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Research Article

Lighting system automation using a relay based on radio frequency identification tag input and kiosks' information access with Telegram application in the modern market

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ABSTRACT

Advancements in technology necessitate the swift and efficient management of systems, particularly concerning electricity consumption and information dissemination. To address this issue, a prototype was developed to automate lighting systems and display kiosk information in modern markets. Key components utilised include an RFID reader, GPS module, NodeMCU ESP8266, and relays, all of which played crucial roles in the functioning of the prototype. The primary objective was to create a device capable of automatically controlling the lighting system through relays triggered by RFID inputs while relaying kiosk information via the Telegram application. For instance, when a registered RFID tag is tapped while the shop is open and the lamp is initially on, the light will be switched off, ensuring energy efficiency and timely response. The GPS module is employed to obtain location data, which can be conveniently accessed through the Telegram app, along with kiosk open/close status. This integration of the GPS module enhances the prototype's functionality by providing valuable location-based information, making it easier for users to monitor and access the information remotely. Test results demonstrate that the RFID tag can be read from a maximum distance of 4.5 cm, with an average processing time of 2.47 seconds for lamp switching and 5.6 seconds for accessing information. These performance metrics validate the efficacy of the prototype methodology in achieving its intended goals of automation, energy efficiency, and seamless information dissemination in modern markets.

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1. INTRODUCTION

Along with the growing development, the need for electricity is also increasing. All that can be seen using electronic and mechanical devices in each building. As a result, every installation requires an adequate electricity supply to meet its lighting or mechanical production needs [1].

A significant challenge arises in the present energy sector because 95% of energy consumption relies on fossil fuels, which have been depleting steadily. Moreover, the use of fossil energy poses considerable environmental risks, contributing to global warming and climate change. Data provided by the Indonesia Directorate of Energy Conservation, Renewable Energy, and Energy Conservation reveals that the overall energy consumption comprises 46% from oil, 31% from coal, and 18% from gas, with only a minimal 5% contribution from new renewable energy sources [2].

Previous research has delved into the automation of lighting systems in room settings [3-4]. For instance, Ferdinand Christian's work [5] focused on a microcontroller-based lighting automation system that utilised a Light Dependent Resistor (LDR) or light sensor [6] to regulate the light according to sunlight detection, turning it off during daylight and on at night. Additionally, a PIR sensor was incorporated to detect human movement [7], adding an element of motion-based control to the system.

Based on previous research findings, the current study aims to fill a specific knowledge gap by proposing creating an integrated system that combines lighting automation [8] with information access, enabling the display of kiosk statuses within a modern market building. This innovative system incorporates a diverse range of components, such as NodeMCU ESP8266, MFRC522 RFID tag reader [9-10], relays, NEO-6MV2 GPS, LED lamps, a buzzer, and small LEDs for indicators. The relays are critical as lamp switches, functioning harmoniously with the kiosks' opening or closing status. At the same time, the GPS module is utilised to gather location data [11] of the building, which can also be conveniently accessed via the Telegram app.

In this system, the microcontroller processes the data received from the reader [12] to record and update the corresponding kiosk's status in the database. Based on the stored information about whether the kiosks are open or closed, the system determines the lamp's condition, either turning it on or off. Additionally, this status information is valuable data accessible to users through the Telegram app's bot [13], allowing them to check whether the kiosk is open before visiting the market. The main goal of this system design is to effectively manage the lamp's operation based on the kiosk's status, thereby reducing energy consumption during closed periods and providing helpful information to users.

2. MATERIALS AND METHOD

This research involves the systematic development of a prototype to gather experimental data. The prototype creation consists of two distinct phases: software and hardware. The microcontroller is programmed using Arduino IDE to handle input processing. Subsequently, the components are carefully positioned and interconnected within the prototype per the design.

