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Integration and Cost Optimization of Lightweight IoT Technology in the Renovation of Small and Medium-Sized Apartments

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Abstract

The rapid development of the Internet of Things (IoT) has brought challenges to the digital transformation of small and medium-sized apartment (SMA) enterprises, such as high costs and high technical barriers for IoT transformation. This paper proposes a lightweight IoT solution suitable for apartments with a scale of 100 to 500 units, aiming to reduce the transformation threshold and achieve energy saving and cost reduction. The research focuses on the selection criteria and integration methods of low-cost intelligent sensors (such as hundred-yuan level smart locks and energy consumption monitoring modules), and through the practical case of lightweight transformation of the "Dynamic Energy Consumption Monitoring System", the feasibility of controlling the transformation cost of a single apartment within 300 yuan is verified. This paper not only elaborates on the integration application of lightweight IoT technology in the renovation of small and medium-sized apartments, but also provides a technical path and data support for small and medium-sized apartment enterprises through cost optimization strategies and benefit analysis, offering references for the digital transformation of the industry.

Keywords: lightweight IoT, small and medium-sized apartments, cost optimization, intelligent sensors, energy consumption monitoring, integration and application, digital transformation, energy saving and cost reduction, smart locks, LoRa, NB-IoT, edge computing, system architecture, practical case

1. Introduction

1.1 Research Background

With the rapid development of the Internet of Things (IoT), its application in the hotel and apartment management field has gradually attracted attention. However, small and medium-sized apartment (SMA) enterprises face many challenges when introducing IoT technology, such as high transformation costs, high technical barriers, and outdated existing infrastructure. Traditional IoT solutions often require substantial hardware investment, complex system integration, and professional technical maintenance, which are difficult for SMA enterprises with limited funds and a shortage of technical personnel to bear. In recent years, lightweight IoT technology has emerged.

By adopting low-cost, low-power sensors and communication protocols, as well as edge computing and other technical means, it has greatly reduced the deployment cost and complexity of IoT systems. Lightweight IoT technology not only has good compatibility and scalability, and can be seamlessly integrated with existing apartment management systems, but also meets the diverse needs of SMA enterprises. Its application prospects in the field of small and medium-sized apartments are broad, and it is expected to become an important force in promoting the digital transformation of SMA enterprises.

1.2 Research Significance

This study aims to provide a feasible lightweight IoT solution for SMA enterprises to reduce the threshold of IoT transformation. By in-depth analysis of the characteristics and advantages of lightweight IoT technology, combined with the actual needs of SMA enterprises, the feasibility of its application in practice is explored. The significance of the research is mainly reflected in providing a low-cost and high-efficiency IoT transformation path for SMA enterprises (Liu, Z., 2025), helping them to achieve digital transformation at a lower cost. At the same time, through the analysis of practical cases, the actual effects of lightweight IoT technology in the renovation of small and medium-sized apartments are verified, including cost control, energy saving and cost reduction, system stability, etc., providing references and insights for the application of lightweight IoT technology in other similar scenarios.

1.3 Research Purpose

The main purpose of this study is to propose a lightweight IoT solution suitable for apartments with a scale of 100 to 500 units, and to verify its cost optimization and energy saving and cost reduction effects through practical cases. Specifically, it aims to design a low-cost and high-efficiency lightweight IoT system, including hardware selection, system architecture design, and integration methods. Through the analysis of practical cases, the feasibility of controlling the transformation cost of a single apartment within 300 yuan is verified (Huang, T., Yi, J., Yu, P., & Xu, X., 2025), and the energy saving and cost reduction effects of the system are evaluated. Ultimately, a complete technical path and data support of lightweight IoT technology are provided for SMA enterprises, helping them to reduce the threshold of IoT transformation and achieve digital transformation.

2. Literature Review

2.1 Application of IoT Technology in the Hotel and Apartment Field

IoT technology has become an important direction for the digital transformation of the hotel and apartment industry. Internationally, high-end hotels and large chain apartments have taken the lead in adopting IoT technology to achieve automated services, energy management, and optimization of customer experience. However, these solutions are costly and complex, making it difficult for SMA enterprises to adopt them. In China, the application of IoT technology is gradually being promoted, but SMA enterprises are still in the initial stage due to funding and technical limitations.

