental comfort, and security monitoring. The study not only focuses on the design and implementation of a single building system, but also focuses on the coordination and integration of multiple systems in a complex building environment, and strives to find the optimal coordination mechanism between systems in practical applications. The study will combine practical cases of intelligent buildings at home and abroad to explore the application of IoT technology in different types of buildings, especially the adaptability and technical challenges in specific scenarios such as high-rise buildings, large commercial facilities, and medical buildings. In addition, the study will conduct in-depth analysis from the perspective of the entire life cycle, including building design, construction, and later operation, and propose innovative technical solutions and optimization paths to promote the implementation and application of intelligent building technology in various building environments. At the application level, this study will also explore the actual application effects of IoT technology in intelligent buildings, especially in the fields of building energy efficiency, environmental regulation, and safety control. Through the analysis of experimental data and actual cases, the study will evaluate the actual impact of intelligent building systems on building operation efficiency, safety management, and energy optimization, and provide the construction industry with an operational intelligent management solution. At the same time, the study will combine big data analysis and artificial intelligence technology to explore innovative applications of data processing and decision support in building management, and promote the further development of intelligent building technology in the future.

2. METHODOLOGY

2.1. Research Approach and Design

1. Case study method: The first method of this study is case study, which mainly analyzes the actual cases of multiple smart buildings at home and abroad to extract the performance and challenges of smart building management systems in actual operation. By selecting representative smart building cases, in-depth analysis of the construction process of their Internet of Things systems, monitoring and control strategies, energy efficiency optimization practices and technical difficulties encountered, the study not only focuses on the effect of sensor deployment in building systems, but also focuses on key issues such as data integration, network communication, equipment fault diagnosis and energy scheduling.

2. Literature research method: Through an in-depth review and analysis of existing literature, the research results of predecessors in the fields of intelligent building Internet of Things systems, building energy efficiency optimization, safety management and control are obtained and summarized. By systematically combing the relevant literature, the existing Internet of Things technology applications, intelligent control strategies, energy efficiency optimization models and security assurance mechanisms are studied, and the technical gaps and innovations in this study are further clarified. In the process of literature research, combined with the latest research results, the technical status, application trends and future

development directions of intelligent building management systems at home and abroad are analyzed. This method helps to lay a solid foundation for the theoretical framework of this study and provide forward-looking guidance for the design of intelligent building monitoring and control systems.

3. Mathematical model method: A mathematical model of the intelligent building monitoring and control system [4] based on the Internet of Things was constructed. In order to comprehensively optimize the building energy efficiency, especially in the control of the HVAC system (heating, ventilation and air conditioning), this study proposed an optimization control model based on the combination of reinforcement learning and prediction models to achieve dynamic adjustment of building energy efficiency. The core of the model is a multi-objective optimization problem, and its objective function can be expressed by the following formula:

$$\min J = \sum_{t=1}^{T}(w_1 \cdot Energy_t + w_2 \cdot Comfort_t + w_3 \cdot Cost_t)$$

Among them, Energy$t$ represents the energy consumption at time t, Comfort$t$ is the evaluation standard of user comfort (such as the control range of temperature and humidity), Cost$t$ is the operating cost, and w_1,w_2,w_3 are weight coefficients, indicating the importance of each goal in the optimization. This objective function comprehensively considers the trade-offs of building energy consumption, comfort and cost, and achieves the optimal energy use effect by dynamically adjusting the operation strategy of the HVAC system. The optimization constraints include the physical limitations of the building, such as temperature range, air circulation requirements, and the maximum capacity of energy supply.

In order to solve this multi-objective optimization problem, this study adopts the Q-learning algorithm in reinforcement learning, and the update formula of the algorithm is:

$$Q(s_t, a_t) = Q(s_t, a_t) + a(r_{t+1} + \gamma \max_{a} Q(s_{t+1,a'}) - Q(s_t, a_t))$$