Once the prototype construction is completed and the code is uploaded, the parameters require continuous monitoring and measurement during the operational phase. This is achieved using an Avometer and a stopwatch. The process initiates with the RFID reader, which detects and reads RFID tag information. Additionally, a GPS module is utilised to acquire location coordinates. The system incorporates six relays to control six different LED lamps, mimicking lighting loads. Moreover, small RGB LEDs and a buzzer serve as indicators.

To manage the entire system, the NodeMCU ESP8266 is the microcontroller programmed using C/C++ language [14]. The NodeMCU ESP8266 is a crucial bridge, facilitating data transmission between the database and users through an internet connection. The complete system design and process can be visualised in Figure 1.

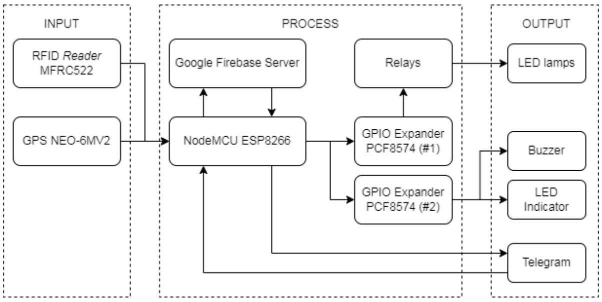

Figure 1. Block diagram of the whole system.

The provided block diagram depicts two inputs: an RFID reader (MFRC522) and a GPS module (NEO-6MV2). The RFID reader serves as the primary input, initiating the entire process. Simultaneously, the GPS module operates in the background, obtaining location coordinates. Within the process block of the diagram, the NodeMCU ESP8266 is responsible for processing the data received from both the RFID reader and the GPS module. It generates outputs based on the programmed algorithm. Finally, the output block is as follows:

1. The LED lamps replicate the lighting system utilised in individual kiosks; each light is linked to a separate relay. In total, six lamps and relays are employed.
2. The buzzer and small LED serve as indicators, providing visual and auditory cues to signify the system's ongoing process and current state.
3. The Telegram app exhibits information stored in the database by sending specific messages or commands through its bot. This app establishes an internet connection to facilitate communication with the microcontroller.

The NodeMCU ESP8266 functions as a wireless transmission device, facilitating the transfer of data generated by the program between system devices and the Telegram app via an internet network. As depicted in Figure 2, each component used in the system requires specific wiring of its pins. Since the NodeMCU ESP8266 operates with 3.3V DC pins [14], while the relays demand a 5V DC [15] supply with adequate current, an additional voltage regulator featuring both 5V DC and 3.3V DC outputs is incorporated into the prototype. The voltage and ground channels are then distributed in parallel through the pin header row before being connected to the other components. The primary supply voltages utilised in this system are 9V DC, and the lamps are powered by a 220V AC supply obtained from a nearby power outlet.

The VCC pin in the RFID reader, GPS module, PCF8574, and relays serve as the voltage supply pin, which is connected to the respective voltage rail based on the required voltage. The NodeMCU ESP8266 and relays utilise a 5V DC supply, while the other components rely on a 3.3V DC supply. The data pins of these components are connected to the NodeMCU ESP8266's GPIO pins. The RFID reader is linked to the ESP8266 through SPI communication [16], utilising GPIO12 to GPIO15 accordingly. For the GPS module, programmed UART is employed, with GPIO0 serving as RX and GPIO2 as TX. This custom virtual UART [17] is implemented to preserve the original UART protocol on the microcontroller, which is shared with a USB port for Serial Monitor debugging.

Moreover, the relays and indicators are connected to GPIO expander modules, establishing communication with the microcontroller through the I2C protocol [18]. GPIO expanders are essential to expand the number of digital pins available for connecting components, compensating for the limited digital pins on the NodeMCU ESP8266. Two expanders were integrated into the prototype, providing an additional 16 digital pins. Out of these, ten pins are utilised by six relays and four indicators, respectively.

