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Design and Implementation of an IoT-Based Remote Lighting Control System for Smart Home Applications

Teti Novrianti[1*], Sylvia Anjani[1], Riza Andriani[1]

[1] *Physics Education, Faculty of Teacher Training and Education, Riau University, Indonesia*

*Corresponding author's email: teti.novrianti3031@student.unri.ac.id

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Abstract- This study aims to design and develop a remote-controlled lighting system for smart homes based on Internet of Things (IoT) technology. The rapid advancement of information and communication technology has enabled the integration of physical devices with internet networks, allowing remote monitoring and control. In this research, a prototype system was developed using the NodeMCU ESP8266 microcontroller, relay module, LCD display, and Blynk application as the user interface. The system allows users to turn lights on and off remotely via a smartphone connected to the internet. The research employed a Research and Development (R&D) method with the ADDIE model, including analysis, design, development, implementation, and evaluation stages. Data were collected through experimental testing under various distances and internet signal strengths. The results indicate that the system successfully operates in real-time with stable performance, although response time is influenced by network quality. This system demonstrates the practical application of physics concepts such as electric current, electromagnetic waves, and electrical energy conversion. The developed prototype offers an efficient, flexible, and user-friendly solution for home automation. It also contributes to energy efficiency and supports the development of smart living environments.

Keywords: *Electrical energy, Internet of Things, NodeMCU ESP8266, Remote control system, Smart home*

1 Introduction

The rapid development of information and communication technology has significantly transformed various aspects of human life, including how people interact with electronic devices in their daily environments. One of the most influential technological advancements in recent years is the Internet of Things (IoT), which enables physical objects to connect and communicate through internet networks. IoT has revolutionized conventional systems into more intelligent, efficient, and automated systems, particularly in the context of smart homes (Risteska Stojkoska & Trivodaliev, 2017). In modern society, convenience, efficiency, and automation have become essential needs. The increasing demand for practical solutions in household management has driven the adoption of smart home technologies. A smart home is defined as a residential environment equipped with interconnected devices that can be controlled remotely or automatically through the internet (Khoa et al., 2020). Among various smart home applications, smart lighting systems have gained considerable attention due to their direct impact on energy consumption and user comfort.

Smart lighting systems allow users to control lighting devices remotely using smartphones or web-based applications without the need for physical interaction with switches. This innovation not only enhances convenience but also improves energy efficiency and safety. For instance, users can turn off lights when they are away from home, reducing unnecessary energy consumption and minimizing risks such as

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electrical hazards or fire (Subri et al., 2024). The integration of IoT in lighting systems thus represents a practical implementation of modern technology in everyday life.

The implementation of IoT-based systems is closely related to fundamental physics concepts, particularly in electricity and electromagnetic waves. Electrical energy is the primary resource that powers lighting devices, while electromagnetic waves play a crucial role in wireless communication between devices. In IoT systems, data transmission occurs through wireless signals, typically utilizing microwave frequencies within WiFi networks, which operate at high speeds and enable real-time communication (Baker et al., 2024). One of the commonly used microcontrollers in IoT applications is the NodeMCU ESP8266. This microcontroller is equipped with built-in WiFi capabilities, allowing it to connect directly to the internet without requiring additional modules. It is widely used due to its affordability, ease of programming, and compatibility with various development platforms such as Arduino IDE (Herlina et al., 2022). In addition, the integration of NodeMCU with relay modules enables the control of electrical circuits, making it suitable for smart lighting applications.

Previous studies have demonstrated the effectiveness of IoT-based lighting control systems. Susilo et al. (2021) developed a smart lighting system using NodeMCU and the Blynk application, which successfully controlled lights in real-time with minimal delay. Similarly, Tambing (2024) reported that IoT-based lighting systems maintain stable performance under different network conditions, highlighting the importance of signal strength in ensuring system reliability. Furthermore, Herlina et al. (2022) emphasized that the Blynk application provides a user-friendly interface, making it accessible even for beginners. Despite these advancements, several challenges remain in the implementation of IoT systems, particularly related to network stability and system responsiveness. Atmaja et al. (2021) pointed out that the performance of IoT devices is highly dependent on internet connectivity. Weak or unstable signals can result in delayed responses or system failures. Therefore, evaluating system performance under varying network conditions is essential to ensure reliability and usability.

In addition to technical aspects, the development of IoT-based systems also contributes to sustainability. Energy efficiency has become a global concern due to increasing energy consumption and environmental issues. Smart lighting systems can reduce energy waste by enabling users to control and monitor lighting usage effectively. According to Saaid and Abdullah (2023), IoT-based systems can significantly improve energy management and support the development of sustainable smart homes. From an educational perspective, the development of IoT-based smart home systems also provides opportunities to integrate physics concepts into real-world applications. Concepts such as electric current, voltage, resistance, and energy conversion are directly involved in the operation of such systems. This integration enhances students' understanding of physics by connecting theoretical knowledge with practical implementation (Setiawan, 2019).