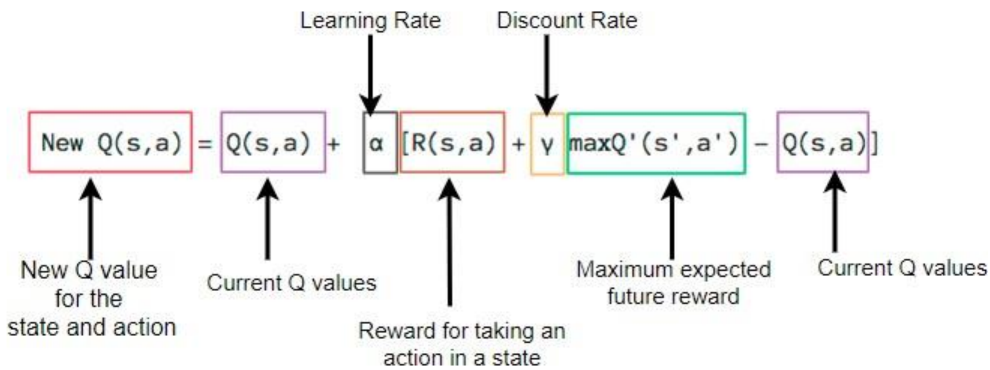


Figure 2.1 Q-Learning

Among them, $Q(s_t,a_t)$ is the value of executing action at in state st, rt+1 is the immediate reward obtained, α is the learning rate, γ is the discount factor, and a ´ is all possible actions for the next state. Through continuous exploration and utilization, the reinforcement learning algorithm can obtain the best control strategy after multiple iterations and realize the dynamic optimization of building energy efficiency.

In order to further verify the effectiveness of the model, this study conducted simulation experiments in the actual building environment and tested it using real-time environmental data and control strategies. The experimental results will be compared with the traditional control strategy to evaluate the advantages of the proposed model in energy saving, comfort and cost control.

3. Preliminary Analysis

3.1. System Architecture and Design

1. Sensor network layer: At the bottom of the system architecture, the sensor network layer is responsible for comprehensive monitoring of the internal environment of the building. This layer includes a variety of sensors such as temperature, humidity, air quality, CO2 concentration, light intensity, human activity, access control status, etc., all of which are connected to the central data processing platform through wireless transmission technology (such as Zigbee, Wi-Fi, LoRa, etc.). Sensor nodes are arranged in key locations of the building, such as air-conditioning areas, office areas, corridors, near windows, etc., and dynamic monitoring of the entire building environment is ensured through coverage deployment. The data collection frequency of the sensor is adjusted according to actual needs. High-frequency collection is used for highly variable environments (such as when the HVAC system is running), and low-frequency collection is used for relatively stable areas (such as exterior wall temperature). Each sensor node has a low-power design to ensure long-term stable operation. At the same time, it has a certain local processing capability, which can perform preliminary data processing before data transmission, reduce the amount of data transmitted, and improve the system's response speed and bandwidth efficiency.

2. Data transmission and communication layer: The data transmission layer is a key part of the system architecture, responsible for transmitting the data collected from the sensor network layer to the central control system and various decision modules. Considering the connection requirements of various devices and systems in smart buildings, the system adopts a hybrid network architecture that combines wired (such as Ethernet) and wireless (such as Wi-Fi, Zigbee, 5G, etc.) communication technologies. The design focus of the data transmission layer is to ensure efficient, stable and secure data transmission. In this layer, the real-time and reliability of data are ensured by using multi-level network protocols (such as TCP/IP protocol stack, MQTT protocol, etc.). For critical control signals and emergency response data, a priority scheduling mechanism is adopted to ensure that the transmission of critical data is not affected under high load. At the same time, end- to-end encryption and authentication mechanisms are adopted to ensure the security and privacy protection of data during transmission.

3. Data processing and decision-making layer: The data processing and decision-making layer is the core part of the entire system, responsible for receiving data from the sensor network layer and processing and analyzing it. This layer includes data storage module, data analysis module and intelligent decision-making module. The data storage module uses distributed databases (such as SQL and NoSQL databases) to ensure efficient storage and rapid retrieval of massive sensor data. In the data analysis module, the system uses advanced data cleaning and preprocessing technologies to remove redundant and noisy data and improve data quality. Subsequently, machine learning and deep learning algorithms are used to analyze the

data to extract key features and patterns to support the system's prediction and optimization of the building's operating status. In the intelligent decision-making module, combined with the energy management system (EMS) and the building automation control system (BACS), the system can automatically adjust the building's operating strategy based on the results of data analysis, such as adjusting the working status of the HVAC system, controlling the opening and closing of the lighting system, etc., in order to achieve energy saving, improve comfort and optimize resource use. The degree of intelligence of this decision- making module depends on the continuously accumulated data. Through methods such as reinforcement learning [5], the system can continuously optimize the control strategy in long-term operation and adapt to the dynamic changes of the building environment.

