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Smart Home Automation Using IoT Sensors and Microcontrollers

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ABSTRACT

The rapid development of Internet of Things (IoT) technology has significantly influenced the way residential environments are managed and controlled. Smart home automation has emerged as an effective solution for improving comfort, security, and energy efficiency through the integration of sensors, microcontrollers, and network communication systems. This study presents the design and implementation of a smart home automation system using IoT sensors and microcontrollers to monitor environmental conditions and automatically control household devices. The proposed system utilizes several sensors to detect parameters such as temperature, humidity, light intensity, and motion, which are processed by a microcontroller to determine appropriate system responses. Based on predefined conditions, the system can automatically activate or deactivate devices including lighting systems, ventilation fans, and security alerts. Wireless communication enables remote monitoring and control through internet-connected devices, allowing users to manage their home environment from different locations. The results show that the system operates reliably and responds quickly to environmental changes, demonstrating effective automation performance. In addition, the implementation of sensor-based control contributes to improved energy efficiency by ensuring that electrical devices operate only when necessary. Overall, the proposed IoT-based smart home automation system provides a practical and scalable approach for developing intelligent residential environments supported by modern digital technologies.

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1. INTRODUCTION

The rapid development of digital technology has significantly transformed how humans interact with their living environments[1]. One of the most prominent innovations emerging from this transformation is the concept of smart home automation[2]. A smart home refers to a residential environment where various devices and systems can communicate, monitor conditions, and operate automatically through interconnected technologies[3]. This concept is strongly supported by the advancement of the Internet of Things (IoT), a technological paradigm that allows physical objects embedded with sensors, microcontrollers, and communication modules to collect and exchange data through networks[4]. By integrating IoT sensors and microcontrollers, modern homes can perform tasks such as monitoring temperature, controlling lighting, managing security systems, and optimizing energy consumption without requiring constant human intervention[5]. Despite the rapid adoption of smart technologies, many residential environments still rely on conventional systems that require manual control[6]. Traditional home electrical systems generally operate independently without the ability to communicate or adapt to changing environmental conditions[7]. This limitation often results in inefficient energy usage, limited monitoring capabilities, and reduced convenience for occupants[8]. For example, lighting systems may remain active even when rooms are unoccupied, or security monitoring may rely solely on manual observation rather than automated detection[9]. These challenges highlight the need for a more intelligent and interconnected home management system that can enhance efficiency, safety, and comfort[10].

The integration of IoT technology into home environments offers a promising solution to these challenges[11]. IoT sensors enable real-time monitoring of environmental parameters such as temperature, humidity, motion, light intensity, and air quality[12]. When connected to microcontrollers, these sensors allow automated responses based on predefined conditions or user preferences. Microcontrollers act as the central processing units within the system, collecting data from sensors, processing the information, and triggering actions through actuators or connected devices[13]. This architecture enables the creation of responsive environments capable of adapting to user needs and environmental changes[14]. Several studies and technological developments have emphasized the importance of IoT-based home automation systems. Previous work in this field has demonstrated the potential of wireless communication technologies such as Wi-Fi, Bluetooth, and Zigbee to connect smart devices within residential networks[15]. Researchers have explored different system architectures that combine sensor networks with microcontroller platforms to enable automated lighting, climate control, and remote monitoring. Some systems focus on energy management by optimizing the use of electrical appliances, while others prioritize security features such as motion detection, surveillance integration, and automated alerts[16].