In this design, three resistors are employed and connected between the LED indicator (labelled 'E' in Figure 2) and the expander. These resistors regulate the current [19] flowing through each RGB terminal, preventing the LEDs from experiencing an excessive current. The specific resistance values are determined using Ohm's Law, considering the current reference and the voltage applied to power the LEDs. The equation used to calculate the resistance can be observed in Equation 1.

$$R = (V_{SUPPLY} - V_{DROP})/I_{LED} \quad (1)$$

In the given equation, R represents the resistance value (Ω), VSUPPLY denotes the voltage used to power the LED (V), VDROP indicates the forward voltage or voltage drop across the LED (V), and ILED represents the current flowing through the LED. Considering a 5V DC voltage source with a typical LED voltage drop of 2V and a current of 15 mA, the resistor value can be calculated as 200 Ω. However, this prototype uses a value of 220 Ω, resulting in a slightly lower current of 13.6 mA passing through the LED.

Based on Figure 2, each lamp is linked to the NO terminal of its corresponding relay. The 220V AC supply's phase line is connected in parallel to the COM terminal of each relay. The neutral line of the supply is connected to a terminal block and then interconnected in parallel before being wired to the neutral terminal of each lamp. The NC terminal of the relays remains unconnected, resulting in the lights being off when no inputs are provided to the relay. Then, when the relay is activated, the contact switches from NC to NO, connecting the lamp to the 220V AC supply [20-21].

Upon receiving power, the system initiates an initialisation process. During this phase, the program establishes a WiFi connection to access the internet network, enabling communication with Firebase's database and users via the Telegram app. In each cycle of operation, the program simultaneously checks inputs from three sources: the GPS module, RFID reader, and Telegram's bot.

The program first verifies if the GPS module has successfully captured a satellite signal. The antenna captures the signal, and the module employs a trilateration process to calculate a coordinate, which is then stored in a variable for future reference, providing location information to the users. Concurrently, the program checks the RFID reader to detect the presence of any tags. Upon tag detection, the program processes the unique ID from the tag [22] by cross-referencing it with the database against the registered card list. The entire program's flow, including these processes, is outlined in Figure 3, presented as a flowchart.

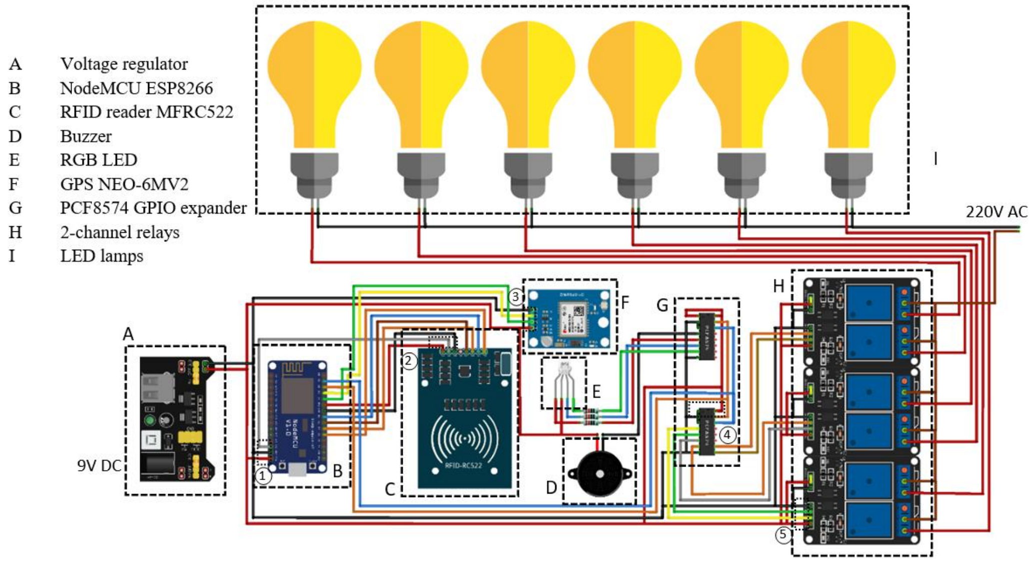

Figure 2. The circuit schematic of the prototype.