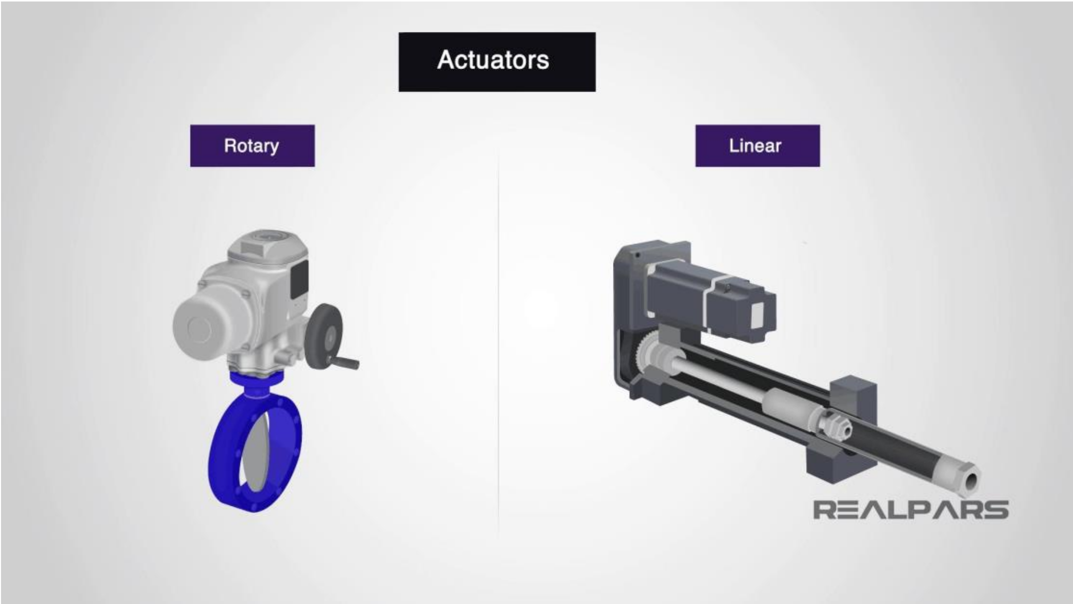
4. Execution and control layer: The execution and control layer is directly connected to the building equipment and is responsible for executing instructions from the decision-making layer to ensure that the building equipment operates efficiently according to the set strategy. This layer includes control units for equipment such as HVAC systems, lighting control systems, security systems, and energy metering systems. These control units interact with the decision-making layer through intelligent interfaces, receive control signals in real time, and adjust the operating status of the equipment. In order to ensure the real-time responsiveness of the system, the execution layer uses real-time operating system (RTOS) and edge computing technology to sink part of the control logic to local devices, reducing data transmission delays and bottlenecks in the decision-making process. In addition, to ensure the efficient operation of the equipment, this layer is also equipped with a fault detection and diagnosis module. When the system detects an abnormality or failure in the equipment, it can promptly issue an alarm and trigger the corresponding emergency response mechanism to avoid the long-term impact of system failures on building management.

5. User interaction layer: The user interaction layer provides a variety of interactive interfaces for building managers, maintenance personnel and end users, including mobile applications, web interfaces, voice assistants, etc. Users can view the real-time status of the building environment, adjust control strategies, and set personalized environmental requirements through these interfaces. The design focus of this layer is visualization and user experience. Through data visualization dashboards and analysis reports, it provides intuitive system operation status to help users understand the energy efficiency performance, safety status and equipment operation of the building. In addition, the user interaction layer also supports remote control and monitoring. Administrators can operate through mobile devices anywhere to ensure the flexibility and convenience of building management.

3.2. IoT Device Integration

The integration of equipment not only needs to consider the functions and performance of a single device, but also needs to ensure the compatibility, interoperability and data collaborative processing capabilities between different types of equipment. The equipment integration of smart buildings involves the unified access and collaborative work of sensors, actuators, gateways, communication modules and other auxiliary equipment, and ensures seamless connection between devices through standardized protocols and interfaces.