In addition, advancements in microcontroller platforms have made smart home development more accessible and cost-efficient[17]. Compact and programmable microcontrollers provide the computational capability required to process sensor data while maintaining low power consumption[18]. These devices can interface with multiple sensors and actuators simultaneously, making them suitable for managing complex home automation tasks[19]. Furthermore, the integration of cloud-based services and mobile applications allows users to monitor and control their home systems remotely, enhancing flexibility and convenience[20]. However, many existing smart home implementations still face challenges related to system integration, scalability, and cost efficiency. Some solutions rely on proprietary platforms that limit compatibility with other devices, while others require complex configurations that may not be practical for widespread residential use. Additionally, issues such as network reliability, data security, and energy efficiency remain important considerations when designing IoT-based automation systems[21]. These limitations highlight the need for more flexible and efficient architectures that can integrate multiple sensors and control mechanisms in a reliable and user-friendly manner[22]. The approach proposed in this study focuses on the design of a smart home automation system that utilizes IoT sensors and microcontrollers as the core components of the architecture[23]. The system is designed to monitor environmental conditions and automatically control household devices through a network-based communication framework. Sensors are deployed to collect real-time environmental data, which is then processed by a microcontroller to determine appropriate actions based on predefined rules or intelligent control mechanisms[24]. The system also incorporates remote monitoring capabilities, allowing users to access system information and control devices through connected platforms[25]. The implementation emphasizes modular design principles to ensure that additional sensors or devices can be integrated without major system modifications[26]. This modular architecture supports scalability and allows the system to adapt to different residential environments[27]. By utilizing commonly available IoT sensors and efficient microcontroller platforms, the system aims to maintain affordability while providing reliable automation capabilities[28]. The proposed framework also considers energy efficiency by ensuring that devices operate only when necessary based on sensor data and environmental conditions.

The innovative value of this work lies in the integration of sensor-based environmental monitoring with adaptive microcontroller-driven automation within a unified IoT architecture. Unlike traditional home automation systems that rely heavily on manual control or isolated device operations, this approach enables continuous data-driven decision-making within the home environment. The combination of real-time sensing, automated processing, and network communication creates a responsive system capable of improving energy efficiency, enhancing security, and increasing user convenience. Furthermore, the system design emphasizes interoperability and flexibility, enabling integration with various types of sensors and communication technologies. This adaptability allows the framework to be implemented in different residential contexts while supporting future technological developments. By demonstrating how IoT sensors and microcontrollers can be effectively combined to create intelligent residential environments, this study contributes to the ongoing development of smart living technologies and provides a foundation for further innovations in automated home systems.

Overall, smart home automation represents an important step toward creating more intelligent, efficient, and sustainable living environments. The continued advancement of IoT technologies and embedded systems will play a crucial role in shaping the future of residential infrastructure. Through the integration of sensors, microcontrollers, and network communication, homes can evolve into adaptive systems that actively respond to the needs of their occupants while optimizing resource usage and enhancing quality of life.

2. RESEARCH METHOD

The development of a smart home automation system based on Internet of Things (IoT) technology requires a systematic methodological approach that integrates hardware design, software development, and system testing. This section describes the stages used to design, implement, and evaluate the smart home automation system utilizing IoT sensors and microcontrollers. The methodology focuses on the development of an integrated system capable of monitoring environmental conditions and automatically controlling household devices through sensor-based data processing.