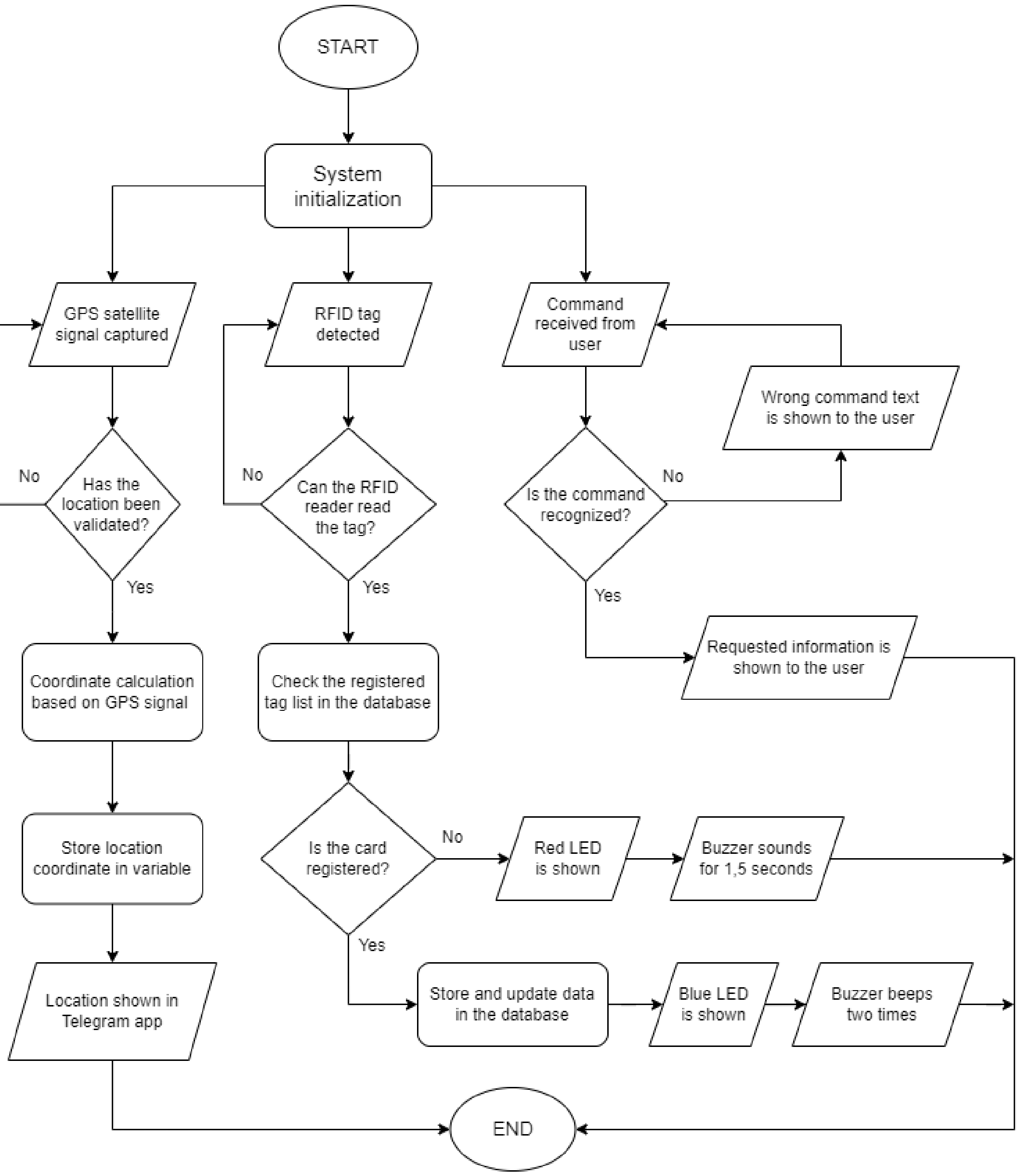

Figure 3. Programming flowchart.

