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Lighting intensity control system using ESP32

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ABSTRACT

Efficient lighting that can be controlled flexibly is an important requirement in supporting comfort and energy efficiency, especially in residential environments. This research designs a lighting control system that can be accessed through various methods, such as touch screens, mobile applications, and physical switches, to provide flexibility in setting light intensity according to user needs. This system design uses an ESP32 microcontroller as the main control center connected to relays, a TFT touchscreen-based interface, a physical switch, and an internet-based Blynk application. The light intensity setting is done using RBDdimmer-based AC dimmer module, and the power consumption monitoring is done through PZEM0-004T sensor. Control and monitoring data are synchronized in real-time between control methods. Test results show that the system is able to properly manage lighting through three control paths in a synchronous manner, even when an internet connection is not available. The system is capable of automatically saving and restoring the last status, and makes it easy for users to adjust the lighting according to their preferences. With these features, this system can be implemented in an efficient IoT-based smart lighting concept.

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1. INTRODUCTION

The development of digital technology has driven various innovations in modern life, one of which is the Internet of Things (IoT), which enables physical devices to be controlled and monitored via the internet [1]. One real-world implementation of IoT is the smart home, which is a house equipped with smart devices that can be controlled automatically or remotely. One of the key aspects of a smart home system is lighting, as optimal lighting affects comfort, energy efficiency, and the health of the occupants [2]. However, lighting control in homes still often uses conventional methods that only support ON/OFF functions, without the ability to adjust light intensity [3]. This contradicts the principles of energy efficiency and visual comfort, where light intensity should be adjusted according to the function of the room, as stated in SNI 6197:2020 (National Standards Agency, 2020) [4]. For example, bedrooms are recommended to have lighting of 50 lux, while kitchens should have up to 250 lux. Inappropriate lighting can have a negative impact on energy consumption and eye health [5].

Previous studies have attempted to provide solutions through remote control based on NodeMCU [6] or ESP32 using the Blynk platform and Google Voice Assistan [7]. Although these systems successfully activate and adjust the intensity of lights remotely, most still rely entirely on an internet connection and do not include manual or offline control options. Additionally, few integrate physical interfaces such as touchscreens, which are more intuitive for users.

Based on these issues, this article proposes the development of an ESP32-based lighting intensity control system that supports two control modes: online via the Blynk app and offline via a TFT touchscreen and physical switches. The system uses an AC Light Dimmer module to adjust light intensity according to room requirements and is tested using a lux meter to ensure accuracy and responsiveness. This approach aims to provide a flexible, energy-efficient, and more reliable solution, particularly for regions with limited internet infrastructure.

2. METHOD

In the process of making a tool, the first step is to design it. The purpose of tool design is to provide a clear picture of how the tool can be designed, produced, implemented, and to ensure that the tool functions properly [8]. This method covers several important aspects regarding block diagrams, circuit working principles, hardware design, and software design. The block diagram of this system illustrates the overall architecture[9] of a hybrid lighting control system, which can be controlled through three main methods, namely: physical control (switch), local control (TFT touch screen), and remote control via smartphone (Blynk IoT). The block diagram of the designed system can be seen in Figure 1.