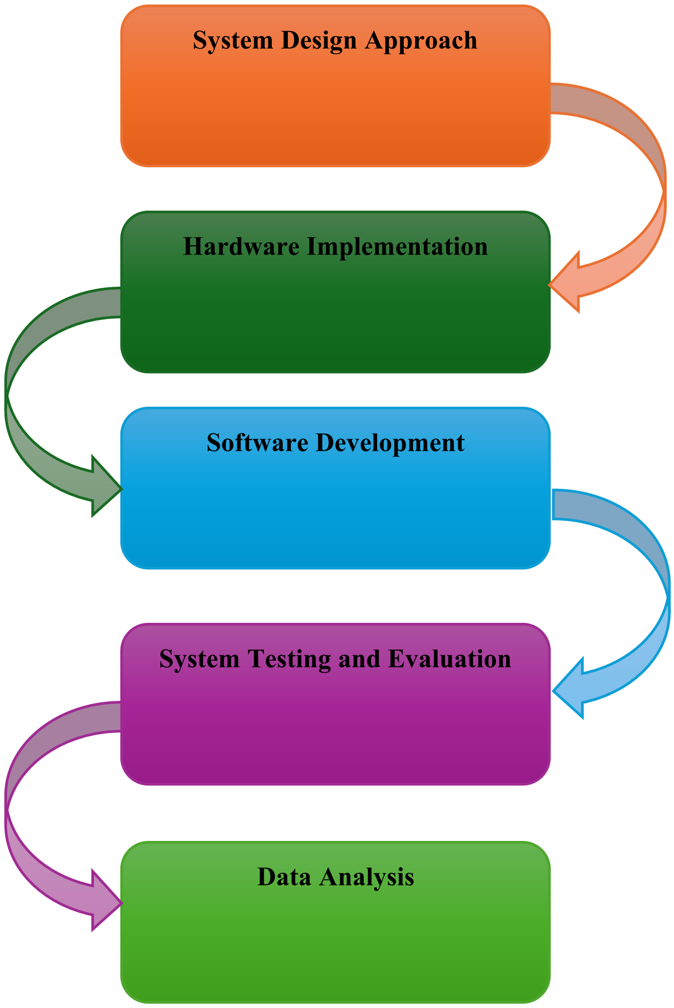

Figure 1. Research Methodology Structure

2.1. System Design Approach

The research adopts a system development approach that emphasizes the integration of sensors, microcontrollers, and communication modules within an IoT-based architecture. The system design begins with the identification of functional requirements related to smart home automation, including environmental monitoring, automated device control, and remote system access. These requirements are used to define the structure of the smart home automation framework. The proposed system architecture consists of three main components: sensing units, processing units, and communication interfaces. The sensing units are responsible for collecting environmental data from the home environment. Various IoT sensors are deployed to measure parameters such as temperature, humidity, motion detection, and light intensity. These sensors continuously monitor environmental conditions and transmit the collected data to the processing unit.

The processing unit is implemented using a microcontroller that acts as the central control system. The microcontroller processes the data received from the sensors and determines the appropriate actions based on predefined system rules. For example, when the light intensity detected by the sensor drops below a certain threshold, the system automatically activates the lighting system. Similarly, motion sensors can trigger security notifications or activate surveillance devices when movement is detected in restricted areas. The communication interface allows the system to transmit data and receive commands through a network connection. Wireless communication technologies such as Wi-Fi are used to connect the microcontroller to the internet, enabling remote monitoring and control of the smart home system. This connectivity allows users to access system information through mobile applications or web-based platforms.

2.2. Hardware Implementation

The hardware component of the system consists of several integrated modules that work together to support smart home automation functions. IoT sensors are deployed at strategic locations within the home environment to monitor various environmental conditions. These sensors include temperature and humidity sensors for climate monitoring, light sensors for automated lighting control, and motion sensors for security detection. The sensors are connected to a microcontroller platform that processes incoming data and executes control commands. The microcontroller is responsible for coordinating communication between sensors and actuators while maintaining efficient system performance. Actuators such as relays are used to control electrical devices, including lighting systems, fans, and other household appliances. Each hardware component is configured to ensure reliable communication and accurate data acquisition. Proper wiring, voltage regulation, and signal calibration are implemented to maintain stable system operation. The hardware design also emphasizes modularity, enabling the integration of additional sensors or control devices into the system as needed.

2.3. Software Development

The software component of the system is responsible for managing data processing, device control, and communication between system components. The microcontroller is programmed using embedded software that reads sensor data, processes the information, and executes control logic. The program includes several operational modules, including sensor data acquisition, decision-making algorithms, device control routines, and network communication protocols. Sensor readings are continuously monitored, and the system evaluates the data against predefined threshold values or control conditions. When specific conditions are met, the system activates corresponding actuators to perform the required action.

