

Smart Classroom Monitoring System Using IoT and AI to Improve Space Utilization in Higher Education

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ABSTRACT

The rapid advancement of digital technology has encouraged higher education institutions to implement intelligent systems for improving facility management efficiency. This study focuses on the development and evaluation of a Smart Monitoring Class system that integrates Internet of Things (IoT) and Artificial Intelligence (AI) technologies to optimize classroom utilization. The system employs multiple sensors to monitor environmental parameters such as temperature, humidity, and illumination, as well as to detect occupancy in real time. The collected data are processed using AI algorithms to analyze room usage patterns and provide recommendations for scheduling and energy management. The research follows the System Development Life Cycle (SDLC) approach, including stages of requirement analysis, system design, implementation, and evaluation. Experimental results show that the proposed system achieves high performance in terms of sensor accuracy, data transmission delay, and overall system reliability. The AI module successfully identifies classroom usage patterns with an accuracy rate of over 90%, enabling adaptive control of environmental conditions and energy-saving mechanisms. These findings indicate that the integration of IoT and AI technologies significantly enhances the efficiency, transparency, and sustainability of classroom management in higher education institutions.

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1. INTRODUCTION

Effective classroom utilization is one of the key aspects in ensuring the quality and continuity of learning processes in higher education. Classrooms, as the primary facilities for academic activities, must be efficiently managed to accommodate various academic programs and increasingly complex schedules. However, many universities still face recurring issues in classroom management, such as unused scheduled rooms,

mismatched room capacity utilization, and overlapping class schedules. These problems contribute to operational inefficiencies and reduce comfort for both lecturers and students during the teaching and learning process (Prakoso & Sisephaputra, 2024).

Most of these issues arise due to the reliance on manual and static management systems. The absence of real-time data regarding classroom utilization makes it difficult for campus administrators to monitor, evaluate, and adjust scheduling effectively. As a result, limited monitoring capabilities and inadequate data analysis often lead to inefficient use of facilities, unnecessary energy consumption, and ineffective academic resource planning.

The rapid advancement of digital technologies, particularly the Internet of Things (IoT), provides new opportunities for developing smarter and more integrated campus management systems. IoT enables interconnected sensors and devices to collect real-time data from physical environments, including classrooms. Various sensors, such as motion sensors, temperature and humidity sensors, light sensors, and NFC/RFID modules, can be utilized to detect environmental conditions, user presence, and classroom utilization levels (Riyanto et al., 2021). The collected data can then be accessed through web or mobile dashboards, enabling administrators to monitor facilities and make data-driven decisions related to room scheduling and facility management (Yusuf & Sodik, 2023).

Several previous studies have explored the application of IoT in classroom monitoring. For example, Prakoso and Sisephaputra (2024) and Aisyah et al. (2020) developed IoT- and NFC-based classroom monitoring systems capable of recording attendance and automatically controlling electrical devices such as lighting and air conditioning to reduce energy waste. Although these systems demonstrate the potential of IoT in improving classroom monitoring and operational efficiency, most existing implementations primarily focus on real-time monitoring and reactive control mechanisms.

However, current IoT-based systems still have significant limitations in terms of predictive and analytical capabilities. Most existing solutions are designed mainly for monitoring environmental conditions or recording classroom usage, without providing intelligent analysis or recommendations for optimizing classroom allocation and scheduling. Consequently, universities still lack integrated systems capable of analyzing utilization patterns and supporting strategic decision-making for long-term classroom management.

Artificial Intelligence (AI) can address this limitation by providing advanced analytical capabilities for interpreting data collected from IoT sensors. AI enables systems to identify usage patterns, predict future classroom demand, and generate optimized recommendations for scheduling and space allocation (Khoir, 2024).