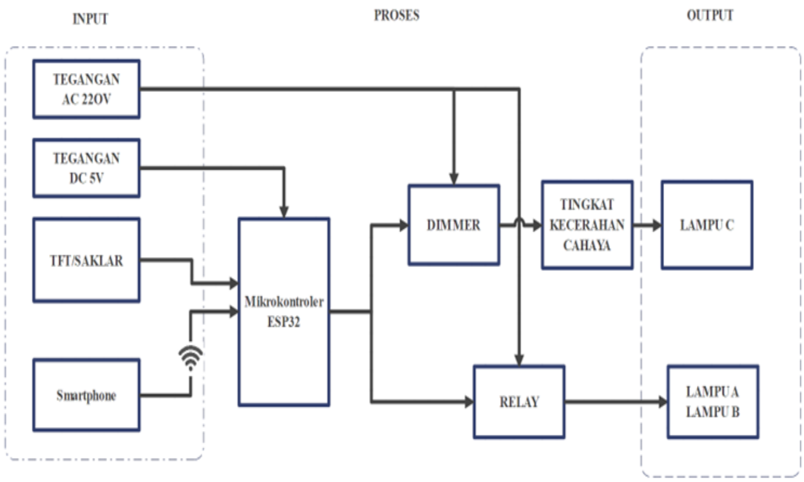


Figure 1. Block diagram

The block diagram in Figure 1 shows the overall workflow of the designed lighting intensity control system. This system consists of three main parts, namely the input part, the process part, and the output part. The input section consists of the main input sources used to control the system, namely an LVGL-based touch screen, physical switches, and an IoT-based Blynk application. These input methods provide flexibility for users to perform local and remote control. Physical switches function as conventional manual controls, while touch screens and Blynk applications provide digital and wireless control access. Additionally, there is a power input consisting of 220V AC voltage for the light load and 5V DC voltage for the ESP32 microcontroller. Next, all inputs are controlled and processed by the ESP32 microcontroller, which acts as the main processing unit in the system. The ESP32 receives signals from the inputs, processes the synchronization logic, and determines the appropriate output based on the current status and control mode (offline/online). This microcontroller is also responsible for handling WiFi connections and communication with the Blynk Cloud server when in online mode. In the output section, the ESP32 controls three actuators, namely two relays and one AC dimmer module. The relays are used to turn the lights on or off, while the dimmer is used to gradually adjust the brightness of the lights. System status information is also displayed on the touch screen in the form of a graphical interface and sent to the Blynk application for remote monitoring. With this structure, the system is capable to performing hybrid, synchronous, and adaptive lighting control based on network conditions, providing users with a more flexible and efficient experience in managing room lighting.

The flowchart in this study is used to illustrate the logical flow of the ESP32 microcontroller-based lighting intensity control system [10]. Each process, from sensor input or user commands (whether via touchscreen, physical switches, or remote applications) [11] to control execution on actuators such as relays and dimmers, is shown in symbols connected sequentially by lines or flow arrows [12]. The creation of this flowchart facilitates understanding of the program structure and aids in the system development process, especially when integrating multiple components simultaneously. This can be seen in Figure 2. The logic flow begins with system initialization, internet connection checking, and then mode selection (online/offline). The system reads input from the active channel and decides whether to execute a dimmer or relay command. Control results are displayed on the TFT screen and also sent to the Blynk application (if online). The system also reads parameters from the PZEM sensor periodically.