In addition to automated control, the system also supports remote monitoring capabilities. Data collected by the sensors can be transmitted to a cloud-based platform or monitoring interface, allowing users to observe environmental conditions and control devices remotely. This feature enhances user convenience and provides real-time access to system status.

2.4. System Testing and Evaluation

After the system is developed, testing procedures are conducted to evaluate the functionality and reliability of the smart home automation system. The testing process involves verifying sensor accuracy, microcontroller response time, and device control performance. Each component of the system is tested individually before performing integrated system testing. Functional testing is conducted to ensure that sensors accurately detect environmental changes and that the microcontroller correctly processes the data. The response of actuators to sensor-triggered commands is also evaluated to confirm proper device operation. In addition, network connectivity tests are performed to verify that remote communication between the system and monitoring platforms operates reliably.

Performance evaluation focuses on system responsiveness, automation accuracy, and operational stability under different environmental conditions. The system is observed during continuous operation to identify potential delays, communication errors, or hardware limitations. Any detected issues are analyzed and addressed through system adjustments or software optimization.

2.5. Data Analysis

The data obtained during system testing are analyzed to determine the effectiveness of the proposed smart home automation framework. Sensor readings, device activation logs, and system response times are recorded and evaluated to assess the overall system performance. The analysis aims to determine whether the system successfully improves automation efficiency, enhances environmental monitoring, and provides reliable remote control functionality. Through this methodological approach, the research demonstrates the practical implementation of IoT sensors and microcontrollers in developing a smart home automation system. The combination of hardware integration, software programming, and systematic evaluation ensures that the system operates effectively and provides a reliable foundation for intelligent residential automation.

3. RESULTS AND DISCUSSION

3.1. System Implementation

The smart home automation system was successfully implemented using IoT sensors integrated with a microcontroller-based control unit. The system architecture consists of environmental sensors, a processing unit, communication modules, and actuator components that control household electrical devices. The sensors continuously monitor environmental conditions and transmit data to the microcontroller for processing. Based on predefined conditions, the system automatically activates or deactivates devices such as lighting systems, ventilation fans, and security alerts.

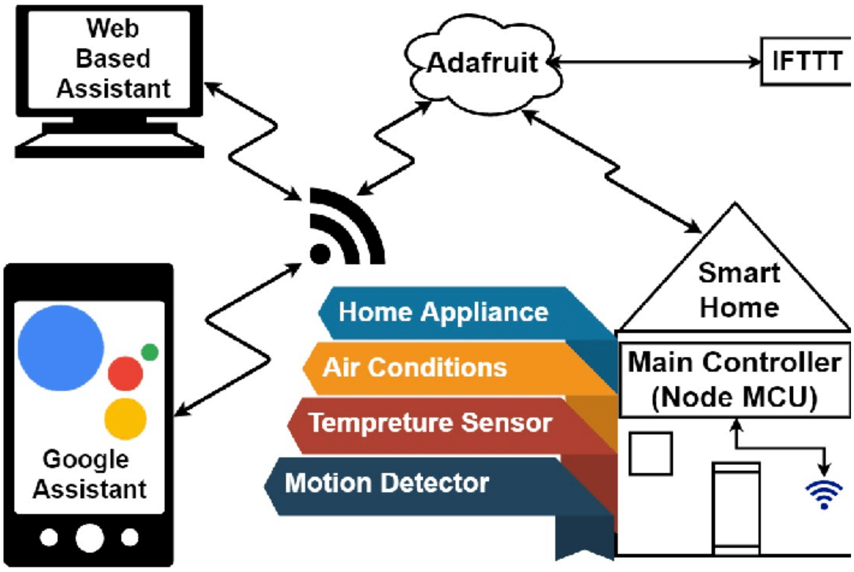

Figure 2. System Architecture of IoT-Based Smart Home Automation

The implemented architecture operates through three main layers: the sensing layer, the processing layer, and the application layer.

a. Sensing Layer : This layer consists of IoT sensors deployed inside the residential environment. The sensors collect environmental information such as temperature, humidity, light intensity, and motion detection.
b. Processing Layer : The microcontroller processes the collected sensor data and determines system actions based on programmed control logic.
c. Application Layer : This layer allows users to monitor the system and control devices remotely through a network connection.

