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IMPLEMENTATION OF A SMART EMERGENCY LAMP HOME PROTOTYPE BASED ON INTERNET OF THINGS (IoT) USING NODEMCU ESP32 MICROCONTROLLER

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Abstract

Power outages in residential environments such as boarding houses often disrupt safety and comfort due to the lack of adequate emergency lighting systems. This study aims to develop a Smart Emergency Lamp Home prototype using the Internet of Things (IoT) with a NodeMCU ESP32 microcontroller. The system is designed to automatically activate emergency lighting during power failures and enable real-time monitoring and control via a web-based interface. The research follows an engineering method involving system design, hardware-software integration, and prototype testing. The hardware includes power sensors (INA219 and PZEM-004T), a 12V battery, inverter, relay module, and TFT display, while the software uses Node.js and a PostgreSQL database for web monitoring. Testing results demonstrate the system's high responsiveness, accurate sensor data transmission, efficient power usage (with power factors above 0.94), and stable operation during simulated blackouts. The notification system also worked effectively, providing timely alerts regarding lamp status and battery conditions. This prototype offers a practical, scalable, and low-cost solution for emergency lighting in residential settings and can be further developed with features like solar charging and mobile-based monitoring.

Keywords: ***Smart Emergency Lamp, Internet of Things (IoT), NodeMCU ESP32, Power Outage, Web-Based Monitoring.***

INTRODUCTION

The availability of electricity is a vital necessity in modern life, especially in densely populated residential environments such as boarding houses or rented accommodations. Electricity supports various essential activities, from studying and working to operating household appliances (Lindawati et al., 2022). However, sudden and unannounced power outages remain a common issue. These disruptions can be caused by extreme weather, network maintenance, or technical failures in the distribution system (Gkika et al., 2023). When outages occur, boarding house residents often lose access to lighting and electronic devices, which not only disrupts comfort but also reduces productivity and safety. Unfortunately, most temporary residences like boarding houses are not equipped with adequate emergency lighting systems. Conventional emergency lights typically provide only temporary illumination with limited operating durations and no automatic control capabilities (Ozenen, 2023). In this context, advancements in Internet of Things (IoT) technology present significant opportunities to enhance emergency lighting systems, making them smarter, more efficient, and remotely accessible. IoT enables the integration of hardware with internet networks, allowing users to monitor and control devices in real- time from different locations (Su & Chen, 2022).

Several previous studies have explored IoT applications in smart home systems, such as controlling lights via mobile apps or voice commands. However, few studies have specifically developed IoT-based emergency lighting systems designed to address power crises in densely populated environments (Sumantri et al., 2022). Therefore, the development of a *Smart Emergency Lamp Home* system based on IoT using the NodeMCU ESP32 microcontroller offers a potential solution to this problem. This system is designed to activate automatically during power outages and provides boarding house owners with monitoring and control access via a web-based interface. The goal of this system's development is to design and implement an IoT-based emergency lamp prototype that delivers automatic lighting solutions during power outages. Additionally, the system is expected to improve the efficiency and effectiveness of emergency lighting management through integrated remote control features via the internet. The reliability and user-friendliness of the system are also key focuses, enabling boarding house owners to easily monitor lamp status and power conditions from anywhere without needing to be physically present. This research not only contributes to the technical aspects of IoT implementation but also holds social relevance by addressing the needs of urban communities living in high-mobility environments. Academically, it strengthens the discourse on the application of the ESP32 microcontroller in developing affordable and practical IoT-based devices. With this approach, the *Smart Emergency Lamp Home* system is expected to become an innovative solution that enhances comfort, safety, and energy efficiency in both modest and modern residential environments.

LITERATURE REVIEW

Smart Emergency Systems in Residential Contexts

Smart emergency systems are increasingly critical in ensuring safety and comfort in residential settings, particularly during unanticipated power outages (Damaševičius et al., 2023). These systems typically integrate sensors, controllers, and communication interfaces to automate emergency responses. In kost or boarding house environments, where electricity reliability significantly affects daily routines, the need for responsive lighting systems becomes more pronounced (Putri & Pramono, 2024). However, most conventional emergency lamps operate independently of modern automation frameworks, limiting their responsiveness and energy efficiency. The development of smart emergency lighting systems aims to address these limitations by employing microcontrollers and sensors that can detect power failures and activate lighting systems automatically (Maheswaran et al., 2024). Moreover, with Internet of Things (IoT) integration, users can remotely monitor and control devices through web-based interfaces, ensuring the system remains active even when occupants are away (Alghamdi et al., 2022). This approach not only enhances system efficiency but also improves the overall user experience in dynamic living environments like shared accommodations.