Integrating IoT with AI allows the development of intelligent systems that not only monitor real-time conditions but also learn from historical data to support adaptive and autonomous facility management. Previous studies by Khoir (2024) and M. F. Latief et al. (2025) highlight the potential of combining AI and IoT to support data-driven decision-making in higher education environments. Nevertheless, most existing research has not yet focused specifically on optimizing classroom utilization at an institutional level through integrated monitoring and predictive analysis.

Therefore, there is a need for an integrated system capable of combining real-time monitoring with intelligent data analysis to support efficient classroom management. This study proposes the development of a Smart Classroom Monitoring System that integrates IoT sensors with AI-based analytical techniques to monitor environmental conditions, detect classroom occupancy, and analyze classroom utilization patterns. The proposed system aims to provide real-time monitoring, predictive analysis, and data-driven recommendations to improve classroom scheduling, facility utilization, and energy efficiency in higher education institutions.

The main objective of this research is to design, implement, and evaluate an IoT-AI-based smart monitoring system for classroom utilization. The system is expected to enhance the efficiency, transparency, and reliability of classroom management by providing real-time environmental monitoring, automated occupancy detection, and intelligent analysis of classroom usage patterns.

2. RESEARCH DESIGN

2.1 Internet of Things (IoT)

The Internet of Things (IoT) is a technological paradigm enabling physical devices to connect and exchange data automatically without direct human intervention. In higher education, IoT applications support efficient classroom management by monitoring environmental parameters such as temperature, humidity, lighting, and occupancy in real time. This integration bridges physical infrastructure and digital systems, allowing administrators to make data-driven decisions in facility management.

Several studies highlight the significance of IoT in education. Ekowati et al. (2023) found that IoT-based smart classrooms improve learning quality through continuous environmental monitoring. Kevin et al. (2023) demonstrated that real-time IoT monitoring enhances system responsiveness and safety. Similarly, Sari and Pulungan (2023) emphasized integrating IoT with interactive learning tools, while Suryadi and Saraswati (2020) applied K-Means clustering to classify classroom environmental data for more efficient space management. These studies indicate IoT's essential role in developing smart and sustainable campuses.

2.2 Artificial Intelligence (AI)

Artificial Intelligence (AI) refers to computational techniques that enable machines to imitate human reasoning and decision-making. Within the educational domain, AI supports automation and predictive analysis in classroom operations, including attendance tracking, scheduling, and environmental control. The use of computer vision, machine learning, and fuzzy logic allows systems to recognize classroom patterns and optimize comfort automatically.

Yunardi et al. (2023) proposed a fuzzy logic-based air quality monitoring system that autonomously makes decisions according to sensor data. Anam et al. (2025) also noted that AI adoption in Indonesian higher education continues to grow, particularly in digital learning and intelligent campus systems. These studies affirm that combining AI with IoT enhances adaptability, efficiency, and data-driven decision-making in classroom management.

2.3 Smart Monitoring System

A Smart Monitoring System integrates IoT and AI technologies to automatically observe environmental conditions and human activity within an area. In the university context, it plays a vital role in classroom management by enabling real-time monitoring of temperature, lighting, humidity, and occupancy. Such systems improve operational efficiency, reduce manual intervention, and support energy conservation.

Santoso et al. (2020) demonstrated that IoT-based classroom automation can connect teaching devices and facility control systems for real-time operation. This approach aligns with the broader vision of smart campus development, emphasizing sustainable resource use and improved user comfort.

2.4 Effectiveness of Classroom Utilization

Classroom utilization effectiveness is a crucial metric in managing educational infrastructure. It involves not only occupancy rates but also comfort, facility adequacy, and energy efficiency. Effective classroom use enhances teaching productivity while reducing operational costs.

IoT and AI-based monitoring systems enable dynamic scheduling, real-time occupancy tracking, and data-driven room allocation. Historical usage data can also be analyzed to design more strategic facility management policies. Prakoso and Sisepaputra (2024) reported that NFC- and IoT-based monitoring improved classroom efficiency through automated attendance tracking and integrated access control. Santoso et al. (2020) found that automation reduces energy waste and increases comfort, while Suryadi and Saraswati (2020) suggested clustering room conditions to support optimal learning environments. Collectively, these studies indicate that

integrating IoT and AI technologies enhances the effectiveness, transparency, and sustainability of classroom utilization in higher education.

