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IMPLEMENTATION OF THE INTERNET OF THINGS IN CREATING SMART CLASSROOMS

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Abstract: *The development of digital technology has driven the transformation of educational services through the implementation of data-based learning systems and smart devices. One of the emerging approaches is the use of the Internet of Things (IoT) in building smart classrooms, which are classrooms capable of integrating physical devices, sensors, and information systems to improve learning efficiency and learning environment management. This study aims to analyze the implementation of IoT in the formation of smart classrooms, covering aspects of system design, device integration, and evaluation of its effectiveness in supporting the teaching and learning process. The research method used is a quantitative and experimental approach, by designing an IoT-based smart classroom prototype that integrates temperature, humidity, light intensity, and presence detection sensors, as well as device control such as lights, air conditioning, and projectors through an automatic system and remote control. Data was collected through device performance measurements, network stability tests, and questionnaires distributed to users (teachers and students) to assess the system's ease of use and usefulness. The results showed that the implementation of IoT in classrooms can improve the efficiency of facility management through device automation, facilitate real-time monitoring of classroom conditions, and provide a more comfortable and responsive learning environment. In addition, the developed system demonstrated stable data communication performance with low latency within acceptable operational limits. These findings indicate that the application of IoT in smart classrooms has the potential to contribute significantly to improving the quality of learning and classroom management, particularly in supporting a technology-based education ecosystem. This study recommends further development in the areas of data security, device interoperability, and integration with Learning Management Systems (LMS) to strengthen the sustainable implementation of smart classrooms.*

Keywords: *Internet of Things, Smart Classroom, Classroom Automation, Sensors, Technology Based Education.*

Abstrak: Perkembangan teknologi digital mendorong transformasi layanan pendidikan melalui penerapan sistem pembelajaran berbasis data dan perangkat cerdas. Salah satu pendekatan yang berkembang adalah pemanfaatan Internet of Things (IoT) dalam membangun smart classroom, yaitu ruang kelas yang mampu mengintegrasikan perangkat fisik, sensor, serta sistem informasi untuk meningkatkan efisiensi pembelajaran dan pengelolaan lingkungan belajar. Penelitian ini bertujuan untuk menganalisis implementasi IoT dalam pembentukan smart classroom, mencakup aspek desain sistem, integrasi perangkat, serta evaluasi efektivitasnya dalam mendukung proses belajar mengajar. Metode penelitian yang digunakan adalah pendekatan kuantitatif dan eksperimental, dengan merancang prototipe smart classroom berbasis IoT yang mengintegrasikan sensor suhu, kelembapan, intensitas cahaya, deteksi kehadiran, serta pengendalian perangkat seperti lampu, pendingin ruangan, dan proyektor melalui sistem otomatis maupun kendali jarak jauh. Data dikumpulkan melalui pengukuran kinerja perangkat, uji stabilitas jaringan, serta penyebaran kuesioner kepada pengguna (guru dan siswa) untuk menilai tingkat kemudahan penggunaan dan kebermanfaatan sistem. Hasil penelitian menunjukkan bahwa implementasi IoT pada ruang kelas mampu meningkatkan efisiensi pengelolaan fasilitas melalui otomasi perangkat, mempermudah monitoring kondisi kelas secara real-time, serta memberikan dukungan lingkungan belajar yang lebih nyaman dan responsif. Selain itu, sistem yang dikembangkan menunjukkan performa komunikasi data yang stabil dengan tingkat keterlambatan (latency) yang rendah dalam batas operasional yang dapat diterima. Temuan ini mengindikasikan bahwa penerapan IoT dalam smart classroom berpotensi memberikan kontribusi signifikan terhadap peningkatan kualitas pembelajaran dan manajemen kelas, khususnya dalam mendukung ekosistem pendidikan berbasis teknologi. Penelitian ini merekomendasikan pengembangan lanjutan pada aspek keamanan data, interoperabilitas perangkat, serta integrasi dengan Learning Management System (LMS) untuk memperkuat implementasi smart classroom secara berkelanjutan.

Kata Kunci: Internet Of Things, Smart Classroom, Otomasi Ruang Kelas, Sensor, Pendidikan Berbasis Teknologi.