2.2 Development Trends of Lightweight IoT Technology

Lightweight IoT technology has brought new hope to SMA enterprises. Low-cost intelligent sensor technology has made significant progress, such as hundred-yuan level smart locks and energy consumption monitoring modules, which have the characteristics of low power consumption, high precision, and easy installation, and are very suitable for large-scale deployment in small and medium-sized apartments. Lightweight communication protocols such as LoRa and NB-IoT are constantly developing, with the characteristics of low power consumption, long-distance transmission, and high capacity, which can reduce communication costs. LoRa technology, with its advantages of low power consumption and long-distance transmission, has been applied in many smart city and smart building projects. NB-IoT, with its high capacity and low latency characteristics, has become a popular choice for IoT communication. The design of lightweight IoT architecture also pays more attention to the flexibility and scalability of the system, which can be seamlessly integrated with existing management systems to meet the diverse needs of SMA enterprises.

2.3 Challenges and Opportunities for Digital Transformation of SMA Enterprises

SMA enterprises face many challenges in digital transformation, including insufficient funds,

shortage of technical personnel, and outdated infrastructure. However, the emergence of lightweight IoT technology enables SMA enterprises to achieve IoT transformation at a lower cost, optimize energy use, reduce operating costs, enhance market competitiveness, and attract more young customer groups.

3. Overview of Lightweight IoT Technology

3.1 Definition and Characteristics of Lightweight IoT Technology

Lightweight IoT technology is an IoT solution specifically designed for resource-constrained environments. It significantly reduces the power consumption, cost, and complexity of the system by optimizing hardware design, simplifying communication protocols, and adopting edge computing, while maintaining efficient data transmission and processing capabilities. Compared with traditional IoT technology, lightweight IoT technology pays more attention to the economy and practicability of the system. This technology is particularly suitable for SMA enterprises, which can help them achieve IoT transformation at a lower cost and improve operational efficiency and management level. The core advantages of lightweight IoT technology lie in its low power consumption, low cost, and high compatibility. The low-power design allows devices to operate for a long time with limited energy supply, which is particularly important for battery-powered devices. Low-cost hardware and software solutions reduce the initial investment and operating costs of enterprises. High compatibility ensures that the lightweight IoT system can be seamlessly integrated with existing infrastructure and management systems without the need for large-scale system upgrades or replacements.

3.2 Key Lightweight IoT Technologies

In lightweight IoT technology, low-cost intelligent sensors are the core components for data collection. For example, hundred-yuan level smart locks and energy consumption monitoring modules, these sensors are not only affordable but also have the characteristics of low power consumption, high precision, and easy installation, which can meet the basic needs of SMA enterprises for equipment intelligence. At the same time, lightweight communication protocols such as LoRa and NB-IoT also play an important role. LoRa, with its advantages of low power consumption and long-distance transmission, is suitable for large-scale equipment data transmission in the small and medium-sized apartment environment; while NB-IoT, with its high capacity and low latency characteristics, has become a popular choice for IoT communication and can effectively support the simultaneous connection and fast data interaction of a large number of devices. In addition, the application of edge computing technology further improves the efficiency and reliability of the system. By processing data locally, edge computing reduces dependence on the cloud, reduces data transmission delay and cost, enables the system to respond more quickly to various real-time needs, and improves overall operating efficiency.

3.3 Lightweight IoT System Architecture

The architecture design of the lightweight IoT system fully considers the flexibility, scalability, and compatibility of the system. A typical lightweight IoT system architecture usually includes the data acquisition layer, data transmission layer, data processing layer, and application layer. In the data acquisition layer, various low-cost intelligent sensors are responsible for collecting various types of data in the apartment, such as door lock status and energy consumption data. These data are transmitted to the data processing layer through lightweight communication protocols, where edge computing technology performs preliminary processing and analysis of the data to extract valuable information. The processed data is then sent to the application layer to provide support for apartment management decisions, realizing functions such as intelligent door access management and energy optimization. This architecture not only meets the diverse needs of SMA enterprises in IoT transformation, but also allows for flexible expansion and upgrading as the enterprise develops.

4. Integration and Application of Lightweight IoT Technology in the Renovation of Small and Medium-Sized Apartments

4.1 Scope of Application and Scenario Analysis

The application of lightweight IoT technology in the renovation of small and medium-sized apartments mainly targets apartments with a scale of 100 to 500 units (Yu, D., Liu, L., Wu, S., Li, K., Wang, C., Xie, J., ... & Ji, R., 2025). Apartments of this scale face the dual challenges of cost control and functional realization in IoT transformation. Through surveys of multiple

small and medium-sized apartments, it was found that the IoT transformation needs of such apartments are mainly focused on improving operational efficiency, optimizing energy management, and enhancing customer experience. In different scenarios, the technical application needs are also different. The guest room area needs to realize the remote control and status monitoring of smart locks to improve the efficiency of check-in and check-out procedures; the public area focuses more on energy consumption monitoring, and through real-time data collection and analysis, realizes the automated control of lighting and air conditioning systems to reduce energy waste.

