A Data-Driven Approach to Performance Improvement in University Dormitory Management Based on Internet of Things Technology

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Abstract: *In the context of smart campus development and the digitalization of university logistics management, traditional dormitory management faces challenges such as information delays, passive control, slow response, resource waste, and subjective evaluation, which hinder refined governance. This study proposes a data-driven dormitory management framework based on Internet of Things (IoT) technology, integrating perception, intelligent application, and performance evaluation. An intelligent dormitory management system was developed using a Raspberry Pi 3B+ and a DHT11 temperature and humidity sensor to enable real-time environmental monitoring and automatic device control. Experimental validation demonstrates that the system can operate reliably and automatically regulate air conditioning based on predefined thresholds, thereby improving management efficiency and students' living experience. The results indicate that IoT technology can promote a transition toward proactive management, data-driven decision-making, and collaborative governance, providing practical support for the digitalization of university logistics management.*

Keywords: *Internet of Things; Data-driven management; University dormitory; Performance improvement*

Introduction

University dormitories constitute a critical component of campus governance, and their management quality is closely associated with student safety, campus stability, and service efficiency. With the expansion of higher education and the increasing diversification of student needs, traditional dormitory management approaches have revealed significant limitations, including low efficiency of manual operations, delayed risk identification, inefficient energy utilization, inadequate environmental regulation, slow service response, and the absence of quantitative performance evaluation mechanisms.

The rapid development of Internet of Things (IoT) technology provides new technical pathways for addressing these challenges. In this study, an intelligent dormitory management system is developed based on a Raspberry Pi 3B+ embedded platform, integrated with a DHT11 temperature and humidity sensor for real-time environmental data acquisition. Through predefined threshold-based control strategies, the system enables automatic regulation of air conditioning devices, thereby facilitating adaptive environmental management within dormitory spaces.

By supporting continuous sensing and integration of key operational data, including environmental parameters and energy usage, IoT technology establishes a reliable foundation for data-driven management. On this basis, this study constructs a data-driven performance improvement framework for university dormitory management and verifies its feasibility through system implementation and functional validation. The research aims to provide both technical support and practical insights for enhancing the efficiency and intelligence of dormitory management.

1. Theoretical Foundations and Technical Framework

1.1 IoT Technology Foundations

An IoT system typically consists of four layers: perception layer, network layer, platform layer, and application layer. Through technologies such as sensors, RFID, Bluetooth, and Wi-Fi, IoT enables the integration of physical and digital spaces.

In this study, Raspberry Pi 3B+ serves as an embedded control unit, combined with a DHT11 sensor for environmental data acquisition. The system supports real-time sensing, local processing, and automatic control, providing reliable and low-cost technical support for dormitory management[1].

1.2 Data-Driven Management Theory

Data-driven management emphasizes the use of data throughout the entire management process, including data collection, integration, analysis, decision-making, and feedback optimization. Compared with traditional experience-based management, this approach enhances accuracy, objectivity, and efficiency, allowing managers to identify problems, allocate resources effectively, and continuously improve performance.

1.3 Performance Dimensions of Dormitory Management

Dormitory management performance can be evaluated across multiple dimensions, including safety control, personnel management, resource utilization, and service response. Traditional evaluation methods rely heavily on subjective judgment and lack quantitative support. In contrast, data-driven approaches enable measurable, dynamic, and continuous performance evaluation.

2. Challenges and Performance Bottlenecks in Traditional Dormitory Management

2.1 Delayed Safety Management

Traditional dormitory safety management primarily relies on manual inspections, which are inherently limited in both coverage and timeliness. As a result, potential safety risks—such as unauthorized appliance usage or abnormal environmental conditions—are often identified only after incidents occur, leading to a reactive rather than preventive management approach.

2.2 Inefficient Energy Management

The lack of real-time monitoring and intelligent control mechanisms results in inefficient energy utilization within dormitories. Common issues, such as prolonged operation of electrical devices without supervision, contribute to unnecessary energy consumption and reflect the absence of data-supported energy management strategies.[2]

2.3 Passive Service Response

Service management in traditional dormitory settings is predominantly passive, relying on manual reporting processes with limited transparency and tracking capabilities. This often leads to delayed responses, inefficient workflow coordination, and reduced service quality, ultimately affecting student satisfaction.

2.4 Lack of Quantitative Evaluation

Performance evaluation in conventional dormitory management largely depends on qualitative assessments and periodic inspections, lacking objective and data-driven metrics. This limitation makes it difficult to accurately identify operational inefficiencies and to establish a continuous improvement mechanism.