Internet of Things (IoT) and NodeMCU ESP32

IoT is one of the innovative technologies that, with the availability of internet access, makes daily activities easier and more efficient. With IoT, objects around us can be connected to the Internet. This IoT- based system can be applied in everyday life (Taufiq, T et al 2023). In the context of home automation, IoT plays a pivotal role in enabling remote control, data logging, and automation of household functions, including emergency lighting systems (Bustami, et al B 2022). IoT devices can operate independently, trigger specific actions based on sensor inputs, and communicate real-time data to centralized dashboards or applications (Siddiqui et al., 2023). One of the key components in IoT development is the NodeMCU ESP32 microcontroller. The ESP32 is a low-cost, low-power system-on-chip with built-in Wi-Fi and Bluetooth capabilities, making it highly suitable for IoT applications (Oner, 2021). Its compatibility with the Arduino IDE and broad GPIO (General Purpose Input/Output) support allows seamless integration with various sensors and actuators (Wibowo et al., 2020). In smart emergency lighting systems, the ESP32 enables real-time monitoring of electrical input, automatic activation of lighting upon power loss, and communication with user interfaces

Web-Based Monitoring and Automation in Emergency Systems

The integration of web-based platforms in emergency systems enhances usability and accessibility for end-users. Web interfaces serve as dashboards to visualize system status, send commands, and receive alerts (Akano et al., 2024). In cost-conscious and high-occupancy environments like rental housing, web monitoring allows property owners to ensure that critical systems such as emergency lighting remain functional without needing to be physically present (Eini et al., 2021).

Previous Research

Several relevant studies have contributed to the development of smart lighting and emergency systems. Mulyanto et al. (2020) developed a Bluetooth-based lighting control system, but its dependency on short-range connections limited practical usage during outages. Hidayati (2022) proposed an IoT-based smart lamp with time-based automation but without real-time sensor feedback, making it less suitable for emergency scenarios. Andika et al. (2024) introduced a sound-activated system, but environmental noise significantly impacted reliability.

More robust implementations like that of Herlina et al. (2022), using NodeMCU ESP8266 with the Blynk application, showed improved interaction via mobile platforms but still faced connectivity delays. Susilo et al. (2021) employed Raspberry Pi-based systems with web browser control, but latency due to network instability persisted as a concern. While these studies show promising advancements, most were not designed for automated emergency response with sustained operation during power outages.

Research Gap

This study addresses these limitations by proposing a Smart Emergency Lamp Home system that integrates IoT technology, microcontroller-based automation (NodeMCU ESP32), and a web interface for real-time monitoring. The system is designed not only to respond automatically to power outages but also to provide reliable communication and control from remote locations. By incorporating data visualization, sensor feedback, and autonomous control, this research contributes a practical solution for energy resilience in residential environments, especially those with limited technical supervision.

METHOD

Research Approach

This study employs an engineering research approach, emphasizing the design, construction, and evaluation of a *Smart Emergency Lamp Home* system based on the Internet of Things (IoT). The method integrates hardware prototyping with software development, aiming to produce a reliable emergency lighting system that automatically activates during a power outage and can be monitored remotely via a web interface.

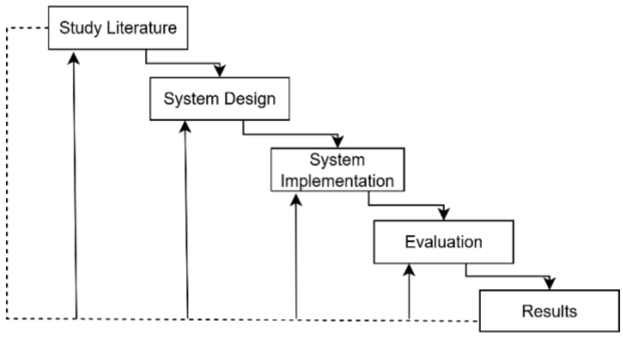

Image 1: Research Approach

The process begins with a literature review to gather relevant theories, previous research findings, and technical references that support the formulation of system requirements. In the System Design stage, both the hardware architecture (sensors, relays, microcontroller, power supply) and software architecture (data flow, dashboard, connectivity) are conceptualized. This is followed by the System Implementation stage, where components are assembled and programmed according to the design specifications. After the system is built, the Evaluation stage involves testing the system under real-world conditions, simulating blackout events to assess system responsiveness, reliability, and usability. Finally, the Results stage documents the findings, analyzes system performance, and draws conclusions regarding the system's effectiveness and potential improvements.