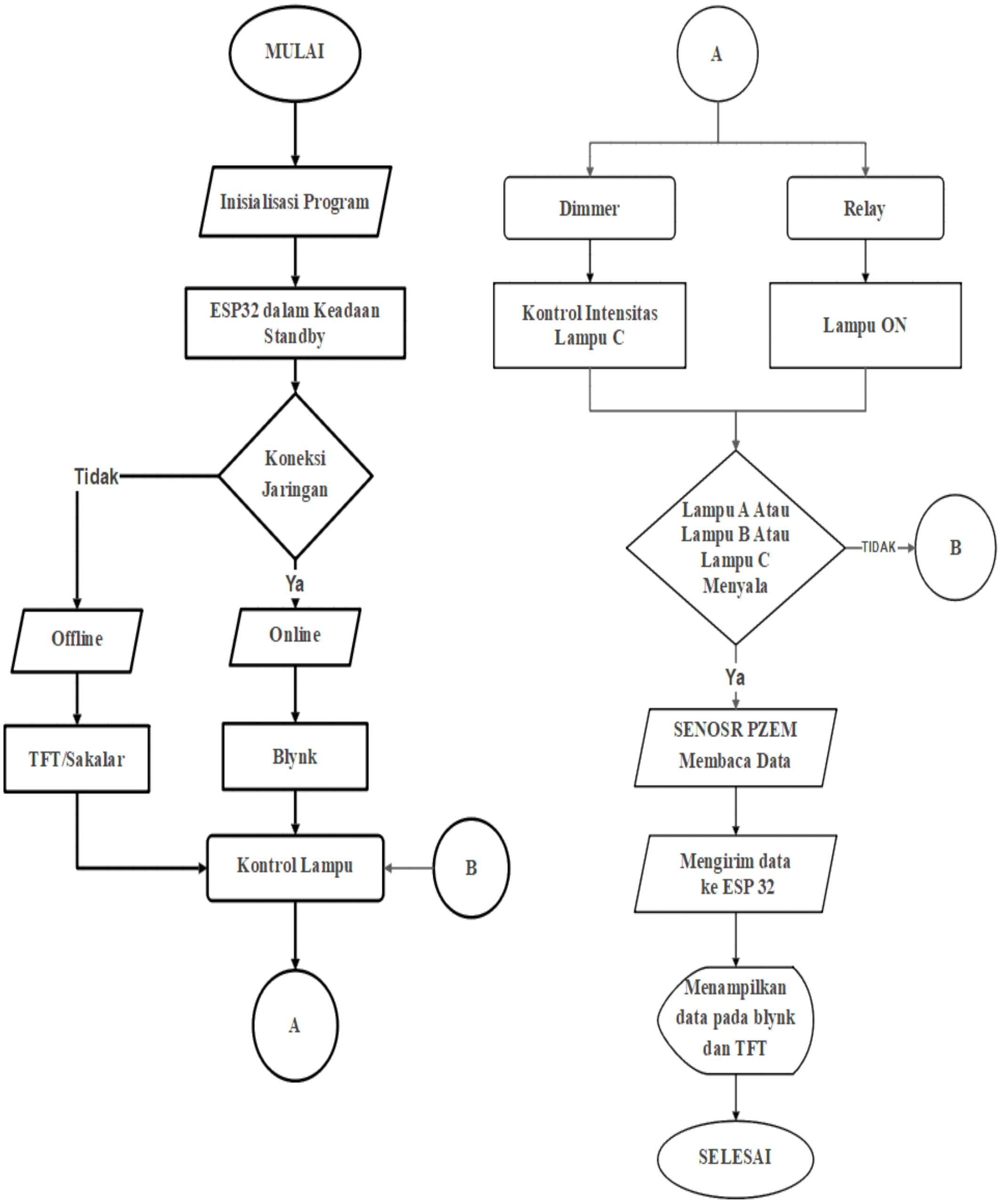


Figure 2. Flowchart

Hardware design is a crucial stage in embedded system development to realize functional designs into physical form [13]. In this study, the hardware design was developed considering the principles of modularity, ease of integration between components, and safety in high and low current load settings. Figure 3 shows the hardware connection diagram of the system, where the ESP32 microcontroller serves as the control center receiving input from three main channels: the Blynk application (online control), the TFT touchscreen display (local control via a graphical interface), and two physical switches (manual control). The output from the ESP32 is sent to two relay modules to control the ON/OFF of two AC lights and one AC dimmer module for adjusting the intensity of the third light. The system is also equipped with a PZEM004T [14] sensor to monitor electrical parameters such as voltage, current, power, and energy in real-time. The power supply provides DC voltage for the ESP32 and supporting devices, as well as AC current supply for the lamp load and sensor. As shown in Figure 3, the entire circuit is assembled on an acrylic trainer board with a layout that separates high-voltage (220V AC) and low-voltage (3.3V–5V DC) paths, ensuring system safety and stability during testing and operation.