Figure 4. The experimental apparatus.

The prototype is constructed based on the design depicted in Figure 2, utilising the components specified in the design list. Each component used in the construction undergoes voltage measurement testing to ensure the proper functionality of the prototype. The voltage values provided in the component datasheets serve as the reference for powering the components within the prototype. The arrangement of the components aligns with the design layout, visible in Figure 4. Specifically, the RFID reader and indicators are positioned inside the black box at the bottom of the image. At the same time, the microcontroller, voltage regulator, and other processing components are housed within the black box on the right side, excluding the relays due to their larger dimensions and the GPS antenna for signal capturing.

3. RESULTS AND DISCUSSION

Voltage measurements are conducted using an Avometer to ascertain the voltage value at each designated test point, as depicted in Figure 2 (marked with numbers). These measurements are taken while the system is operational and during standby mode when no input is applied. The test results from the voltage measurements are categorised into two sections: 3.3V and 5V. Table 1 presents the findings for components utilising 3.3V. The table illustrates that the measured voltage exhibits slight variations due to diverse load requirements on each component, leading to voltage drops. However, it is essential to note that the results of these voltage measurements remain well within the voltage references specified in the components' datasheets.

Subsequently, Table 2 displays the outcomes of the voltage measurements for the 5V components. The measured voltage of both components aligns with the specified voltage reference. In conclusion, all the measurements for the components employed in this prototype have been performed, confirming their proper functionality following the design.

Table 1. The measurement of voltage on 3.3V components.

Label number	Pin	Voltage reference (Volt)	Measured voltage (Volt)
2	VCC RFID reader	2.5 - 3.3	3.202
3	VCC GPS module	3 - 5	3.14
4	VCC PCF8574	2.5 - 6	3.263

Table 2. The measurement of voltage on 5V components.

Label number	Pin	Voltage reference (Volt)	Measured voltage (Volt)
1	VCC NodeMCU	4.5 - 10	4.95
5	VCC relays	5	5.0

3.1. RFID tag detection distance and response time measurements

A ruler is placed perpendicular to the RFID reader to measure the distance, and the RFID tag is positioned directly above the reader at a predetermined distance. This measurement determines the reader's reading distance [23]. Simultaneously, the response time is measured using a stopwatch to determine the time required to generate output after reading the tag. Two tags are utilised in this test to distinguish between measurements: registered and unregistered. The findings are presented in Table 3.

As per the information provided in the datasheet, the RFID reader has a maximum reading distance of less than 5 cm [24]. Therefore, the test is conducted within the 5 to 4 cm range, with intervals of 5 mm. As shown in Table 3, the tag is successfully detected at a distance of 4.5 cm, validating the agreement with the component datasheet.

There is a notable difference in the measured time between registered and unregistered tags. The registered tag takes longer processing time because the program has to upload processed data to Firebase's database and switch the corresponding relay before the indicators signal the completion of the process. Conversely, with an unregistered tag, the absence of an upload process allows the program to complete its process more rapidly.

Table 3. The measurement of RFID tag detection distance and response time.

Tests	Measured distance (cm)	Reader detection	Tag status	Measured times (s)
1	5.5	Not detected	Registered	-
			Unregistered	-
2	5.0	Not detected	Registered	-
			Unregistered	-
3	4.5	detected	Registered	2.59
			Unregistered	0.45
4	4.0	detected	Registered	2.35
			Unregistered	0.45

3.2. Information request response on the Telegram app

This section involves a test to observe the system's response when receiving messages or commands the user sends through the Telegram app. Additionally, the time taken from sending a message to receiving a reply is measured. When the system receives a message, the program matches a predefined set of commands to determine the information that should be returned to the user. The results of the time measurements are displayed in Table 4. An example of the information received by the user is depicted in Figure 5.

Table 4 shows significant variations in the measured time between replies, with an average of 5.6 seconds. This variance is attributed to the stability of both the system's and users' internet networks. Additionally, the microcontroller's clock speed [25] influences the duration of this process. However, despite these factors, the system effectively provides the requested information to the users.