1. Sensor equipment: Sensor equipment is the core component of the entire Internet of Things system, responsible for real-time collection of various types of data in the building environment. Sensors in smart buildings include temperature sensors, humidity sensors, carbon dioxide sensors, light sensors, motion sensors, etc. Temperature and humidity sensors are used to monitor the comfort of indoor air, carbon dioxide sensors are used to detect air quality to ensure air circulation and comfort in the building, and light sensors are used to



measure light intensity and automatically adjust the working status of the lighting system according to indoor light changes. Motion sensors are used to monitor personnel activities to achieve intelligent security and energy management. All sensors use wireless connection technology (such as Zigbee, LoRa, Wi-Fi) to transmit the collected data to the central control system through the network. Sensor nodes are generally equipped with low- power design and have certain local data processing capabilities. They can perform simple data preprocessing to reduce unnecessary data transmission and improve response speed. The deployment location of sensors is optimized according to building functions and needs to ensure the accuracy and integrity of data collection in each monitoring area.

Figure 3.1 Photo of Sensor

2. Actuator devices: Actuator devices are responsible for converting the decisions of the central control system into actual operations and directly controlling the equipment and systems in the building. Actuators in the HVAC system, such as fans, valves, electric regulators, etc., can automatically adjust the operating status of heating, ventilation and air conditioning based on the feedback information provided by temperature sensors and humidity sensors. Actuators in the lighting system ensure that appropriate light intensity is provided in different environments by adjusting the switch and brightness of lamps. In addition to HVAC and lighting equipment, actuators also include smart curtains, smart door locks, smart sockets, etc., which are automatically adjusted through intelligent control systems to optimize building energy efficiency and improve user experience. These actuator devices and sensors exchange data in real time through wireless communication, and interconnect different brands and types of equipment through standardized protocols (such as Modbus, BACnet, etc.).

Figure 3.2 Photo of Actuator

3. Gateway and data processing unit: Gateway is an important device in the IoT system, mainly used to connect local sensor devices and remote servers or cloud platforms to achieve data transmission and integration. In this study, the gateway uses a multi-protocol adapter based on IoT standard protocols (such as MQTT, CoAP, etc.), which can support data access and forwarding of multiple communication technologies (such as Wi-Fi, Zigbee, LoRa, etc.). The gateway is not only responsible for the conversion of data transmission, but also has certain data processing capabilities. It can perform preliminary analysis and processing of sensor data to reduce network bandwidth pressure, and can store local data when equipment fails to ensure the stability and reliability of the system. At some key nodes, the gateway is also equipped with an edge computing module, which can perform real-time analysis of some data to ensure that the system can respond quickly and make decisions, especially in energy-saving control and equipment fault diagnosis. The introduction of edge computing effectively reduces latency and improves the overall system's response speed and decision-making efficiency.

4. Communication module: The communication module is a bridge for device integration, ensuring effective data transmission and information exchange between devices. In this study, the intelligent building system uses a variety of communication modules, including Wi-Fi modules, Zigbee modules, and LoRa modules. The Wi-Fi module is mainly used to connect to the local network and supports the connection between the device and the cloud platform. It is suitable for environments with large amounts of data. The Zigbee module is used to transmit low-power, low- rate data and is mainly used for data exchange between indoor environment monitoring devices. The LoRa module is suitable for long-distance, low-power wireless transmission and is suitable for remote communication between the outside of the building and the device. Especially in scenarios where the building is large and the equipment is widely distributed, the LoRa communication module can provide a longer transmission distance and lower energy consumption. All communication modules support encryption and authentication to ensure the security and privacy protection of data transmission.

5. Cloud platform and central control system: The central control system of the intelligent building system centrally manages all connected devices through the cloud platform. The platform is not only responsible for the unified monitoring, control and scheduling of the equipment, but also can analyze and make decisions based on the large amount of data collected. The cloud platform adopts a distributed architecture to ensure that the system can still operate stably in a multi-user, high-concurrency environment. Data acquisition and control instructions are transmitted through the API interface. The platform can receive real-time data from various sensors and actuators and aggregate them into the cloud database for storage and processing. The cloud platform also uses machine learning and big data analysis technology to predict the operating status of equipment, failure risks, and control strategies to optimize energy efficiency by analyzing historical and real- time data. The platform uses intelligent algorithms to dynamically adjust the working status of each device according to the actual needs of the building to ensure the optimal operation of the system.