The system is designed to automatically respond to environmental changes. For example, when the light intensity falls below a defined threshold, the lighting system is automatically activated. Similarly, motion detection triggers security alerts or surveillance system activation.

a. Sensor Monitoring Results

The sensors' performance was evaluated by collecting environmental data during system operation. Sensor readings were recorded periodically to observe system responsiveness and accuracy.

Table 1. Environmental Monitoring Results

Time	Temperature (°C)	Humidity (%)	Light Intensity (Lux)	Motion Detection	System Action
08:00	26.2	70	450	No	Lights OFF
10:00	28.1	65	620	No	Lights OFF
14:00	30.4	60	700	No	Fan ON
18:30	27.5	68	150	Yes	Lights ON
22:00	26.0	72	80	Yes	Lights ON

The results demonstrate that the system can continuously monitor environmental parameters and respond according to the predefined automation rules. During daylight hours, the lighting system remained inactive due to sufficient natural light intensity. However, when the light level dropped in the evening, the system automatically activated the lighting devices. Temperature monitoring also allowed the system to activate ventilation devices when the temperature exceeded a specific threshold, helping maintain indoor comfort.

3.3. Automation Performance

The system's automation performance was evaluated by measuring the response time from sensor detection to device activation. The system demonstrated efficient response behavior under different environmental conditions.

Table 2. Automation Response Time

Sensor Event	Trigger Condition	Device Activated	Response Time (seconds)
Motion Sensor	Movement detected	Security Alert	1.2
Light Sensor	Light < 200 Lux	Lighting System	1.5
Temperature Sensor	Temperature > 30°C	Ventilation Fan	2.1
Motion Sensor	Movement detected at night	Lighting + Alert	1.8

The results indicate that the system responds quickly to environmental changes. Most automated actions occur within two seconds after the detection of sensor events. This response time is considered acceptable for residential automation applications that require immediate system response.

b. Smart Home Device Integration

The system integrates multiple household devices through relay-based actuator control. The microcontroller sends control signals to relays that switch electrical appliances on or off depending on sensor input and system logic.

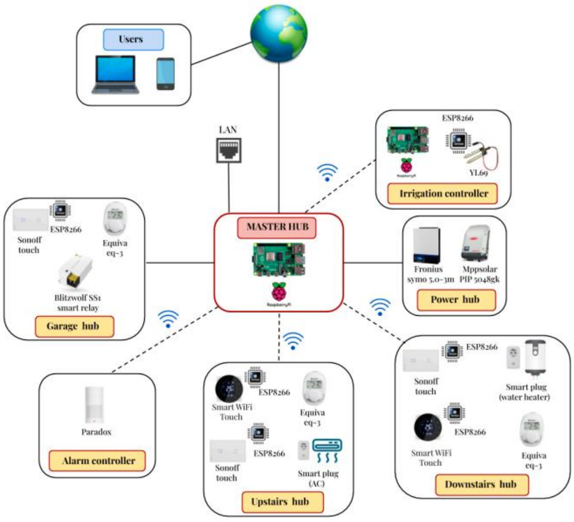

Figure 3. Architecture of IoT-Based Smart Home Automation System Using Microcontroller and Sensor Networks

The implemented prototype demonstrates the capability to control multiple devices simultaneously. For example, when motion is detected during nighttime conditions, the system activates both lighting and security alerts. This coordinated automation improves residential safety and user convenience.