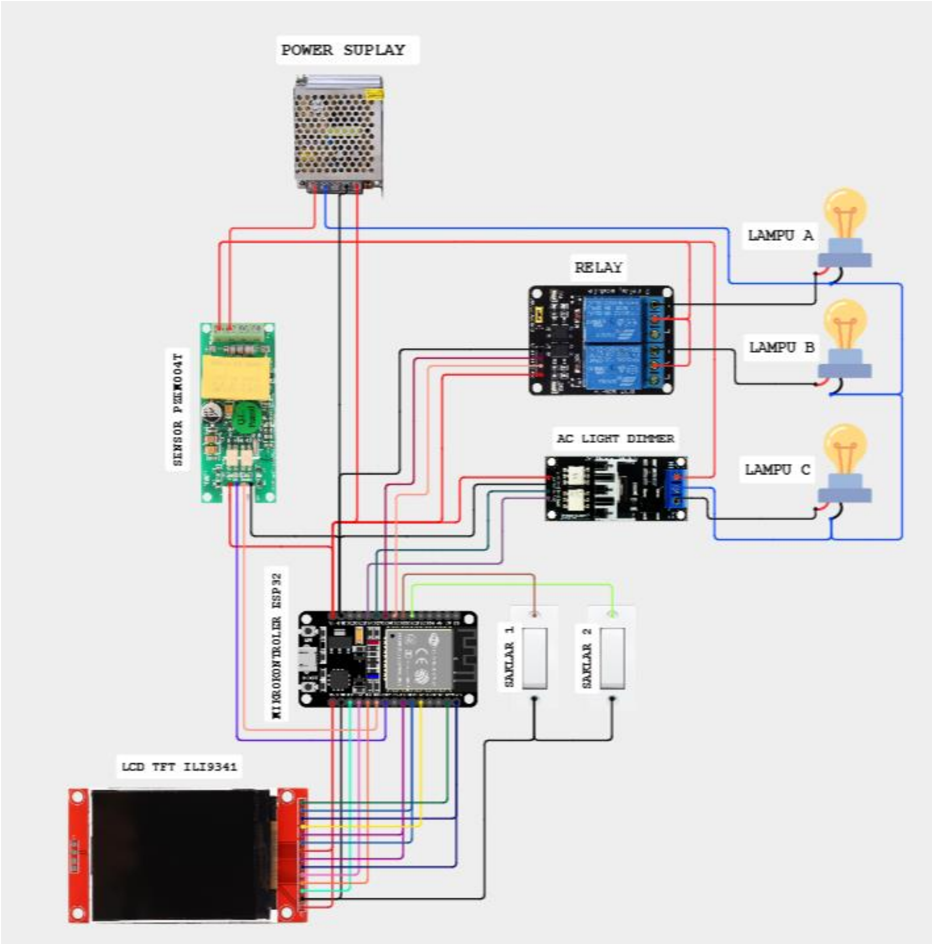


Figure 3. Electrical circuit design

As shown in Figure 4, the mechanical system design aims to simplify the assembly and testing processes and reduce the potential for errors during use. The system is designed in the form of a rectangular panel, consisting of one 20 × 30 cm acrylic sheet and four additional 10 × 30 cm panels. All main components, such as the power sensor, relay module, dimmer, switch, and indicator, are placed on the panel surface to facilitate operation and observation. This design supports ergonomic, safety, and functional aspects, making it suitable for use as an educational tool or test prototype in a laboratory.

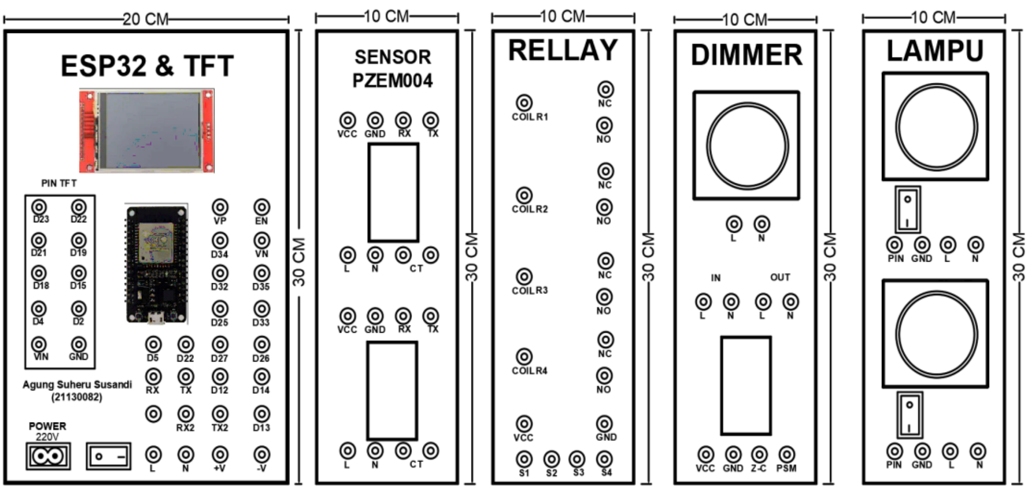


Figure 4 Mechanical System Design

This stage involves the software design process for a lighting intensity control and monitoring system based on the Blynk application. This application is designed to connect to the ESP32 microcontroller via a local network using a WiFi connection [11]. This can be seen in Figure 5. The application interface was developed using various widgets available on Blynk, such as virtual buttons (V1–V3) to control lights A and B and the dimmer, as well as graphs to monitor voltage, current, power, and energy (V10–V13). With these features, the monitoring and control system can be operated in real time from a mobile device. The Blynk platform facilitates integration with Internet of Things (IoT) technology, which is a multidisciplinary field with a dynamic universal network infrastructure

(a) (b)

Figure 5. Software design (a) Program view on arduino IDE and (b) Data display on blynk

3. RESULTS AND DISCUSSION

Testing was conducted to determine whether the system was functioning properly. The purpose of this testing was to ensure that all of the device's functions were working properly, from the ESP32, PZEM-004T sensor, and relay module to the process of sending data from the ESP32 to the Blynk application on a smartphone [15]. The physical form of the ESP32-based lighting intensity control system is shown in Figure 6. The trainer is designed using one sheet of acrylic measuring 20 × 30 cm and four sheets measuring 10 × 30 cm to integrate all the main components, namely the ESP32, TFT touchscreen display, relay module, PZEM004T power sensor, AC light dimmer, and physical switch as manual control.