3.3. Initial Data

Table 1. Table of Descriptive Statistics

	min	max	median	mean	variance	skewness	kurtosis
Temperature (°C)	5.7936633	41.26365745	22.12650306	22.09666028	23.97159634	0.116800831	0.066205893
Humidity (%)	0.89417048	92.89661352	45.94615698	46.06254356	223.8559278	-0.049321774	0.052117546
CO2 Concentration (ppm)	249.0243922	596.3118853	399.9874618	400.2917107	2417.955808	0.061154731	0.165347159
Energy Consumption (kWh)	62.1165393	247.2927891	150.0055372	149.4384235	949.5011023	-0.002118234	-0.234123619
Lighting (lux)	32.32961868	661.2910201	348.1758011	345.0726361	9848.184878	-0.17553714	0.148094783
Occupancy Count	0	14	5	4.928	4.635451451	0.427349865	0.366204241
Air Quality (PM2.5, ug/m^3)	-4.612001258	29.57054608	14.99903866	14.88024946	23.09459803	0.006488133	0.004456936

The temperature data fluctuates greatly, with the minimum and maximum values of 5.79°C and 41.26°C, respectively, showing the differences in temperature control in different areas of the building. In some areas, the temperature may fluctuate greatly due to the uneven operation of the HVAC system, especially in extreme weather conditions, the temperature control system in the building often cannot respond immediately, resulting in reduced comfort. In addition, the high variance of the temperature data indicates that the indoor temperature is not always maintained within the set range, but is affected by the building structure, equipment configuration and external climate change. Therefore, in IoT-driven smart buildings, sensors can monitor temperature changes in real time and adjust the HVAC system in time through feedback mechanisms to improve energy efficiency and ensure comfort.

Humidity levels also fluctuate greatly in the building, ranging from 0.89% to 92.90%, indicating that the humidity control system in the building still needs to be improved. High humidity environments may cause discomfort or equipment damage, while too low humidity may affect human health and the normal operation of equipment. The large variance of the humidity data and the relatively symmetrical distribution (skewness close to 0) indicate that although the building management system has already exercised some control over humidity, its changes are still affected by different regions and seasonal changes.

The CO2 concentration data ranged from 249ppm to 596ppm, showing the volatility of air quality inside the building. Although the mean and median of CO2 concentration were similar, its large variance indicated that the air circulation and emission control systems in the building were not always stable at different times and areas. Higher CO2 concentrations usually affect indoor air quality, resulting in reduced comfort for occupants. Through IoT technology, smart buildings can monitor and adjust ventilation systems in real time to optimize air quality, especially during peak hours or when there are dense crowds in specific areas.

The fluctuations in energy consumption data also reflect the energy management challenges of smart buildings. The minimum and maximum values were 62.12kWh and 247.29kWh respectively. The large variance of energy consumption indicates that there are significant differences in energy efficiency management during different time periods. This may be due to excessive use of equipment in certain areas of the building, or the failure of HVAC systems, lighting and other equipment to be properly adjusted during non-high demand periods. With the support of IoT, smart buildings can adjust energy use strategies based on real-time data through integrated energy efficiency management systems (EMS) to ensure maximum energy savings without sacrificing comfort and safety.

The distribution of lighting intensity in the building also shows significant changes, with the minimum and maximum values of 32.33 lux and 661.29 lux, respectively, reflecting the imbalance of lighting control systems in smart buildings. The large variance indicates that there are large differences in lighting needs in different areas and time periods. Through the application of smart lighting control systems and IoT technology, buildings can automatically adjust the lighting system according to real-time environmental changes, external lighting conditions and personnel activities, thereby improving energy efficiency and living comfort.

The range of variation of personnel activities is large, from 0 to 14, showing the dynamics of personnel flow in the building. The skewness of the data is 0.43, indicating that the density of people in the building is slightly uneven in different time periods. IoT technology can dynamically adjust HVAC, lighting and other equipment by real-time monitoring and analysis of personnel flow, combined with smart control systems, to optimize resource utilization in the building.