c. System Reliability and Efficiency

During continuous system testing, the smart home automation framework showed stable operation and reliable sensor communication. The microcontroller effectively processed incoming data from multiple sensors without significant delay. Network connectivity also allowed remote monitoring of system status through an internet-based interface. One of the key advantages observed during system evaluation is improved energy efficiency. Automated control prevents unnecessary operation of electrical devices when they are not required. For instance, lighting systems remain inactive when sufficient natural light is available, reducing electricity consumption. Similarly, ventilation systems operate only when temperature thresholds are exceeded.

d. Discussion

The results demonstrate that integrating IoT sensors with microcontroller platforms provides an effective approach for implementing smart home automation systems. The system architecture successfully combines environmental monitoring with automated device control, creating a responsive residential environment. Compared with traditional manual home control systems, the proposed IoT-based framework offers several advantages. First, it enables real-time environmental monitoring, allowing the system to detect changes and react automatically. Second, automation reduces the need for continuous user interaction, improving convenience and efficiency. Third, the system supports remote monitoring capabilities, allowing users to control and monitor their home environment from external locations.

Another important aspect of the system is scalability. The modular architecture allows additional sensors or smart devices to be integrated without major system modifications. This flexibility enables the system to adapt to various residential environments and technological advancements. However, several challenges remain in implementing IoT-based home automation systems. Network security and data privacy must be carefully considered to protect user information and prevent unauthorized access to smart home devices. Additionally, system reliability depends on stable internet connectivity and proper hardware configuration. Overall, the experimental results confirm that IoT sensors and microcontrollers can effectively support intelligent home automation. The system demonstrates reliable environmental monitoring, efficient device control, and rapid response to sensor-triggered events. These capabilities contribute to the development of smarter, safer, and more energy-efficient residential environments.

4. CONCLUSION

The development of a smart home automation system using IoT sensors and microcontrollers demonstrates the potential of integrating modern digital technologies to improve residential comfort, efficiency, and security. The system designed in this study successfully integrates environmental sensors, microcontroller-based processing units, and communication networks to create an automated and responsive home environment. Through continuous monitoring of environmental parameters such as temperature, humidity, light intensity, and motion detection, the system is capable of automatically controlling household devices according to predefined conditions. The experimental results show that the system can respond quickly to sensor inputs and activate appropriate devices such as lighting systems, ventilation fans, and security alerts with minimal delay. In addition, the implementation of wireless communication enables remote monitoring and control through internet-connected devices, allowing users to manage their home environment from different locations. The modular system architecture also provides flexibility for future expansion, allowing additional sensors or devices to be integrated without significant system modifications. Furthermore, the automation process contributes to improved energy efficiency by ensuring that electrical devices operate only when necessary. Overall, the proposed IoT-based smart home automation framework provides an effective and scalable solution for intelligent residential management. The integration of sensor technology, microcontrollers, and network communication plays an important role in supporting the development of smarter, safer, and more energy-efficient living environments in the era of digital technology.

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6. REFERENCES (10 PT)

[1] D. Hanandini, "Social Transformation in Modern Society: A Literature Review on the Role of Technology in Social Interaction," *J. Ilm. Ekotrans Erud.*, vol. 4, no. 1, pp. 82–95, 2024, doi: 10.69989/j0m6cg84.

[2] Y. Park and J. Han, "Smart Home Advancements for Health Care and Beyond: Systematic Review of Two Decades of User-Centric Innovation," *J. Med. Internet Res.*, vol. 27, no. 1, p. e62793, 2025, doi: 10.2196/62793.

[3] A. Chakraborty, M. Islam, F. Shahriyar, S. Islam, H. U. Zaman, and M. Hasan, "Smart Home System: A Comprehensive Review," *J. Electr. Comput. Eng.*, vol. 2023, no. 1, p. 7616683, 2023, doi: 10.1155/2023/7616683.

[4] N. O. Nwazor and E. E. Audu, "Data Communications Network for Real-Time Industrial Control Systems," *Niger. J. Technol. Dev.*, vol. 19, no. 1, pp. 48–59, 2022, doi: 10.4314/njtd.v19i1.6.