System Design

The system is designed to activate emergency lighting automatically when a power failure is detected, while allowing real-time monitoring via a web platform. The design is divided into two primary aspects: hardware and software.

Table 1. System Design

Hardware Architecture	Software Architecture
1. **Power Sensors:** INA219 and PZEM-004T for AC and DC current/voltage detection 2. **Relay Module:** 5V, 4-channel, to control lamp activation 3. **Backup Power Supply:** 12V sealed lead- acid battery and 200W inverter 4. **Display Unit:** LCD TFT 1.8" for local system status visualization 5. **Lighting:** 10W LED lamps simulating residential emergency lighting	1. **Embedded System:** The ESP32 is programmed using Arduino IDE, enabling it to control relays, read sensor data, and send data to a server 2. **Web Dashboard:** Built using Node.js and PostgreSQL, the system backend stores and manages data sent from the device. A responsive web interface allows users to monitor voltage, lamp status, battery condition, and receive alerts

System Schematic

To facilitate system development and ensure that no components are omitted during implementation, a complete schematic diagram of the system was designed. This schematic illustrates the integration of various electronic components and their respective roles within the Smart Emergency Lamp Home system, which is based on the NodeMCU ESP32 microcontroller and IoT monitoring. The visual representation helps clarify the working relationships between hardware elements and supports easier debugging during installation or testing.

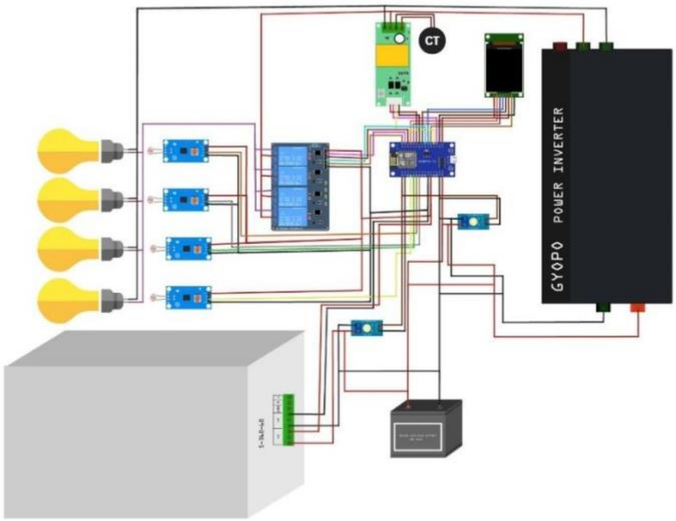

Image 2: Research Approach

In this schematic, the main components include a 12V lead-acid battery as a backup power source, a DC-to-AC inverter for lamp activation during blackouts, and several sensors (PZEM-004A, INA219, INA129) for monitoring power and voltage conditions. The NodeMCU ESP32 acts as the control center, interfacing with all sensors, relay modules, and a 1.8-inch TFT display to present real-time data. Additionally, the system features a web-based interface for remote access via Wi-Fi. The schematic also incorporates color-coded wiring for clarity: red for positive voltage, black for ground, yellow and green for signal transmission, and additional colors (white, blue, orange, purple) for data communication lines. This organized layout not only ensures optimal system performance but also simplifies the identification of potential issues during maintenance or troubleshooting.