Table 4. Information request response and time measurements.

Number of tests	Command sent	Time measured (s)
1	/shoplist	5.42
2	/shopstatus	5.90
3	/openshop	6.35
4	/location	4.84

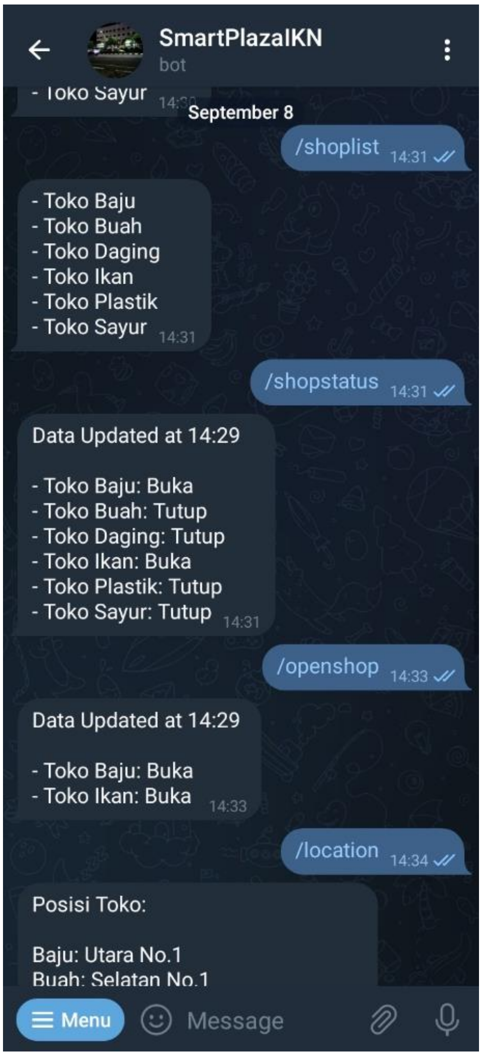

Figure 5. Information request response on telegram.

4. CONCLUSION

The successful design and construction of the system prototype have conclusively demonstrated the feasibility of combining various subsystems into a single, integrated device capable of automating the lighting system and facilitating user communication through the internet network. By incorporating RFID technology, GPS integration, and a microcontroller (NodeMCU ESP8266), the research achieved the primary objective of creating a seamless interface between lighting automation and user interaction, all within one cohesive system.

Throughout the research process, extensive testing and measurements were conducted to validate the system's performance. The components used in the prototype were thoroughly evaluated by measuring electrical readings and observing the device's response time, confirming that the design operates as intended. Notably, all the measured voltage values for both 3.3V and 5V components closely align with the corresponding values in the datasheets. Any slight variations observed can be attributed to the specific load requirements of each element.

Furthermore, the successful implementation of this prototype in modern market buildings can significantly enhance the efficiency of lighting systems, resulting in reduced energy consumption during closed hours, contributing to energy conservation and cost savings. Additionally, the ease of information access for users through the Telegram app can enhance their decision-making processes when visiting the market, providing up-to-date kiosk statuses for a more convenient shopping experience.

Several recommendations can be made to advance this research further. Firstly, exploring opportunities to optimise power consumption within the system, such as efficient power management and low-power modes, could lead to improved energy efficiency. Additionally, implementing security features to protect sensitive data in the database would enhance the system's overall reliability. Moreover, conducting user feedback and usability studies would aid in refining the interface, ensuring an intuitive and user-friendly experience for all users.

In conclusion, this research demonstrates the successful integration of multiple subsystems into a cohesive and innovative device that automates lighting systems and facilitates user communication through the Internet. The achieved objectives and notable findings emphasise the potential of such integrated systems in various practical applications. The advancement of science and technology in this direction carries significant implications for energy efficiency, user convenience, and enhanced automation in diverse industries.

CONFLICTS OF INTEREST

The author declares that no competing financial interests could have appeared to impact the work.

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