Moreover, IoT technology fosters interdisciplinary learning, combining physics, electronics, programming, and communication technology. This aligns with modern educational approaches that emphasize STEM (Science, Technology, Engineering, and Mathematics) integration. By developing IoT-based projects, students can acquire essential skills such as problem-solving, critical thinking, and technological literacy (Verina et al., 2025). Based on the background described above, this study focuses on designing and developing a remote-controlled lighting system for smart homes using IoT technology. The system utilizes the NodeMCU ESP8266 microcontroller, relay modules, and the Blynk application to enable remote control via smartphones. The research aims to evaluate the functionality, reliability, and performance of the system under different conditions.

Specifically, this study seeks to answer the following research questions: (1) How can a remote-controlled lighting system based on IoT be designed and implemented effectively? and (2) What are the underlying working principles of the system in terms of physics and electronic processes. The significance of this research lies in its contribution to both technological development and educational innovation. From a technological perspective, the system provides a practical solution for home automation that is efficient, flexible, and user-friendly. From an educational perspective, it serves as a learning medium that demonstrates the application of physics concepts in real-life technology (Ritonga, 2025). In conclusion, the integration of IoT in smart home systems represents a promising direction for future technological development. By combining physics principles with modern communication technology, IoT-based systems can enhance efficiency, convenience, and sustainability in daily life. Therefore, further research and development in this field are essential to optimize system performance and expand its applications in various domains.

2 Research Methodology

This study employed a Research and Development (R&D) approach aimed at designing, developing, and evaluating a prototype of a remote-controlled lighting system based on Internet of Things (IoT) technology. The development process followed the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. In the analysis stage, the research problem was identified based on the need for an efficient and practical system to control household lighting remotely. Literature studies were conducted to understand the principles of IoT, microcontroller systems, wireless communication, and electrical circuits. This stage also involved identifying the required components, such as NodeMCU ESP8266, relay modules, LCD displays, and smartphone-based applications

The design stage focused on creating the system architecture, including circuit schematics, workflow diagrams, and prototype layout. The NodeMCU ESP8266 was selected as the main controller due to its integrated WiFi capability. A relay module was used as an electronic switch to control the lamp, while an LCD 16x2 display was included to provide real-time status information such as WiFi connectivity and lamp condition (ON/OFF). The system was designed to communicate with the Blynk application, which serves as the user interface.

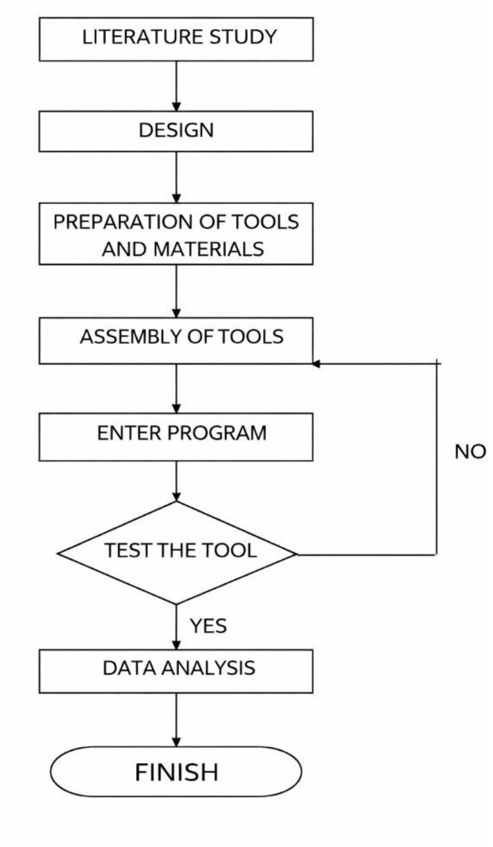

Figure 1. Research Flow

The development stage involved assembling the hardware components and programming the microcontroller using Arduino IDE. The program included WiFi configuration, communication with the Blynk server, and control logic for switching the relay. The hardware assembly included connecting the NodeMCU to the relay module, LCD display via I2C module, and the lamp using jumper wires. Care was taken to ensure proper electrical connections and stable power supply using a power bank or adapter.