System Implementation and Testing

The implementation phase involved assembling all hardware components into a compact and functional prototype. The NodeMCU ESP32 was programmed using the Arduino IDE to read sensor data, control the relay module, and transmit system status to the web dashboard via Wi-Fi. All components, including sensors (INA219, PZEM-004T, INA129), a relay module, a 12V lead-acid battery, and a DC-to- AC inverter, were installed in a controlled environment that mimics real residential conditions. The system was tested in a simulated blackout environment to evaluate its ability to respond automatically. When grid voltage dropped to zero, the system successfully activated the emergency lamp by switching to battery power via the inverter. During this event, sensor data such as voltage, current, power, and temperature were transmitted and displayed correctly on both the local TFT display and the web dashboard. Testing scenarios were conducted repeatedly over multiple one-hour sessions to assess :

- **System Responsiveness**: Time delay between power outage detection and lamp activation
- **Data Accuracy**: Comparison of sensor readings with multimeter results
- **Web Monitoring Functionality**: Reliability of dashboard updates and connectivity
- **System Stability**: Consistency of operation over prolonged standby periods and repeated switching

The system performed reliably across all test cases, demonstrating successful integration of hardware and software components. The use of Wi-Fi connectivity proved effective for real-time monitoring, and the system's ability to function during extended outages confirmed its potential for practical use in residential settings.

RESULTS AND DISCUSSION

Implementation Results

The Smart Emergency Lamp Home system was successfully implemented using a combination of NodeMCU ESP32 microcontroller, real-time power sensors (INA219, PZEM-004T), a 12V lead-acid battery, a DC-to-AC inverter, an LCD TFT display, and a web interface developed with Node.js. The system was designed to automatically detect power loss, activate emergency lighting, and provide real- time status updates via a web dashboard.

Image 3: Prototype smart emergency lamp home

During standby mode, the system remains responsive and is ready to activate the emergency lamp. Users can interact with the system either manually through hardware switches or remotely through the web interface. Both control methods are synchronized with the monitoring system, ensuring real-time updates are reflected on both the LCD TFT and the online dashboard.

System Testing Results

1. DC Power Sensor Testing

The INA219 sensor was used to monitor battery charge level, health percentage, and temperature during a continuous one-hour test. Battery values were recorded at three-minute intervals.

Table 1I. Sample DC Power Sensor Data

No	Time Interval	Charge (%)	Health (%)	Temp (°C)	Status
1	0–3 mins	47	93	35	Normal
2	6–9 mins	6	89	-	Critical
3	33–36 mins	0	96	38	Critical
4	45–48 mins	18	90	33	Warning
5	57–60 mins	61	97	39	Normal

The battery charge percentage fluctuated significantly, showing periods of deep discharge, particularly in the 6–36 minute range. The "Critical" status indicates moments when the system reached dangerously low power levels, posing a risk to lamp uptime. However, battery health remained above 88%, suggesting that the power cells were still physically reliable. The temperature stayed within safe operating limits (below 40°C), ensuring sensor accuracy and preventing thermal stress.

2. AC Power Sensor Testing

The PZEM-004T sensor was tasked with monitoring the AC supply output from the inverter during lamp activation. Voltage, current, power, power factor, and efficiency were recorded every three minutes.

Table II1. Sample AC Power Sensor Data

No	Interval	Voltage (V)	Current (A)	Power (W)	Power Factor	Efficiency (BTU/W)
1	0-3 mins	208.0	0.064	13.1	0.98	10.16
2	18-21 mins	208.5	0.062	12.7	0.98	10.18
3	42-45 mins	216.4	0.000	0.0	0.00	0.00
4	51-54 mins	211.8	0.022	4.4	0.94	10.59

The output voltage remained stable throughout the test, with minor fluctuations around the nominal value of 210V. A temporary drop to zero power (at minute 45) likely indicates a standby condition, or the system entered idle mode after detecting sufficient ambient light or low usage. The power factor remained high (>0.94), indicating efficient energy transfer from inverter to load. The efficiency values (10.14–10.59 BTU/W) confirm minimal energy loss, making the system viable for extended emergency usage.

3. Lamp Status Monitoring

Lamp activation and control states were recorded to evaluate synchronization between hardware relays and system feedback (status + intensity readings).

Table 1V. Lamp Monitoring Results

No	Lamp ID	Pin	Status	isValue	Relay
1	Lamp 2	2	OFF	4005	OPEN
2	Lamp 3	3	OFF	4095	OPEN
3	Lamp 4	4	OFF	2244	OPEN

All lamps in the example remained OFF with relays in an OPEN state, indicating no current flow. The isValue readings—ranging from 2244 to 4095—suggest that the system records PWM (pulse-width modulation) or brightness levels even when lamps are off, possibly for dimming memory or calibration. These values provide insight for further control logic enhancements, such as dynamic brightness based on battery status.