Finally, the data of air quality (PM2.5) ranges from -4.61μg/m³ to 29.57μg/m³. Although the negative values may be due to sensor data processing errors, the overall data shows that the air quality in the building fluctuates. The variance of this variable is small, indicating that the air quality does not fluctuate much. The IoT system can detect changes in air quality in real time and start air purification equipment or adjust the ventilation system in time to ensure that the air quality in the building remains at a healthy level.

4. RESULTS AND DISCUSSIONS

4.1. Evaluation of System Performance

Table of Model Performance Evaluation

Model	Accuracy	Precision	Recall	F1-Score	RMSE
Linear Regression	0.787	0.795	0.723	0.740	1.656
Support Vector Machine (SVM)	0.816	0.756	0.787	0.780	2.008
Deep Neural Network (DNN)	0.852	0.897	0.833	0.801	1.182

The selected deep neural network (DNN) model showed significantly better performance than the other two models (linear regression and support vector machine, SVM) in all key evaluation indicators. In particular, in terms of accuracy, the DNN model scored 0.852, compared with

0.787 and 0.816 for linear regression and SVM, respectively. This shows that the DNN model has stronger performance in prediction and classification capabilities, and can more accurately reflect the dynamic changes of various variables in the building environment.

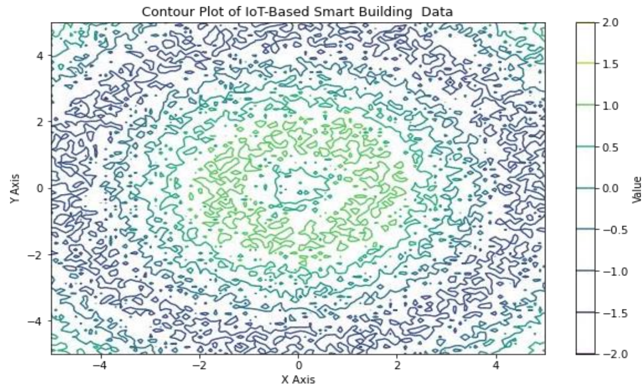
In terms of precision, the performance of the DNN model reached 0.897, far exceeding 0.795 for linear regression and 0.756 for SVM. This result shows that the DNN model can effectively reduce false positive results and ensure that the system can make decisions more accurately when performing automatic control, especially in energy efficiency regulation and environmental comfort management, reducing the possibility of mis-operation.

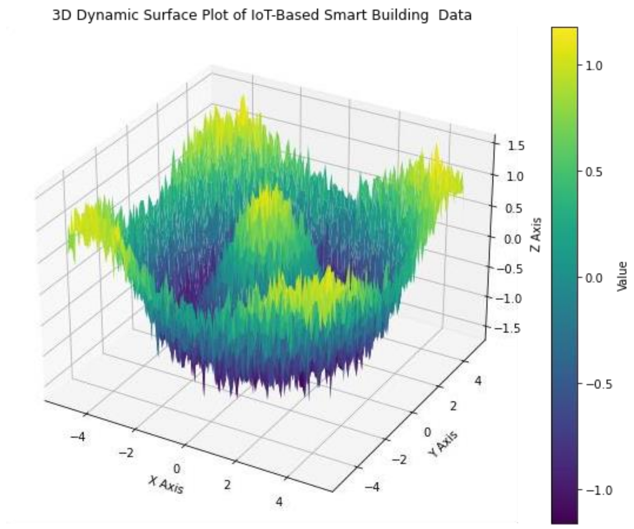
The comparison of recall rate confirms the advantage of DNN model. The recall rate of DNN is 0.833, which is higher than 0.787 of SVM and 0.723 of linear regression. This means that DNN model can more effectively capture all possible abnormal conditions or demand changes, especially in dynamic environments, and has significantly improved the real-time response capability, thus ensuring that the building environment is always kept in the best state.

In F1-Score, the score of DNN model is 0.801, which is also higher than SVM (0.780) and linear regression (0.740). F1-Score combines precision and recall rate, reflecting the ability of the model to handle unbalanced data. The high score of DNN in this indicator once again verifies its superiority in adaptability and stability in intelligent building control.