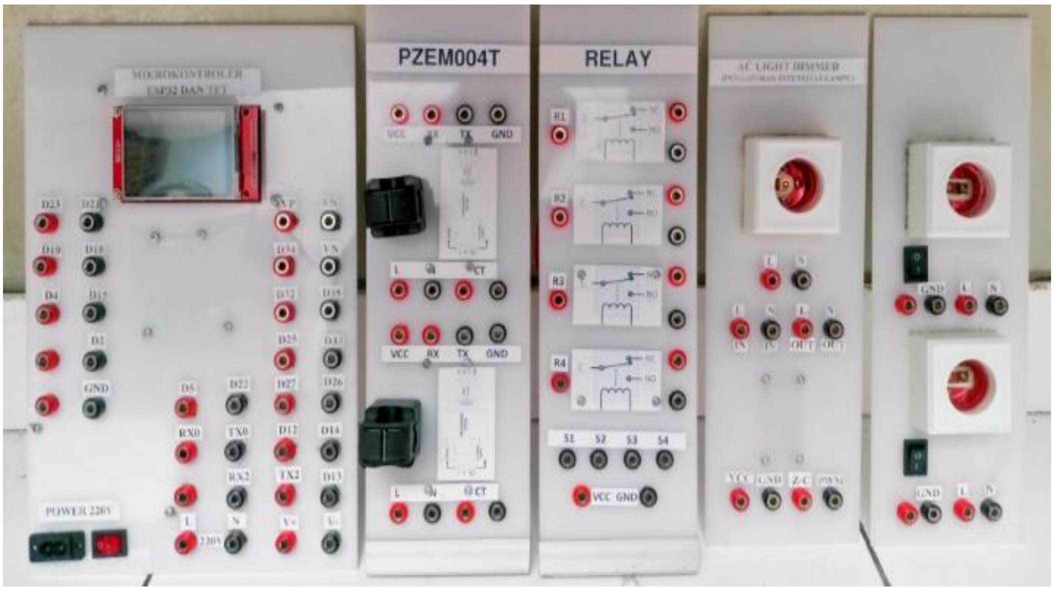
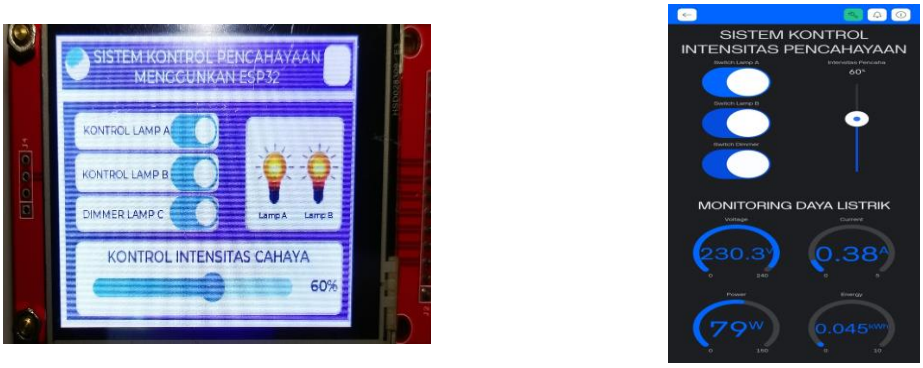


Figure 6. Trainer Design Results

The program was designed using the Arduino IDE application. The program was uploaded to the ESP32 microcontroller via a USB cable. Testing was conducted to ensure that the program functioned as designed, by testing all components connected to the ESP32. Initial testing focused on the TFT screen interface display and connection to the Blynk application to ensure that cloud-based control and monitoring functions worked properly. Once the program was successfully run, the ESP32 would automatically connect to the WiFi network according to the configuration in the program code, enabling direct communication with the Blynk application on the smartphone. This can be observed in Figure 7.