3. IoT-Based Data-Driven Framework for Dormitory Management Performance Improvement

To overcome the limitations of traditional dormitory management, this study proposes an IoT-based data-driven framework that integrates data acquisition, processing, application, and feedback into a unified management mechanism. The framework emphasizes the closed-loop interaction between physical sensing, data analysis, intelligent control, and performance optimization, thereby supporting continuous improvement in management efficiency and service quality.

3.1 Data Acquisition and Integration Mechanism

The foundation of the proposed framework lies in real-time data acquisition from the dormitory environment. In this study, a Raspberry Pi 3B+ embedded platform is adopted as the core control unit, interfaced with a DHT11 temperature and humidity sensor through GPIO ports. This configuration enables continuous monitoring of environmental parameters and ensures the accuracy and timeliness of data inputs.

Collected data are further transmitted to a centralized platform for integration and management. By aggregating multi-source data and performing standardization, the system eliminates data fragmentation and establishes a unified data foundation for subsequent analysis and decision-making.

3.2 Data Analysis and Intelligent Application Mechanism

Based on the integrated data, the framework performs multi-dimensional analysis to extract meaningful information for management purposes. This includes environmental trend analysis, anomaly detection, and energy consumption monitoring, which provide data support for safety management and resource optimization.

The analytical results are directly applied to intelligent control processes. Specifically, the system automatically regulates air conditioning devices according to predefined temperature thresholds, enabling adaptive environmental control. This mechanism transforms traditional passive management into a proactive and responsive model, significantly improving operational efficiency and user experience.

3.3 Analysis Layer: Data Processing

To ensure continuous improvement, the framework incorporates a data-driven performance evaluation mechanism. Key performance indicators, such as safety status, energy efficiency, and service responsiveness, are quantified based on real-time data, allowing for objective assessment of management outcomes.

Furthermore, evaluation results are utilized as feedback inputs to refine management strategies.[3]Through iterative adjustment and continuous monitoring, the system forms a closed-loop optimization process, ensuring sustained enhancement of dormitory management performance over time.

4. System Implementation and Functional Validation

4.1 System Architecture and Implementation

The intelligent dormitory management system proposed in this study is implemented based on a Raspberry Pi 3B+ embedded platform, which serves as the core control unit for data processing and device coordination. A DHT11 temperature and humidity sensor is connected to the Raspberry Pi via GPIO interfaces, enabling real-time acquisition of environmental data within the dormitory. The system is developed using Python, which is responsible for sensor data acquisition, preprocessing, and the execution of control logic.

From an architectural perspective, the system adopts a lightweight hardware–software integrated design, consisting of a sensing module, a control module, and an execution module. The sensing module is responsible for continuous environmental data collection, while the control module processes incoming data and applies predefined rules. The execution module translates control decisions into physical actions, such as activating or deactivating air conditioning devices. This modular architecture enhances system flexibility and facilitates future scalability.

In terms of data flow, environmental parameters are periodically sampled and transmitted to the embedded controller, where they undergo basic preprocessing, including filtering and threshold comparison. The processed data are then used to trigger corresponding control actions or stored for subsequent analysis. This continuous data acquisition and processing mechanism ensures the timeliness and reliability of system responses, forming a solid foundation for intelligent management.

The system is designed with considerations for low cost, ease of deployment, and operational stability. The use of Raspberry Pi and low-power sensors enables rapid prototyping and practical implementation in real dormitory environments. Overall, the proposed architecture demonstrates both technical feasibility and application potential for IoT-based dormitory management systems.

4.2 Control Mechanism and Operational Process

The system operates based on a continuous sensing–processing–control cycle, forming the core mechanism for automated and adaptive dormitory environment management. In this cycle, environmental data acquired by the DHT11 sensor are periodically sampled and transmitted to the Raspberry Pi controller, where real-time processing and decision-making are performed. A threshold-based control strategy is adopted to ensure efficient and stable system operation.

Specifically, the control mechanism defines both upper and lower temperature thresholds to regulate air conditioning devices. When the detected temperature exceeds the predefined upper limit, the system generates a control signal to activate the cooling function. Conversely, when the temperature drops below the lower threshold, the system automatically deactivates the device. To enhance operational stability and avoid frequent switching, the control logic incorporates a hysteresis mechanism, ensuring that minor fluctuations in sensor readings do not trigger unnecessary control actions.