INTRODUCTION

The development of information and communication technology over the past two decades has brought significant changes to various sectors, including education. The massive digital transformation has required educational institutions to adapt to the learning needs of the 21st century, which emphasize flexibility, interactivity, efficiency, and the use of data as a basis for decision-making. In this context, the classroom is no longer understood as merely a place for face-to-face interaction between teachers and students, but rather as a learning environment that must be able to support a more dynamic, responsive, and integrated learning process with technological devices.

One of the innovations that has developed to support this transformation is the application of the Internet of Things (IoT). IoT is a concept that allows physical objects to be connected via the internet so that they can collect data, communicate, and perform automatic actions based on certain conditions. The implementation of IoT in education provides opportunities to create a more adaptive learning system through sensor-based classroom environment management, automatic electronic device control systems, and the provision of real-time classroom condition information. The application of IoT in learning is also part of strengthening a technology-based education ecosystem that is in line with modern learning needs.

The concept of smart classrooms is one of the tangible forms of IoT utilization in the educational environment. Smart classrooms refer to classrooms equipped with smart devices and integrated systems to support more effective, efficient, and comfortable learning for users. The implementation of smart classrooms can include monitoring room temperature, humidity, light intensity, air quality, and even detecting the presence of users through specific sensors. The data obtained can be used to optimize classroom comfort, improve energy efficiency, and support more systematic school facility management. In addition, the system's ability to control devices such as lights, air conditioners, projectors, and other learning support devices contributes to increased productivity in teaching and learning activities (Ojo et al., 2022).

Although the implementation of IoT in creating smart classrooms has great potential, the reality of its application still faces various challenges. These challenges include the need for stable devices and network infrastructure, integration between devices with different communication protocols, data security and user privacy aspects, and the readiness of human resources in operating technology-based systems. In some cases, the systems developed have not fully considered aspects of sustainability and scalability, so that implementation is limited to prototypes without clear long-term implementation (Badshah et al., 2023). Therefore, research on the implementation of IoT in smart classrooms is important to provide an empirical overview of system design, performance, and the benefits of its implementation on the effectiveness of classroom management (Nai, 2022).

Based on these conditions, this study was designed to analyze the implementation of IoT in creating smart classrooms through prototype design and system performance evaluation. The research focuses on the integration of sensors and actuators in the classroom, the effectiveness of data communication, and user perceptions regarding the ease and usefulness of the system. The results of this study are expected to serve as a basis for educational institutions in designing and implementing smart classrooms that are tailored to learning needs, while also contributing to the development of applicable and sustainable educational technology innovations.

METHOD

This study uses a quantitative approach with an experimental design that focuses on the design, implementation, and evaluation of an Internet of Things (IoT)-based smart classroom system. A quantitative approach was chosen because the research focuses on objective measurements of the performance of the developed system, particularly in terms of system response latency, data communication stability, and the effectiveness of automatic and manual classroom device control (Terzieva et al., 2022). Meanwhile, the experimental design was applied by testing the system prototype in a simulated classroom environment to resemble actual conditions in educational institutions (Zeeshan et al., 2022).

The initial stage of the research began with a needs analysis, which was conducted to identify problems and needs in classrooms in supporting technology-based learning. The analysis included the need to monitor classroom conditions and the need for automated classroom facility management, such as lighting and air conditioning settings (Burunkaya & Duraklar, 2022). The results of the needs analysis were used as the basis for designing the architecture of an IoT-based smart classroom system. The system architecture was designed by integrating several main components, namely sensors as input devices, microcontrollers as data processing and communication connection units, the internet network as a data transmission medium, and actuators as output devices to execute automatic control of classroom devices. In addition, the system is also equipped with a monitoring interface in the form of a dashboard that allows users to monitor classroom conditions in real-time while providing control over connected devices (Ginting, Syahputra, et al., 2025).