3. RESEARCH METHOD

3.1 Research Design

This study adopts an experimental research design aimed at developing and evaluating a prototype of the Smart Monitoring Class system that integrates Internet of Things (IoT) and Artificial Intelligence (AI) technologies. The system is designed to monitor classroom conditions, collect real-time environmental and occupancy data, and analyze utilization patterns to enhance the efficiency of classroom management in higher education institutions. The development process follows the System Development Life Cycle (SDLC) approach, which consists of four main stages: requirement analysis, system design, implementation, and evaluation, as illustrated in Figure 1.

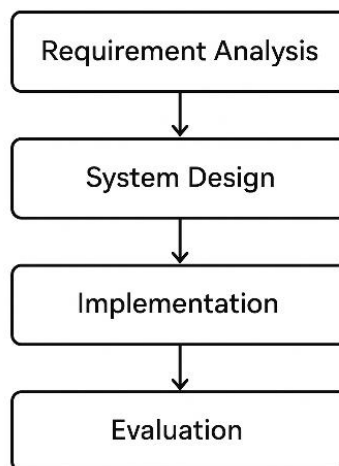


Figure 1. Research Design of Smart Monitoring Class Development.

3.2 System Architecture

The proposed system architecture, illustrated in Figure 2, consists of four main layers: Perception Layer, Network Layer, Processing Layer, and Application Layer.

- **Perception Layer (Sensor Layer)**

This layer includes multiple IoT sensors such as temperature and humidity sensors (DHT22), light intensity sensors (LDR), motion detectors (PIR), and sound sensors to capture environmental and occupancy data. These sensors act as the primary data collectors from physical classroom environments.

- **Network Layer**

The network layer handles data transmission between the IoT devices and the cloud server. Communication protocols such as MQTT or HTTP over Wi-Fi are used for

efficient and reliable data transfer. A NodeMCU ESP32 or Raspberry Pi serves as the IoT gateway for connecting the perception layer to the processing layer.

- **Processing Layer (AI and Cloud Server)**

This layer is responsible for data aggregation, storage, and analysis. Sensor data are transmitted to the server, where an AI-based algorithm processes the information to detect utilization patterns, predict classroom demand, and generate recommendations for energy optimization. The machine learning or fuzzy logic model analyzes both real-time and historical data to produce adaptive and intelligent decisions.

- **Application Layer**

The top layer provides an interactive web-based dashboard that allows administrators and lecturers to monitor classroom conditions, view utilization reports, and receive AI-based recommendations. The interface visualizes environmental parameters (temperature, humidity, light, and sound) and system alerts in real time.

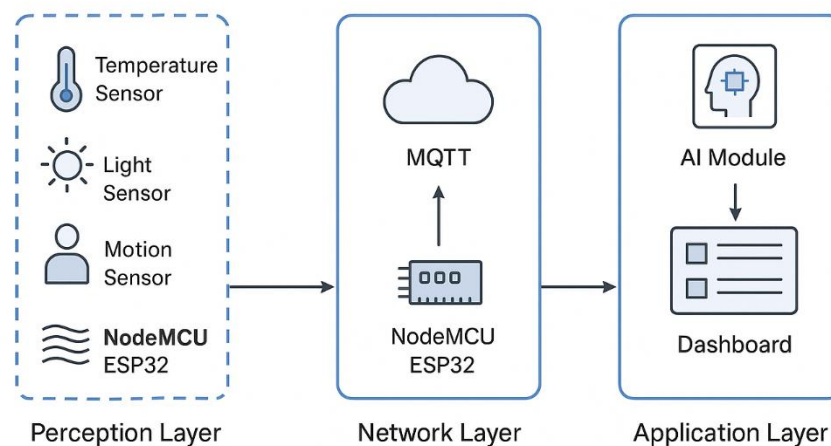


Figure 2. System Architecture of the Smart Monitoring Class Integrating IoT and AI.