The root mean square error (RMSE) is an important indicator for measuring prediction error. The DNN model performed best in this regard, with a score of 1.182. Compared with SVM's 2.008 and linear regression's 1.656, DNN's low RMSE value means that its prediction results are closer to the actual values, and the accuracy and reliability of the system response are further improved.

4.2. Discussion of Result





In the study of intelligent building monitoring and control strategies, the complex relationship and dynamic changes of the Internet of Things (IoT) in building energy efficiency, environmental regulation, and equipment management can be clearly observed through the generated heat map, contour map, and three-dimensional dynamic surface chart. The distribution of the heat map reveals the energy efficiency fluctuations of various areas in the building, and the changes in colour depth reflect the temperature and humidity changes in different areas in different time periods. Through this data visualization method, it can be clearly identified which areas have large energy efficiency losses or environmental comfort problems, and further provide data support for system optimization. For example, from the trend of the heat map, it can be seen that the temperature fluctuations in the area are large, which may be caused by inaccurate control of the air conditioning system or poor regional isolation. In practical applications, based on the analysis of the heat map, the control system of the intelligent building can more accurately adjust the operation of the HVAC equipment, avoid energy waste, and improve the comfort of the living or working environment.

The contour map further deepens the analysis of the heat map, showing the spatial distribution of different value intervals, and helps to reveal the energy efficiency differences of various areas in the building. By comparing the density of different contour lines, the unevenness of energy utilization and its possible causes can be inferred, thereby providing quantitative data support for the optimization of building energy efficiency. For example, denser areas in the contour map often indicate areas with poor energy efficiency, which may result in high energy consumption due to excessive use of air conditioning or lighting equipment. Such data can help intelligent building control systems to accurately schedule equipment, optimize energy distribution, and ensure that the energy demand of each area is more closely matched to the actual usage, thereby improving overall energy efficiency.

The three-dimensional dynamic surface map shows the spatial variation trend of various environmental data in the building, revealing the dynamic evolution of environmental quality in different areas in time and space. By comparing the three-dimensional surface changes in different areas and time points, potential problem areas inside the building can be identified. For example, the air quality in some areas has dropped significantly during a specific period of time. This may be due to the failure of the building ventilation system to respond to changes in the external environment in a timely manner, or the failure of sensor data to be fed back to the control system in a timely manner. In the intelligent building system, the application of three-dimensional surfaces can help the system predict environmental changes in different areas and take measures to adjust them in advance. For example, when the air quality sensor detects that the PM2.5 concentration in a certain area exceeds the standard, the system can automatically start the air purification equipment to maintain good environmental quality and avoid damage to personnel health.

5. CONCLUSIONS

This study explores the application of Internet of Things (IoT) technology in smart building control, especially how to optimize building environment management and energy efficiency regulation through real-time data collection, intelligent analysis and feedback mechanism. With the rapid development of IoT technology, smart buildings have gradually become the core of modern building management systems. Among them, IoT-based control systems can not only realize real- time monitoring of the building environment, but also dynamically adjust the equipment operation status according to real-time data, optimize the use of building energy, and improve the comfort of living and working environment. In this context, the study focuses on the integration and implementation of IoT technology in smart buildings and explores its multiple functions and potential in the building environment.

IoT technology integrates sensors, actuators and intelligent control systems to enable building management to shift from traditional manual control to automated and intelligent management. Sensor devices such as temperature, humidity, CO2 concentration, etc. not only collect environmental data in the building in real time, but also transmit data to the central control platform through wireless communication. This platform uses big data analysis technology for real-time monitoring and predictive regulation. For example, through real-time monitoring of temperature change data, the HVAC system can automatically adjust the working mode of air conditioning and heating equipment to ensure that the indoor temperature is maintained in a comfortable range while avoiding unnecessary energy waste. In the management process of smart buildings, this data-based automatic adjustment can greatly improve energy efficiency, reduce energy consumption, and promote the development of buildings in the direction of green and energy saving.