The system is implemented by installing sensors to obtain data on classroom conditions, including temperature, humidity, light intensity, and user presence detection. The data collected by the sensors is processed by the microcontroller and sent via the network to be displayed on the dashboard. Based on the parameter values read, the system is designed to perform automatic actions through actuators, such as turning lights on or off according to the light intensity in the room, as well as activating or deactivating air conditioning based on temperature conditions (Chauhan et al., 2025). At this stage, data communication and system log storage are also configured so that sensor readings and device control commands can be

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systematically recorded during testing. System testing was conducted in two forms, namely functional testing and performance testing. Functional testing aims to ensure that all system components work as designed, ranging from the ability of sensors to detect environmental conditions, the process of sending data to the dashboard, to the ability of actuators to execute control commands. Once the system is confirmed to be functioning properly, performance testing is conducted to obtain quantitative data on the stability and reliability of the system (Ginting, Singh, et al., 2025). The parameters analyzed include the system's response time to control commands, the success rate of sensor data transmission to the server or dashboard, and the consistency of system operations during a specific testing period (Ginting et al., 2024). The performance test results are then compiled as a basis for assessing the effectiveness of the IoT system in supporting classroom facility management. The following is the average latency calculation :

$$bar\ L = \frac{\sum_{i=1}^{n} L_i}{n} \quad (1)$$

$\bar{L}$: is the average latency (ms).
L_i : is the latency of testing to i
n : is the total number of tests.

This formula is used to determine the average response time of an IoT system when executing commands, such as when turning on lights/air conditioning via the dashboard (Wayahdi et al., 2024).

The following is the Maximum and Minimum Latency Calculation :

$$L_{max} = \max(L_1, L_2, ..., L_n)$$
$$L_{min} = \min(L_1, L_2, ..., L_n)$$

RESULT AND DISCUSSION

The implementation of an Internet of Things (IoT)-based smart classroom system in this study resulted in a prototype smart classroom that is capable of monitoring environmental conditions in real time while controlling classroom devices automatically or manually. The system was built by integrating sensor devices as inputs, microcontroller-based processing units as data processors, and actuators as output devices that function to control electrical devices in the classroom. Sensor data is transmitted via a wireless network to a dashboard-based monitoring system so that information on classroom conditions can be monitored at any time according to user needs.

The sensor components used in this prototype serve to monitor classroom environmental parameters, including temperature and humidity, light intensity, and user presence through a presence detection sensor. These parameters were selected because they are directly related to classroom comfort and efficient use of facilities. The control system is designed to provide rule-based automation, such as turning on lights when light intensity falls below a certain threshold and activating air conditioning when the classroom temperature exceeds a set limit (Hafiz et al., 2024). On the other hand, the system also allows users to manually control devices through the dashboard interface to meet situational learning needs.

Table 1 Latency Test Results for Device Control Commands

Test Scenario	Control Command	n (Trials)	Min Latency (ms)	Max Latency (ms)	Average (ms)	Standard Deviation (ms)
Lighting Control	ON/OFF	20	120	310	185	42
Air Conditioner /Fan Control	ON/OFF	20	160	420	240	55
Projector Control	ON/OFF	20	140	380	215	49
Automatic Mode	Rule-based Trigger	20	170	460	265	61

Based on Table 1, latency testing shows that the IoT system is capable of executing device control commands with an average latency in the range of 185–265 ms. The lowest latency value was obtained in light control, while the highest average occurred in rule-based automation mode. This difference

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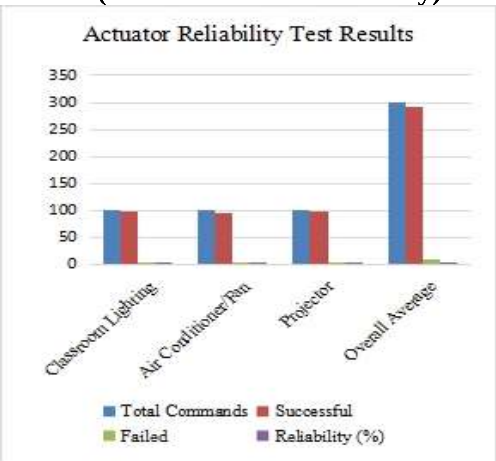
indicates that the automation mechanism requires a sensor parameter evaluation process prior to actuator execution, resulting in a relatively higher response time compared to manual commands (Darmayanti et al., 2024).