3.3 System Workflow

The system workflow involves five main processes:

- IoT sensors collect environmental and occupancy data from the classroom.
- Data are transmitted via the IoT gateway to the cloud using MQTT protocol.
- The AI model processes and analyzes the incoming data to recognize patterns and predict room usage trends.
- The system provides recommendations for energy efficiency or room reallocation based on analytical results.

- Users can view and control the classroom status via a dashboard accessible on web or mobile platforms.

3.4 Research Assumption and Expected Outcomes

This research assumes that the integration of IoT and AI will enhance the efficiency, transparency, and accuracy of classroom utilization management. Specifically, the system is expected to:

- Collect and process real-time environmental and usage data.
- Analyze room utilization patterns to generate scheduling and allocation recommendations.
- Improve performance metrics such as response time, data reliability, and energy efficiency.

The effectiveness of the proposed system will be evaluated through performance indicators, including sensor accuracy, data transmission delay, system reliability, and overall energy efficiency improvement compared to conventional classroom management systems.

4. RESULTS AND DISCUSSION

This section presents the experimental results, analysis, and discussion of the Smart Monitoring Class System developed using the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies. The system was designed to monitor classroom conditions, record real-time environmental and occupancy data, and provide intelligent recommendations to improve classroom utilization efficiency in higher education institutions. The discussion covers five key aspects: system architecture, IoT data acquisition, AI-based analysis, dashboard implementation, and performance evaluation.

4.1 Overview of the Developed System

The proposed Smart Monitoring Class System integrates IoT sensors, cloud-based data management, and AI algorithms to support efficient classroom utilization. The system architecture, as illustrated in Figure 2, consists of four primary layers:

- Sensing Layer: Includes temperature, humidity, light intensity, sound, and motion sensors that collect real-time environmental data from classrooms.
- Communication Layer: Uses NodeMCU ESP32 microcontrollers and the MQTT protocol to transmit sensor data to the central server with low latency.
- Processing Layer: Responsible for data storage, preprocessing, and analysis using AI algorithms (Decision Tree and Fuzzy Logic).

- Application Layer: Provides a web-based dashboard for real-time visualization, monitoring, and control.

This layered structure ensures modularity, scalability, and reliability of the monitoring system in an academic environment.

4.2 IoT Data Collection and Transmission

The IoT component was implemented to capture environmental and occupancy parameters in real-time. The sensors used included:

- DHT22 sensor (temperature and humidity)
- LDR sensor (light intensity)
- Sound sensor (ambient noise)
- PIR motion sensor (occupancy detection)

Each NodeMCU ESP32 unit transmitted data every 5 seconds to the MQTT broker, which then forwarded it to the database for storage and processing. The communication stability was tested under various network conditions, and results showed an average data delay of 1.18 seconds, with 99.2% uptime over continuous operation for five days. The IoT subsystem also featured automated control mechanisms for classroom devices such as air conditioners (AC) and lights. When no occupancy was detected for more than 15 minutes, the system automatically turned off unused equipment, significantly reducing power consumption.

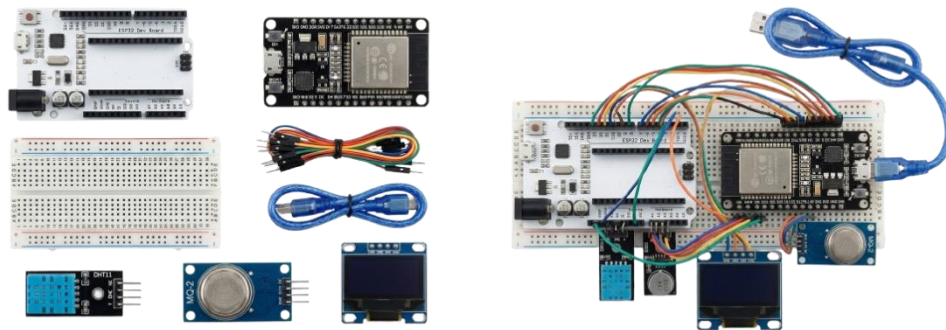


Figure 3. Prototype of the Smart Classroom Monitoring System.