From an operational perspective, the system follows a periodic execution process, including data acquisition, preprocessing, threshold evaluation, and control signal output. This structured workflow ensures that environmental changes are detected and addressed in a timely manner. The continuous execution of this cycle enables real-time responsiveness and reduces reliance on manual intervention, thereby improving management efficiency.

The integration of automated control with real-time monitoring allows the system to dynamically adapt to environmental variations. Compared with traditional passive management approaches, this mechanism significantly enhances responsiveness, operational consistency, and user comfort. Overall, the proposed control mechanism provides a reliable and efficient solution for intelligent dormitory environment management within IoT-enabled scenarios.

4.3 Experimental Validation and Performance Analysis

To evaluate the effectiveness of the proposed system, experimental validation was conducted under simulated dormitory conditions by varying ambient temperature within a controlled range. The experimental setup aimed to assess three key aspects of system performance: data acquisition accuracy, control responsiveness, and operational stability. During the testing process, temperature conditions were adjusted incrementally to observe system behavior under different environmental scenarios.

The results demonstrate that the system is capable of reliably collecting environmental data and executing control commands in a stable and consistent manner. Sensor readings remain coherent with expected environmental changes, indicating acceptable measurement accuracy for practical applications.[4] In terms of responsiveness, the system exhibits a short and stable reaction time, typically within a few seconds after threshold conditions are met, ensuring timely regulation of indoor temperature.

Furthermore, the system maintains stable performance over multiple test cycles, with no significant delay, oscillation, or data transmission failure observed. The incorporation of threshold-based control, together with stable data acquisition and processing mechanisms, contributes to the robustness of system operation. These results indicate that the system can sustain continuous operation under typical dormitory conditions without performance degradation.

From a functional and performance perspective, the proposed system effectively achieves automated environmental monitoring and intelligent device control. Compared with traditional dormitory management approaches, it significantly improves response timeliness and reduces reliance on manual intervention. These findings not only verify the technical feasibility of the system implementation but also provide empirical support for the effectiveness of the IoT-based data-driven framework proposed in this study.

5. Data-Driven Performance Improvement Strategies

Building upon the proposed IoT-based framework and system implementation, this study develops three key data-driven strategies to enhance dormitory management performance. These strategies integrate real-time sensing, intelligent control, and data analysis to improve safety, environmental quality, and management efficiency.

5.1 Proactive Safety and Service Management

Traditional dormitory management is predominantly reactive, relying on periodic manual inspections and post-event responses, which limits the ability to identify and mitigate risks in a timely manner. In contrast, the proposed IoT-based system enables proactive safety management through continuous environmental sensing and real-time data analysis. By monitoring key environmental parameters, such as temperature fluctuations and device operating states, the system can detect abnormal conditions and trigger early warnings, allowing potential risks to be addressed before they escalate into critical incidents.

In addition to safety enhancement, the system significantly improves service management efficiency. Through continuous data collection and analysis, operational anomalies and maintenance requirements can be identified in advance, enabling preventive intervention rather than delayed response. This data-driven approach reduces service latency and enhances process transparency, thereby improving the overall quality and reliability of dormitory services.

The integration of real-time monitoring with automated control mechanisms supports the transition from passive management to proactive governance. By leveraging IoT data as a basis for timely decision-making and intervention, the system enhances both risk management capability and service responsiveness, contributing to a more efficient and intelligent dormitory management model.

5.2 Adaptive Environmental and Energy Management

The proposed system enables adaptive environmental regulation based on real-time data collected by the DHT11 temperature and humidity sensor, forming a data-driven mechanism for coordinated environmental and energy management. By continuously monitoring indoor environmental conditions, the system dynamically adjusts device operations to maintain stable and comfortable living conditions within dormitory spaces.

Specifically, a threshold-based control strategy is employed to regulate air conditioning devices. When environmental parameters exceed predefined limits, corresponding control actions are automatically triggered to restore optimal conditions. To enhance operational stability and avoid unnecessary device switching, the control mechanism incorporates tolerance ranges, allowing the system to respond selectively to meaningful environmental variations rather than minor fluctuations.

Beyond environmental regulation, this mechanism also contributes to improved energy efficiency. By aligning device operation with actual environmental demand, the system minimizes redundant energy consumption and avoids the inefficiencies associated with manual control. This data-driven approach enables more precise allocation of energy resources, reducing waste while maintaining user comfort.