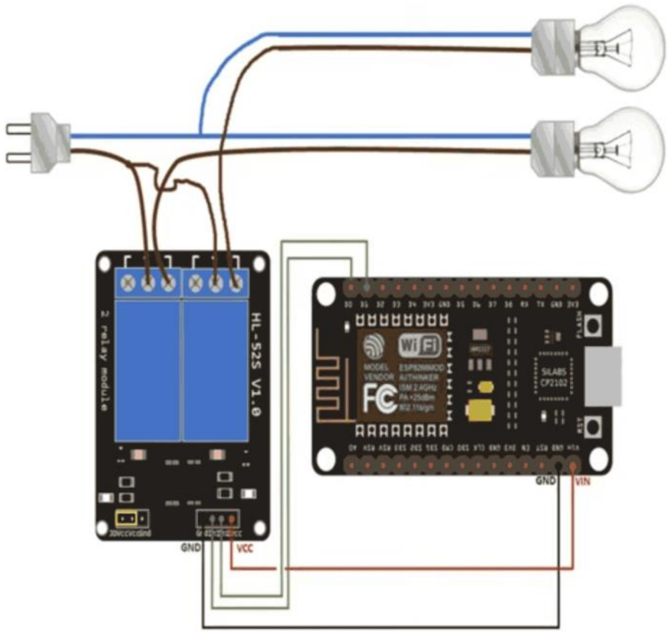

Figure 2. Prototype System Illustration

The implementation stage involved testing the system under different conditions. The prototype was tested at various distances ranging from short distances (a few meters) to long distances (up to approximately 187 km) using internet connectivity. The testing parameters included response time, signal strength (measured in Mbps), and system reliability in executing ON/OFF commands. The evaluation stage focused on analyzing the collected data using descriptive quantitative analysis. The performance of the system was evaluated based on its responsiveness, reliability, and dependency on network quality. Any system limitations, such as delays caused by weak signals, were identified and used as a basis for further improvement.

3 Results and Discussion

The results of this study demonstrate that the developed IoT-based remote lighting control system operates successfully and fulfills its intended functions. The prototype system was able to control the lamp remotely through a smartphone using the Blynk application, as shown in the experimental setup. The system consists of several main components: NodeMCU ESP8266 as the controller, a relay module as an electronic switch, a 3V light bulb as the output device, and an LCD display for status monitoring. When the system is powered on, the NodeMCU automatically connects to a predefined WiFi network. Once connected, it establishes communication with the Blynk server, enabling remote control via a mobile application.

Figure 3. Remote Lights in an IoT-Based Smart Home in On and Off Modes

Figure 4. Electronic Components in a Smart Home

Code Description:

1. NodeMCU ESP8266 (As a microcontroller that connects hardware devices (such as relays and lights) to the internet network.
2. 2 Channel Relay (Electronic switch to turn lights on or off).
3. 3V light bulb.

When a user presses the ON or OFF button in the application, the command is transmitted through the internet in the form of digital signals. These signals propagate as electromagnetic waves, particularly in the microwave frequency range used by WiFi communication. The NodeMCU receives the signal and processes it, activating or deactivating the relay accordingly. When the relay is activated, the electrical circuit is closed, allowing current to flow to the lamp and produce light. Conversely, when the relay is deactivated, the circuit is open, and the lamp turns off.

Table 1. Experimental Data

No	Distance	Signal Strength (Mbps)	Lamp Status	Response Time (s)
1	5 m	13.2	ON	1.2
2	5 m	17.1	ON	1.0
3	5 m	2.32	ON	2.8
4	5 m	2.58	ON	2.5
5	5 m	1.8	ON	3.2

The data indicate that signal strength significantly affects system performance. At higher signal strengths (above 10 Mbps), the response time is relatively fast (around 1 second). However, when the signal strength decreases below 3 Mbps, the response time increases noticeably, reaching up to 3 seconds.

Interestingly, the distance factor does not significantly affect performance, as long as both the NodeMCU and smartphone are connected to stable internet networks. This confirms that IoT systems rely more on network quality than physical distance.

From a physics perspective, the system demonstrates several fundamental principles:

- Electric current flow: The lamp operates when current flows through the circuit.
- Ohm's Law: The relationship between voltage, current, and resistance determines the electrical behavior.
- Electromagnetic waves: Wireless communication occurs through microwave signals.
- Energy conversion: Electrical energy is converted into light energy in the lamp.

The LCD display successfully provided real-time feedback, improving user interaction by showing connection status and lamp conditions. This feature enhances system usability and monitoring.

However, several limitations were identified:

1. The system depends heavily on internet availability.
2. Weak signals result in delayed responses.
3. The prototype is still limited to basic ON/OFF control without automation features.

Despite these limitations, the system proves to be effective, reliable, and applicable for smart home implementation.

4 Conclusion

This study successfully designed and developed a remote-controlled lighting system based on Internet of Things (IoT) technology for smart home applications. The system integrates hardware components such as NodeMCU ESP8266, relay modules, LCD displays, and a smartphone-based application to enable real-time control of lighting devices.

The results show that the system functions effectively in controlling the lamp remotely with a stable and reliable performance. The response time of the system is influenced primarily by the strength of the internet signal rather than the physical distance between the user and the device. This confirms that IoT-based systems rely heavily on network quality for optimal performance. In addition, the system demonstrates the practical application of fundamental physics concepts, including electric current, electromagnetic waves, and energy conversion. These concepts are essential in understanding how the system operates and highlight the relevance of physics in modern technological innovations.

Although the prototype performs well, several limitations remain, particularly its dependency on internet connectivity and lack of advanced automation features. Future development could include the integration of sensors, voice control, and enhanced security systems to improve functionality and usability. Overall, this research contributes to the development of smart home technology by providing a simple, cost-effective, and efficient solution for remote lighting control. It also serves as an educational tool that bridges theoretical physics concepts with real-world applications, promoting innovation and technological literacy.

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