4. Notification System Performance

The system generated 20 automatic notifications over the course of testing, including 8 lamp status updates and 12 battery warnings. Critical warnings were triggered at <10% battery levels, while warnings occurred between 10–20%. All messages were timestamped and delivered to a registered user.

Table V. Notification Summary

No	Type	Trigger Condition	Count
1	Lamp Status	2	OFF
2	Battery Warning	3	OFF
3	Battery Critical	4	OFF

The notification engine functioned as expected, sending timely updates based on internal thresholds. The majority of critical alerts occurred during the first 30 minutes, correlating with deep discharge episodes. Alerts serve to inform users remotely and preempt potential lighting failure by prompting recharging or manual intervention. This feature is particularly useful for unattended monitoring in kost or rental properties.

5. Lamp Usage History

To assess usage patterns, the system logged lamp ON/OFF activity and usage by time of day.

Table VI. Frequency of Lamp Activation

No	Lamp ID	ON	OFF	Total
1	L1	3	3	6
2	L2	1	3	4
3	L3	5	5	10
4	L4	3	3	6

Lamp 3 had the highest number of activation cycles, indicating frequent usage—either for practical needs or as part of a testing loop. The balanced ON/OFF counts suggest proper relay synchronization. This data can also help determine wear level or relay lifespan per channel, supporting future preventive maintenance.

System Interface Implementation

The monitoring and control system for the *Smart Emergency Lamp Home* is implemented as a web- based application, enabling users—primarily kost or boarding house owners—to monitor power status, control lamps remotely, and receive automated notifications. The web system is built using Node.js for backend operations and MySQL as the data management engine, ensuring real-time data transmission from the ESP32 microcontroller via Wi-Fi.The interface is designed to be responsive, user-friendly, and functionally integrated with the hardware. It provides centralized access to various system data, such as battery condition, lamp usage history, and control status, without requiring users to physically access the device. The following are the main components of the system interface:

1) Login Page

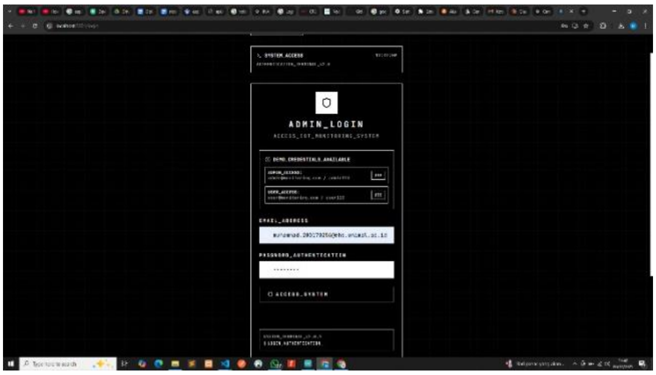

Image 4: Login Page

The login page functions as the system's secure entry point. Users are required to enter a valid email and password to access the system. Real-time validation is embedded to ensure secure and authenticated sessions. This page is intentionally minimalistic, focusing on clarity and security to prevent unauthorized access to device data and controls.

2) Dashboard Page

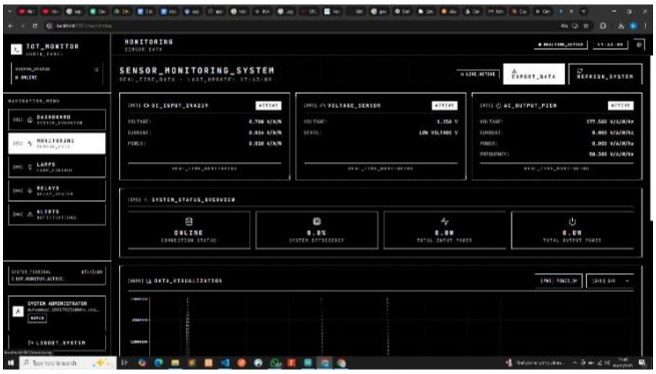

Image 5: Dashboard Page

After successful login, users are directed to the main dashboard. This page displays real-time data such as battery charge percentage, battery health, temperature, lamp statuses, and relay positions. Each lamp's state is updated dynamically, ensuring accurate synchronization between the hardware and visual interface. The dashboard also shows active alerts and sensor readings, supporting situational awareness for the user. The clean layout makes it easy to identify critical statuses such as low battery levels or inactive relays.