The integration of environmental sensing and intelligent control supports the development of sustainable dormitory management practices. Compared with traditional approaches, the proposed system enhances both environmental adaptability and energy utilization efficiency, demonstrating the effectiveness of IoT-based solutions in achieving a balance between user experience and resource conservation.

5.3 Data-Driven Decision-Making and Performance Optimization

The integration of IoT-generated data provides a robust foundation for data-driven decision-making in dormitory management. Through continuous acquisition and aggregation of environmental and operational data, the system enables comprehensive monitoring of dormitory conditions, including environmental status, device utilization, and system performance. These data serve as critical inputs for analytical processes that support informed managerial decisions.

Building upon the collected data, the system facilitates multi-dimensional analysis, such as trend identification, anomaly detection, and performance comparison. These analytical capabilities enable managers to identify inefficiencies and potential risks in a timely manner, thereby improving the accuracy and responsiveness of decision-making processes.[5] Compared with traditional experience-based approaches, this data-driven paradigm significantly enhances the objectivity and reliability of management decisions.

The analytical results support the establishment of quantitative performance evaluation mechanisms. Key performance indicators can be derived from real-time data, allowing for objective assessment of management effectiveness across multiple dimensions. Based on evaluation outcomes, management strategies can be dynamically adjusted and refined, forming a closed-loop optimization process of "data acquisition–analysis–decision–feedback."

This continuous optimization mechanism not only improves short-term operational efficiency but also promotes long-term enhancement of dormitory management performance. Overall, the proposed approach demonstrates the value of integrating IoT data analytics into management practices, providing a systematic pathway toward intelligent and performance-oriented dormitory governance.

6. Supporting Mechanisms

To ensure the effective implementation and sustainable operation of the proposed IoT-based dormitory management system, this study establishes a comprehensive set of supporting mechanisms from technical, institutional, and operational perspectives. These mechanisms provide essential guarantees for system stability, data security, and long-term performance optimization.

6.1 Technical and Data Support Mechanism

The technical foundation of the system relies on stable and reliable IoT infrastructure. In this study, the Raspberry Pi 3B+ platform and DHT11 sensors are deployed to ensure continuous and accurate environmental data acquisition. A secure and efficient data transmission process is established to maintain data integrity and prevent information loss during communication.

In addition, a unified data management framework is adopted to support data storage, processing, and access. Standardized data handling procedures are implemented to improve data quality and usability, providing a solid foundation for subsequent analysis and decision-making. These technical measures ensure the robustness and scalability of the system in real-world dormitory environments.

6.2 Technical and Data Support Mechanism

To support the standardized operation of the system, corresponding institutional mechanisms are required. This includes the establishment of data governance policies that regulate the collection, storage, and use of dormitory-related data. Clear guidelines are defined to ensure that data usage remains within appropriate boundaries.

At the same time, privacy protection is a critical concern in IoT-based management. This study emphasizes the principle of minimal data collection, ensuring that only necessary information is gathered. Access control mechanisms are implemented to restrict data usage based on user roles, thereby reducing the risk of unauthorized access and protecting students' personal information.

6.3 Operational and Resource Support Mechanism

Effective system operation depends on adequate human and financial support. On the one hand, personnel training programs are required to enhance administrators' ability to operate IoT devices and data platforms. Technical support teams should also be established to handle system maintenance, troubleshooting, and upgrades.

On the other hand, sufficient financial investment is necessary to support system deployment, maintenance, and future expansion. Budget allocation should cover hardware procurement, platform operation, and technological upgrades. Through the integration of human, financial, and managerial resources, the system can maintain stable operation and achieve continuous performance improvement.

7. Conclusion

This study develops a data-driven dormitory management model based on Internet of Things (IoT) technology and verifies its feasibility through system implementation and experimental validation. By integrating an embedded system built on Raspberry Pi 3B+ with DHT11 sensors, the proposed approach enables real-time environmental data acquisition, automated control, and continuous operational monitoring. The results demonstrate that the system can effectively improve management efficiency and service quality by supporting a closed-loop mechanism of data acquisition, analysis, decision-making, and feedback, thereby facilitating the transition from reactive to proactive management. Furthermore, the study incorporates performance improvement strategies and supporting mechanisms from technical, operational, and institutional perspectives, ensuring the practicality and sustainability of the proposed model. Overall, this research not only confirms the applicability of IoT technologies in dormitory management but also provides a feasible and scalable pathway for the digitalization and intelligent governance of university residential environments.

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