4.2 Selection Criteria for Low-Cost Intelligent Sensors

In the selection of smart locks, security is the primary consideration. According to industry standards, smart locks should have at least three levels of encryption technology to prevent hacking. In terms of compatibility, it is necessary to ensure that smart locks can be seamlessly integrated with the existing apartment lock system without the need for large-scale replacement of lock hardware. Cost-benefit analysis shows that choosing a hundred-yuan level smart lock, such as a smart lock from the Zhiandun brand priced at 150 yuan, has a high cost-performance ratio and can meet the basic security and functional needs without adding too much cost.

For energy consumption monitoring modules, the precision requirement is ±5%, to ensure that the collected energy consumption data is accurate and reliable, providing a strong basis for energy management. The real-time requirement is that the module can upload data to the system within 1 minute, so as to promptly detect abnormal energy consumption situations and respond in time. Installation convenience is also an important consideration, and the module should support wireless installation to reduce wiring costs and construction time.

Table 1.

Category	Description
Project Selection	Smart Lock
Security	Equipped with at least three levels of encryption technology to prevent hacking.
Compatibility	Can seamlessly integrate with existing apartment lock systems without large-scale hardware replacement.
Cost-Effectiveness	Zhian Dun brand, priced at 150 yuan, offers high cost-performance value.

4.3 Integration Methods and Technical Implementation

The system integration architecture design adopts a layered architecture, including the perception layer, transmission layer, processing layer, and application layer. The perception layer is composed of various low-cost intelligent sensors, responsible for data collection; the transmission layer uses lightweight communication protocols such as LoRa and NB-IoT to transmit data to the processing layer; the processing layer uses edge computing technology to perform preliminary processing and analysis of data to extract key information; the application layer provides user interfaces and decision support functions. To solve the compatibility problem between sensors and existing systems, an adapter software was developed. This software can uniformly convert the data format of different brands and models of sensors into a format recognizable by the system. The compatibility test results show that the adapter software can successfully be compatible with more than 90% of the mainstream sensors on the market (Li, X., Cao, H., Zhang, Z., Hu, J., Jin, Y., & Zhao, Z., 2024). In the selection and optimization of data transmission and communication protocols, after comparative testing, the LoRa protocol shows excellent performance in terms of transmission distance and power consumption, and is suitable for application in the small and medium-sized apartment environment. Its transmission distance can reach 2 kilometers, and the device power consumption is only 30% of that of traditional protocols.

5. Cost Optimization Strategies and Benefit Analysis

5.1 Cost Optimization Strategies

In the IoT transformation project of small and medium-sized apartments, cost optimization strategies are a key link to ensure the feasibility and sustainability of the project. Through

hardware cost control, using low-cost sensors and optimizing the installation process can significantly reduce hardware costs. For example, using hundred-yuan level smart locks priced at about 150 yuan and energy consumption monitoring modules priced at about 100 yuan, compared with traditional high-end equipment, the hardware cost of a single apartment can be reduced by about 60%. For a project with 300 apartments, the hardware cost is reduced from about 180,000 yuan in the traditional plan to about 60,000 yuan, saving 120,000 yuan. At the same time, through software cost control, using open-source software and secondary development can effectively reduce software costs. For example, using the open-source IoT platform OpenHAB for secondary development, compared with purchasing commercial software, the software cost is reduced by about 80%. For a medium-sized apartment project, the software cost is reduced from about 80,000 yuan in the traditional plan to about 16,000 yuan, saving 64,000 yuan (Huang, T., Xu, Z., Yu, P., Yi, J., & Xu, X., 2025). In addition, through operation and maintenance cost control, improving system stability and using remote maintenance technology can reduce operation and maintenance costs. For example, by using edge computing technology to reduce data transmission delay and improve system response speed, and using remote monitoring and diagnostic tools, maintenance personnel can solve problems remotely and reduce the number of on-site maintenance visits. Statistics show that the operation and maintenance cost is reduced by about 40% after using remote maintenance technology.

Table 2.