3) Device Page

Image 6: Lamp Control Page

This section lists all hardware devices currently registered and connected to the system. Users can filter devices, search by name, or check device ID and associated parameters. Each entry includes key data such as power usage, voltage, and connection timestamps. This page is essential for managing multiple installations and supports scalability for future multi-device deployments.

4) Battery Monitoring Page

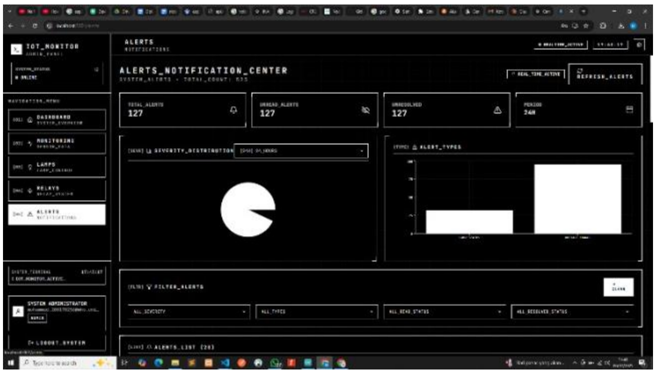

Image 7: Battery Monitoring Page

The battery monitoring page provides a detailed breakdown of the power supply system. Users can track the battery's voltage, charge level, temperature, and power consumption. The interface also includes historical charts displaying fluctuations in battery performance over time. This graphical representation aids in diagnosing power issues and planning maintenance. At the bottom of the page, a “Control All” button allows users to simultaneously activate or deactivate all connected lamps, providing centralized command functionality.

The web interface for *Smart Emergency Lamp Home* is designed for functionality, accessibility, and clarity. Each page focuses on a specific operational aspect—ranging from user authentication, system status, device management, to energy monitoring. This structure supports reliable remote control and enhances transparency for users responsible for overseeing the safety and lighting reliability of kost or rented facilities. Web-based implementation ensures that the system can be accessed anytime, anywhere, provided internet connectivity is available. The modular interface also makes the system adaptable for future enhancements, such as user roles, mobile access, or integration with smart home ecosystems.

CONCLUSION

This research successfully designed, implemented, and evaluated a Smart Emergency Lamp Home system using Internet of Things (IoT) technology. The system is capable of automatically activating emergency lighting during power outages while simultaneously providing real-time monitoring and remote control through a web-based interface. Testing results showed that the system performed reliably in terms of sensor accuracy, response time, energy efficiency, and connectivity. The battery monitoring system effectively tracked power conditions, while the lamp control mechanism operated in sync with both manual and remote triggers. The web interface—featuring dashboard visualization, device lists, and real-time notification alerts—proved to be an effective tool for users to monitor system performance and manage lamp usage remotely.

Furthermore, the system maintained efficient energy usage, with average power factors near unity and stable performance under repeated test cycles. The integration of multiple sensors (INA219, INA129, and PZEM-004T), along with the NodeMCU ESP32 controller and a user-friendly web application, demonstrated that an affordable and scalable emergency lighting solution can be developed using open-source tools. The system also showed potential to be expanded into broader smart home environments, particularly in residential or small-scale commercial settings that demand reliable power backups and visibility during outages. However, several limitations were noted. The system's reliance on Wi-Fi means that its performance may degrade in areas with unstable internet connectivity. Battery endurance, while sufficient for short-to- moderate outages, may require optimization or enhancement such as the integration of solar charging support for more prolonged use. For future work, several improvements are recommended to enhance system robustness and scalability. These include the integration of mobile-based applications to improve accessibility and user interaction, especially for remote monitoring; the addition of solar panel modules to ensure autonomous battery recharging during outages; the implementation of offline logging mechanisms that allow sensor data to be stored locally during disconnections and synchronized once connectivity is restored; and the deployment of the system in multi-location setups with centralized control to accommodate larger-scale use cases, such as apartment buildings or public facilities. Overall, this study contributes a practical and implementable solution that merges IoT technology with emergency preparedness, offering value for users seeking real-time, remote, and intelligent control over critical lighting systems.

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