[5] P. K. Dutta, S. M. El-kenawy, G. Ali, and K. Dhoska, "An Energy Consumption Monitoring and Control System in Buildings using Internet of Things," *Babylonian J. Internet Things*, vol. 2023, pp. 38–47, 2023, doi: 10.58496/bjiot/2023/006.

[6] Sri Harsha Koneru, "Securing the Modern Healthcare Ecosystem: Endpoint Management for Medical Environments," *J. Comput. Sci. Technol. Stud.*, vol. 7, no. 4, pp. 71–78, 2025, doi: 10.32996/jcsts.2025.7.4.8.

[7] T. M. Tung, D. H. Lan, and T. Le Tan, "Bridging The Gap: Effective Communication Strategies for Climate Change Adaptation in Rural Communities," *Pakistan J. Life Soc. Sci.*, vol. 22, no. 2, pp. 1039–1060, 2024, doi: 10.57239/PJLSS-2024-22.2.0073.

[8] M. Al Mughairi, T. Beach, and Y. Rezgui, "Post-occupancy evaluation for enhancing building performance and automation deployment," *J. Build. Eng.*, vol. 77, p. 107388, 2023, doi: 10.1016/j.jobe.2023.107388.

[9] T. Herzog, M. Brandt, A. Trinchi, A. Sola, and A. Molotnikov, "Process monitoring and machine learning for defect detection in laser-based metal additive manufacturing," *J. Intell. Manuf.*, vol. 35, no. 4, pp. 1407–1437, 2024, doi: 10.1007/s10845-023-02119-y.

[10] M. S. R. Jahid, "Ai-Powered Smart Home Automation: Enhancing Security, Energy Efficiency, and User Experience in Modern Housing," *Am. J. Interdiscip. Stud.*, vol. 06, no. 02, pp. 76–114, 2025, doi: 10.63125/1sh45802.

[11] T. Magara and Y. Zhou, "Internet of Things (IoT) of Smart Homes: Privacy and Security," *J. Electr. Comput. Eng.*, vol. 2024, no. 1, p. 7716956, 2024, doi: 10.1155/2024/7716956.

[12] F. Felgueiras, Z. Mourão, A. Moreira, and M. F. Gabriel, "Indoor environmental quality in offices and risk of health and productivity complaints at work: A literature review," *J. Hazard. Mater. Adv.*, vol. 10, p. 100314, 2023, doi: 10.1016/j.hazadv.2023.100314.

[13] F. Baskoro, B. Suprianto, L. Anifah, and Y. A. Indriyani, "Beyond Smart Devices: Fostering Critical, Communication and Collaborative Thinking in IoT-Based Sensor and Actuator Competence Learning Outcomes," *TEM J.*, vol. 12, no. 4, pp. 2396–2407, 2023, doi: 10.18421/TEM124-52.

[14] I. MUSA, A. T. OLUSOLA, and S. MAGAJI, "Effects of Climate Change on Environmental Security among Vulnerable Groups in Zango Kataf Local Government Area of Kaduna State," *Loka J. Environ. Sci.*, vol. 2, no. 2, pp. 228–250, 2025, doi: 10.38142/ljes.v2i2.251.

[15] R. Abdul Salam, N. Iqbal Ratyal, U. Ahmed, I. Aziz, M. Sajid, and A. Mahmood, "An Overview of Recent Wireless Technologies for IoT-Enabled Smart Grids," *J. Electr. Comput. Eng.*, vol. 2024, no. 1, p. 2568751, 2024, doi: 10.1155/jece/2568751.

[16] A. Yaldaie, J. Porras, and O. Drögehorn, "Innovative Home Automation with Raspberry Pi: A Comprehensive Approach to Managing Smart Devices," *Asian J. Comput. Sci. Technol.*, vol. 13, no. 1, pp. 27–40, 2024, doi: 10.70112/ajcst-2024.13.1.4260.