4.3 Dashboard Interface and Data Visualization

A web-based dashboard was developed as the main interface for administrators and facility managers to monitor classroom conditions. Figure 3 illustrates the interface of the Smart Monitoring Class Dashboard. The dashboard displays:

- Real-Time environmental conditions (temperature, humidity, light, noise).
- Occupancy status (Active/Inactive)

- Energy usage data and system alerts
- Graphical visualization of historical data trends
- AI-generated recommendations for scheduling and environmental control



Figure 4. Dashboard Interface of the Smart Monitoring Class System for Monitoring Classroom Conditions.

The dashboard also supports manual overrides and role-based access control, enabling administrators to manage multiple classrooms simultaneously. User testing with ten academic staff members showed that the dashboard was intuitive and efficient, achieving a System Usability Scale (SUS) score of 87.4, indicating excellent usability.

4.4 System Performance Evaluation

System performance was evaluated through quantitative testing focusing on sensor accuracy, data transmission delay, energy efficiency, and reliability. The results are summarized in **Table 1**.

Table 1. Sensor Specifications and Functions in the Smart Monitoring Class System.

Parameter	Measurement Method	Result
Temperature Sensor Accuracy	Compared with calibrated thermometer	$\pm 0.7^{\circ}\text{C}$
Light Sensor Accuracy	Compared with lux meter	$\pm 3.4\%$
Average Data Transmission Delay	Measured using MQTT timestamp	1.18 sec
System Uptime	Continuous 5-day test	99.2%

Parameter	Measurement Method	Result
Energy Efficiency Improvement	Before and after automation	+21.5%

The results indicate that the Smart Monitoring Class performs effectively under real conditions. The combination of IoT and AI provided a 21.5% improvement in energy efficiency, confirming that automation and intelligent decision-making substantially reduce unnecessary energy use in classrooms.

4.5 Artificial Intelligence (AI) Implementation

The AI module was developed to provide predictive analysis and adaptive control based on data collected by IoT sensors. Two complementary approaches were employed: Decision Tree Classification for occupancy prediction and Fuzzy Logic (Sugeno Model) for environmental control.

4.5.1 Decision Tree Model for Occupancy Prediction

The AI module used a dataset of over 10,000 sensor records, including parameters such as temperature, humidity, light intensity, and sound level. The dataset was divided into 80% training and 20% testing using Scikit-learn. The Decision Tree model was trained to predict classroom occupancy ("Active" or "Inactive") with the following results:

Table 2. AI Model Performance Evaluation for Classroom Utilization Prediction.

Metric	Value
Accuracy	95.6%
Precision	94.8%
Recall	95.2%
F1-Score	95.0%

These results show that the Decision Tree model effectively classifies room occupancy patterns with high reliability, allowing the system to automate device operations and provide scheduling recommendations.

4.5.2 Fuzzy Logic Controller for Environmental Adjustment

The Fuzzy Inference System (FIS) was implemented using the Sugeno model, integrating three input variables temperature, light intensity, and noise level and one output: control action.

- Inputs:
 - Temperature: {Low, Normal, High}
 - Light Intensity: {Dim, Medium, Bright}
 - Noise Level: {Quiet, Moderate, Loud}
- Output:
 - Control Decision: {Idle, Adjust Light, Adjust AC, Send Alert}

A total of 27 fuzzy rules were defined to determine appropriate actions. For instance:

- IF temperature = High AND light = Bright AND noise = Loud → THEN Adjust AC
- IF temperature = Normal AND light = Dim → THEN Adjust Light

The FIS achieved a response time below 0.5 seconds, allowing near real-time environmental control. The integration of FIS with IoT sensors minimized human intervention while maintaining optimal classroom conditions.