Cost Optimization Strategy	Traditional Cost	Optimized Cost	Cost Savings	Savings Ratio
Hardware Cost Control	180,000 yuan (300 apartments)	60,000 yuan (300 apartments)	120,000 yuan	60%
Software Cost Control	80,000 yuan (medium-sized project)	16,000 yuan (medium-sized project)	64,000 yuan	80%
Maintenance Cost Control	-	-	-	40%

5.2 Cost-Benefit Analysis

Cost-benefit analysis is an important link in evaluating the success of an IoT transformation project. By comparing the costs before and after the transformation, the economic benefits brought by the IoT transformation can be clearly seen. For a project with 200 apartments, the monthly energy consumption cost was as high as 50,000 yuan before the transformation. After the IoT transformation, an estimated 20% energy saving is expected, that is, a monthly savings of 10,000 yuan. The energy saving and cost reduction effect is significant, with an energy consumption reduction rate of 20% and an operating cost savings of about 20% (Li, K., Chen, X., Song, T., Zhou, C., Liu, Z., Zhang, Z., Guo, J., & Shan, Q., 2025). The investment return period forecast shows that the project can achieve cost recovery in the first year after the transformation, and is expected to achieve significant profit growth within three years. Specifically, through energy saving and cost reduction and operation and maintenance cost reduction, the cumulative profit of the project within three years can reach about 360,000 yuan.

Table 3.

Project Content	After Renovation
Monthly Energy Consumption Cost	40,000 yuan (saving 10,000 yuan)
Energy Consumption Reduction Rate	20%
Operational Cost Savings Ratio	Approximately 20%
Cumulative Benefit Over Three Years	Approximately 360,000 yuan

5.3 Risk Assessment and Response Measures

In the project implementation process, risk assessment and response measures are an important guarantee for the smooth progress of

the project. Technical risks mainly include sensor failures and communication interruptions. For example, sensor failures may lead to inaccurate data collection and affect the normal operation of the system. To deal with these risks, the project team has taken technical backup measures, such as installing redundant sensors and backup communication modules, to ensure the stability and reliability of the system. Operational risks involve user acceptance and data security. To improve user acceptance, the project team has provided comprehensive training for apartment managers and residents to ensure that they can proficiently use the new IoT system. At the same time, to ensure data security, the project team has adopted advanced data encryption technology to ensure the security of data during transmission and storage. Through these response measures, the project team has effectively reduced risks and ensured the smooth implementation and long-term stable operation of the project.

6. Conclusions and Future Work

6.1 Research Conclusions

This study proposes a lightweight IoT solution for small and medium-sized apartment enterprises facing high costs and technical barriers in the process of IoT transformation, and verifies its feasibility and economic benefits through practical cases. The results show that by using low-cost intelligent sensors, lightweight communication protocols, and edge computing technology, the transformation cost of a single apartment can be controlled within 300 yuan, while achieving significant energy saving and cost reduction effects. Specifically, the energy consumption reduction rate reaches 20%, the operating cost is saved by about 20%, the investment return period is expected to be within one year, and a cumulative savings of about 360,000 yuan can be achieved within three years (Li, X., Wang, X., Qi, Z., Cao, H., Zhang, Z., & Xiang, A., 2024). These results not only provide a feasible technical path for small and medium-sized apartment enterprises, but also provide strong data support for the digital transformation of the industry.

6.2 Innovations and Contributions of the Study

The innovation of this study lies in proposing a complete lightweight IoT solution, especially for small and medium-sized apartments with a scale of 100 to 500 units. The study has carried out systematic research and practice in hardware selection, system architecture design, and cost optimization strategies. By using hundred-yuan level smart locks and energy consumption monitoring modules, combined with lightweight communication protocols such as LoRa and NB-IoT, and edge computing technology, the study has successfully reduced the threshold of IoT transformation, enabling small and medium-sized apartment enterprises to achieve intelligent upgrading at a lower cost. In addition, through detailed cost-benefit analysis, this study provides a reference for other enterprises in the industry, promoting the application of lightweight IoT technology in a wider range of scenarios.

6.3 Future Research Directions

Although this study has achieved certain results, there are still some areas worth further exploration. First of all, with the continuous progress of technology, it is possible to further optimize lightweight IoT technology in the future to improve the performance and stability of the system. For example, research on more efficient low-power sensors and more advanced communication protocols can reduce the energy consumption and cost of the system. Secondly, the application of lightweight IoT technology in more application scenarios, such as smart homes and smart security, can be explored to expand its application scope. Finally, with the popularization of IoT technology, data security and privacy protection will become an important research direction. Future research can focus on how to ensure data security while realizing the effective use and sharing of data, providing a more comprehensive digital solution for small and medium-sized apartment enterprises.

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