[17] M. J. C. Simwaba and M. Shabiyemba, "IoT Based Smart Home Automation System: Design and Development," *Sci. J. Eng. Technol.*, vol. 2, no. 2, pp. 45–52, 2025, doi: 10.69739/sjet.v2i2.438.

[18] R. Wainbuch and A. J. Samuel, "TinyML: Deploying Machine Learning on Microcontrollers for IoT Applications," *J. Sci. Technol. Eng. Res.*, vol. 2, no. 2, pp. 44–57, 2024, doi: 10.64206/d8sh8k34.

[19] V. A. Orfanos, S. D. Kaminaris, P. Papageorgas, D. Piromalis, and D. Kandris, "A Comprehensive Review of IoT Networking Technologies for Smart Home Automation Applications," *J. Sens. Actuator Networks*, vol. 12, no. 2, p. 30, 2023, doi: 10.3390/jsan12020030.

[20] P. O. Ayeni and O. C. Adesoba, "IoT-based home control system using NodeMCU and Firebase," *J. Edge Comput.*, vol. 4, no. 1, pp. 17–34, 2025, doi: 10.55056/jec.814.

[21] S. A. Ajagbe, O. A. Adeaga, O. O. Alabi, A. B. Ikotun, M. A. Akintunde, and M. O. Adigun, "Design and development of arduino-based automation home system using the internet of things," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 33, no. 2, pp. 767–776, 2024, doi: 10.11591/ijeecs.v33.i2.pp767-776.

[22] M. Aarif K. O., A. Alam, and Y. Hotak, “Smart Sensor Technologies Shaping the Future of Precision Agriculture: Recent Advances and Future Outlooks,” *J. Sensors*, vol. 2025, no. 1, p. 2460098, 2025, doi: 10.1155/js/2460098.

[23] T. Zhang *et al.*, “MCU Intelligent Upgrades: An Overview of AI-Enabled Low-Power Technologies,” *J. Low Power Electron. Appl.*, vol. 15, no. 4, p. 60, 2025, doi: 10.3390/jlpea15040060.

[24] R. K. Megalingam, S. R. R. Vadivel, S. S. Kotaprolu, B. Nithul, D. V. Kumar, and G. Rudravaram, “Cleaning Robots: A Review of Sensor Technologies and Intelligent Control Strategies for Cleaning,” *J. F. Robot.*, vol. 42, no. 5, pp. 2234–2259, 2025, doi: 10.1002/rob.22515.

[25] A. Punia, P. Gulia, N. S. Gill, E. Ibeke, C. Iwendi, and P. K. Shukla, “A systematic review on blockchain-based access control systems in cloud environment,” *J. Cloud Comput.*, vol. 13, no. 1, p. 146, 2024, doi: 10.1186/s13677-024-00697-7.

[26] Q. Yang *et al.*, “Exosome-based delivery strategies for tumor therapy: an update on modification, loading, and clinical application,” *J. Nanobiotechnology*, vol. 22, no. 1, p. 41, 2024, doi: 10.1186/s12951-024-02298-7.

[27] L. Huang, R. Said, H. C. Goh, and Y. Cao, “The Residential Environment and Health and Well-Being of Chinese Migrant Populations: A Systematic Review,” *Int. J. Environ. Res. Public Health*, vol. 20, no. 4, p. 2968, 2023, doi: 10.3390/ijerph20042968.

[28] Olakunle Babatunde Alao, Oritsematosan Faith Dudu, Enoch O. Alonge, and Chukwuka Emmanuel Eze, “Automation in financial reporting: A conceptual framework for efficiency and accuracy in U.S. corporations,” *Glob. J. Adv. Res. Rev.*, vol. 2, no. 2, pp. 040–050, 2024, doi: 10.58175/gjarr.2024.2.2.0057.