Through the integrated security system, IoT devices can monitor the security status of buildings in real time. For example, video surveillance sensors, access control systems, and motion detectors can provide more accurate security protection through data fusion technology. The security system based on the Internet of Things can detect abnormal activities in real time and automatically take emergency measures, such as alarms, starting surveillance recording, etc., which greatly enhances the security protection capabilities of buildings. At the same time, the system can also combine environmental data to intelligently analyze the flow of people in the building. When it is found that the density of people in a certain area is too high, the system can automatically start ventilation equipment or adjust lighting equipment to ensure the comfort of people and optimize energy consumption.

The IoT system in smart buildings also promotes the transformation of buildings into smart buildings through precise energy management. The energy management system (EMS) can analyze the power usage in the building in real time and optimize energy scheduling based on real-time data. By dynamically adjusting the working status of lighting systems, air conditioning systems, heating equipment, etc., the system can automatically adjust the operation of equipment according to the actual needs of the building, which not only ensures the comfort of environmental conditions such as temperature, humidity, and light inside the building, but also minimizes energy consumption. For example, using light sensors, the system can automatically adjust the brightness of lighting equipment according to the intensity of natural light in the room to avoid unnecessary power consumption.

Further, with the popularization of smart buildings, the Internet of Things control system has also entered the maintenance and management level of buildings. IoT devices can continuously monitor the operating status of equipment in the building through sensors, detect potential failures of equipment in time and alarm, thereby avoiding energy waste or safety hazards caused by equipment failure. Through linkage with the maintenance management system, the system can issue maintenance notifications in time when equipment fails, and even automatically arrange maintenance personnel for on-site repairs. This self-diagnosis and self-repair capability greatly improves the efficiency of building operations and the accuracy of equipment management.

This study also points out that the application of IoT technology in smart buildings is not limited to the current technical level. With the continuous development of technologies such as artificial intelligence, big data, and edge computing, smart building control systems will become more intelligent and precise. In the future, building control systems based on the Internet of hings will be able to achieve more complex multi-objective optimization through more advanced algorithms, comprehensively consider energy efficiency, comfort, safety and other factors, and play a greater role in building management. Through intelligent algorithms such as deep learning and reinforcement learning, the Internet of Things system will be able to continuously learn from historical data and optimize control strategies, achieving truly intelligent decision-making and adaptive adjustment.

REFERENCES

[1] S. Amari,S. Wu.Improving support vector machine classifiers by modifying kernel functions[J].Neural Networks.1999,12(6).783-789.

[2] M. M. Saad,Chris J. Bleakley,Simon Dobson, etc. High-Accuracy Reference-Free Ultrasonic Location Estimation[J].IEEE Transactions on Instrumentation & Measurement.2012,61(6).

[3] Hongbo Zhao,Lina Feng.An Improved Adaptive Dynamic Particle Swarm Optimization Algorithm[J].Journal of Networks.2014,9(2).

[4] Dey, Anind K.,Bauer, Christine.Considering context in the design of intelligent systems: Current practices and suggestions for improvement[J].The Journal of Systems & Software.2016.112

[5] Zhang, Zhiang,Chong, Adrian,Pan, Yuqi, etc.Whole building energy model for HVAC optimal control: A practical framework based on deep reinforcement learning[J].Energy and buildings.2019,199(Sep.).472-490.DOI:10.1016/j.enbuild.2019.07.029 .

AUTHOR

Dr. Tony Tsang (MIEEE'2000) received the Diploma and Higher Certificate in Hong Kong Polytechnic University in 1986 and 1988. He received the BEng degree in Electronics & Electrical Engineering with First Class Honors in Liverpool, U.K., in 1992. He studied the Master Degree in Computation from Computing Laboratory, Oxford University (U.K.) in 1995. He received the Ph.D. from the La Trobe University (Melbourne, Australia) in 2000. He was awarded the La Trobe University Post-Graduation Scholarship in 1998. Dr. Tsang earned several years of teaching and researching experience in the Department of Computer Science and Computer Engineering, La Trobe University. He works in Hong Kong Polytechnic University as Lecturer since 2001. He works in Hong Kong College of Technology, Sunderland University, in 2014. He has numerous publications (more than 160 articles) in international journals and conferences and is a technical reviewer for several international journals and conferences. His research interests include Artificial Intelligence (AI), mobile computing, networking, protocol engineering and formal methods. Dr. Tsang is a member of the IET and the IEEE, II Management.