(a) (b)

Figure 7. hasil Software design (a) Data display TFT and (b) Data display on blynk

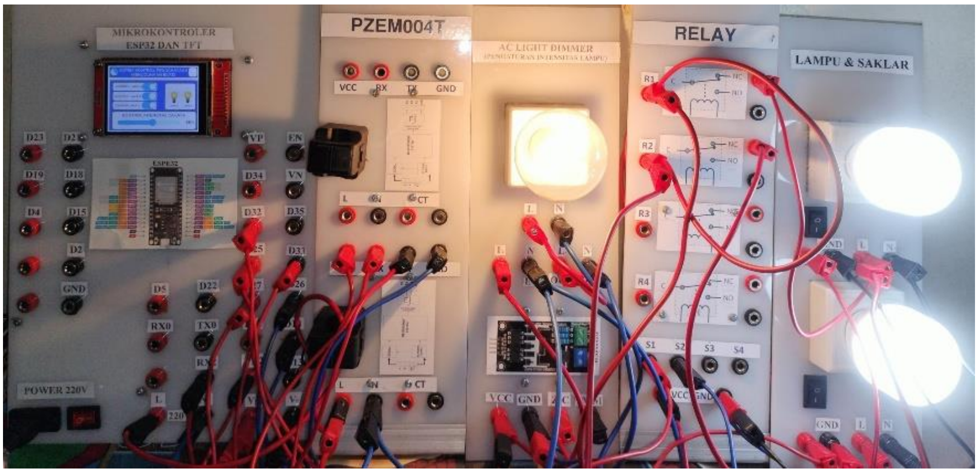


Figure 8. Results of Cable Assembly and Installation on the Trainer

Remote control system testing was conducted to ensure that the system is capable of responding to control commands from different locations via the internet using the Blynk application. This is a crucial aspect of the ESP32-based flexible control system, as it provides users with the flexibility to control lighting remotely without needing to be at the device location. The testing was conducted at three different locations: Solok Selatan (West Sumatra), Lampung, and Dharmasraya (West Sumatra).

Table 1 Results of Delay Testing on the Control System

No.	Location	Average Delay of Tested Components		
		Relay 1	Relay2	Dimmer
1.	Solok Selatan West Sumatra	01.38 s	01.27 s	02.66 s
2.	Dhamasraya West Sumatra	01.36 s	01.34 s	01.66 s
3.	Lampung	01.63 s	01.28 s	01.55 s

Table 1 shows the results of testing the ESP32-based lighting intensity control system, which was tested remotely using the Blynk application and was able to respond to commands stably, even when controlled from distant locations. The testing was conducted at three different locations, namely South Solok, Dharmasraya, and Lampung. The test results show that the average delay values from the three locations were within the tolerance limits.

Table 2 Testing of Lighting Intensity Based on Dimmer Percentage Values

No.	Dimmer Point Setting (%)	Dimmer Lighting Intensity (lux)	SNI Lighting Intensity (lux)	Description (SNI Room)
1.	10	0	40	Not Suitable for Rooms
2.	20	0	40	Not Suitable for Rooms
3.	30	11.5	40	Not Suitable for Rooms
4.	40	80.5	50	Ideal for bedrooms, living rooms, and storage rooms.
5.	50	116	100	Ideal for Bathrooms
6.	60	118.5	100	Ideal for family rooms and dining rooms
7.	70	156	150	Ideal for the living room
8.	80	176	150	Ideal for the living room
9.	90	186.5	250	Not ideal for kitchen spaces
10.	100	188	250	Not ideal for kitchen spaces

Table 2 shows the results of testing the ESP32-based lighting intensity control system, which was tested remotely using the Blynk application and was able to respond to commands stably, even when controlled from distant locations. The testing was conducted in three different locations, namely South Solok, Dharmasraya, and Lampung. The test results show that the average delay values from the three locations were within the tolerance limits. Based on Table 2, the light intensity meets the lighting standards according to SNI (40–250 lux) in the dimmer set point range of 40% to 80%, with results ranging from 80.5 lux to 176 lux. This means that within this range, the system is suitable for use in bedrooms, living rooms, dining rooms, and guest rooms.

4. CONCLUSION

An ESP32-based lighting intensity control system has been successfully designed and implemented with two control methods: offline via a TFT touch screen and physical switch, and online via the Blynk app. The system can respond to remote commands for controlling Relay 1, Relay 2, and the dimmer with an average delay of 1.28 to 1.94 seconds, which is still considered responsive for smart home applications. The triac-based dimmer module can stably adjust light intensity within the dimmer set point range of 40% to 80%, with intensity levels ranging from 80.5 lux to 176 lux. This means that within this range, the system is suitable for lighting needs in bedrooms, living rooms, dining rooms, and even guest rooms.

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