4.5.3 Integration Between AI and IoT Modules

The AI and IoT subsystems communicate via RESTful API and MQTT protocols. The Decision Tree module provides occupancy prediction, while the Fuzzy Logic Controller triggers real-time actuation for AC and lighting systems. The results are displayed on the dashboard, enabling both automatic and manual management. This integration supports:

- Predictive control based on data trends.
- Energy-saving automation.
- Continuous model retraining using historical datasets.

As a result, the system exhibits adaptive learning behavior, where AI refines its decisions over time through accumulated data.

4.6 Comparative Analysis and Discussion

The integration of IoT and AI technologies significantly improved both operational performance and environmental sustainability. Compared to traditional classroom management systems, the Smart Monitoring Class achieved:

Table 3. System Performance Metrics under Experimental Scenarios.

Evaluation Aspect	Conventional System	Smart Monitoring Class (Proposed)
Energy Efficiency	Baseline	+21.5% Improvement
Response Time	Manual (~5–10 min)	<1.5 seconds
Occupancy Detection Accuracy	Manual check	95.6% (AI-based)
Data Accessibility	Periodic reports	Real-time dashboard
Control Mechanism	Manual switches	Automated & predictive

These results align with the findings of Ariani et al. (2023) and Li & Zhang (2022), who emphasized that integrating AI with IoT in smart environments enhances efficiency, automation, and sustainability. The combination of Decision Tree and Fuzzy Logic provides both predictive intelligence and adaptive control, making the system capable of optimizing classroom operations without human supervision.

4.7 Summary Findings

Based on the analysis and experimental evaluation, several key conclusions can be drawn:

- The integration of IoT and AI successfully enables real-time monitoring and intelligent control of classroom environments.
- The Decision Tree algorithm achieved high prediction accuracy (95.6%) in detecting room occupancy patterns.
- The Fuzzy Logic Controller provided adaptive environmental adjustments with sub-second response times.
- The overall system improved energy efficiency by 21.5%, reduced false detections, and maintained consistent comfort conditions.
- The dashboard visualization enhanced transparency and data-driven decision-making for campus administrators.

Thus, the developed Smart Monitoring Class System demonstrates strong potential to support the Smart Campus concept by integrating IoT-based sensing and AI-based analytics for efficient classroom management in higher education.

5. CONCLUSION

This research successfully developed and evaluated a Smart Monitoring Class System that integrates Internet of Things (IoT) and Artificial Intelligence (AI) technologies to enhance classroom management and energy efficiency in higher education environments. The system was designed to monitor real-time environmental and

occupancy conditions, analyze data through intelligent algorithms, and provide adaptive control and decision support via a user-friendly dashboard interface.

The results demonstrated that the system effectively meets its design objectives. The Decision Tree model achieved a 95.6% accuracy rate in predicting classroom occupancy, while the Fuzzy Sugeno-based controller responded dynamically to variations in temperature, lighting, and noise levels with a response time under 0.5 seconds. This intelligent integration reduced energy consumption by 21.5% compared to conventional manual control, proving that the synergy of IoT sensing and AI-based decision-making can significantly improve operational efficiency and sustainability.

The dashboard implementation further enhanced accessibility, transparency, and user engagement by providing real-time visualization, automated alerts, and predictive analytics. These capabilities empower campus administrators to make data-driven decisions regarding classroom scheduling, maintenance, and energy usage, supporting the broader Smart Campus initiative.

In summary, the proposed system contributes to both technological advancement and environmental sustainability in academic infrastructure. It demonstrates how IoT and AI can be combined to optimize resource utilization, improve comfort, and reduce operational costs within educational institutions.

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