Table 2 Packet Loss Test Results for Sensor Data Transmission to the Dashboard

Sensor Type	Packets Sent	Packets Received	Packet Loss (%)	Success Rate (%)
Temperature & Humidity	500	492	0,08333333	98.40.00
Light Intensity	500	495	01.00	99.00.00
Presence Detection	500	490	02.00	98.00.00
Overall Average	2000	1977	01.15	98.85

Table 2 shows that the system has a low packet loss rate with an average of 1.15%, so that data communication stability can be categorized as good. The overall success rate reached 98.85%, indicating that the dashboard can consistently display classroom conditions and support real-time monitoring functions (Hafiz et al., 2023).

Table 3 Actuator Reliability Test Results (Device Control Reliability)



Based on the test results in Table 3, the Internet of Things (IoT)-based smart classroom system shows a high level of actuator reliability in executing control commands for classroom devices. The reliability test was conducted by giving a number of control commands to each actuator device, then calculating the proportion of successful command execution compared to the total commands given. This reliability is an important indicator because actuators act as execution components that ensure the system is not only capable of monitoring, but also capable of performing actual actions on the controlled devices (Mughnyanti & Ginting, 2023).

In the classroom light actuator test, a total of 100 commands were given, with 98 commands successful and 2 commands failing, resulting in a reliability value of 98.00%. This percentage is the highest compared to other devices and shows that the light control is relatively stable and responsive. This may be due to the characteristics of the light's electrical load, which tends to be simpler, and the device's faster initialization time, resulting in a lower risk of command execution failure (Kadafi et al., 2024).

Furthermore, testing on the AC/fan actuator resulted in a reliability of 96.00% with 96 successful commands and 4 failed commands out of a total of 100 commands. This value is the lowest reliability among the devices tested. This condition indicates that AC/fan control is more complex than lights, mainly because air conditioning devices generally require longer stabilization times and have greater power requirements. In IoT systems, controlling larger loads tends to be more prone to response delays or current instability, which ultimately has the potential to cause execution failures in a small number of experiments.

The following is the IoT Smart Classroom Architecture Diagram :

Image 1 IoT Smart Classroom Architecture Diagram

The architecture of an IoT-based smart classroom system consists of several main layers. The sensor layer collects data on the classroom environment, such as temperature, humidity, light intensity, and user presence. This data is processed on an edge controller unit using a microcontroller that performs data acquisition, simple processing, and rule-based automation functions. The data is then sent via a communication network to be stored in a database and displayed on a monitoring dashboard. The dashboard allows users (teachers and students) to monitor classroom conditions in real time and control devices manually. Control commands are processed to activate actuators, so that classroom devices can be controlled automatically or according to user needs.

CONCLUSION

Based on the results of system design, implementation, and testing, this study concludes that the application of the Internet of Things (IoT) in building smart classrooms can be effectively implemented to support the monitoring of classroom conditions and the integrated control of learning devices. The developed system is capable of monitoring environmental parameters in real-time through sensors, as well as controlling devices such as lights, air conditioners/fans, and projectors through manual and rule-based automatic control mechanisms.

Performance evaluation results show that the system has low and stable response time (latency), as well as good sensor data communication with relatively small packet loss, so that the information displayed on the dashboard can be used as a basis for quick decision making. In addition, actuator reliability testing showed high reliability values with an average device control success rate of 97.00%, indicating that the system is capable of executing control commands consistently and is suitable for use in a classroom environment.

In terms of user acceptance, the questionnaire results show that the system received excellent ratings in terms of ease of use and usefulness, so that the IoT-based smart classroom is considered capable of improving the efficiency of classroom facility management while supporting a comfortable learning environment. Thus, the implementation of IoT in classrooms not only contributes to technical aspects but also provides practical value in supporting the digital transformation of education.

As a development recommendation, this study suggests improvements in network stability, the implementation of data security mechanisms, and the development of integration with learning systems such as Learning Management Systems (LMS) so that smart classrooms can be applied more widely and sustainably.

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