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# Autonomous Streetlight Brightness and Angle Adjustment System for Enhanced Road Safety and Energy Efficiency

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ABSTRACT

An increasing number of road traffic accidents (RTAs) and the limitations of traditional streetlight systems have prompted the development of more intelligent, adaptive lighting solutions. This paper introduces an autonomous streetlight system that adaptively modifies brightness and angle coverage in response to environmental conditions and the presence of vehicles. The system incorporates a Raspberry Pi Pico 2 W microcontroller, Light Dependent Resistor (LDR) sensors, piezoelectric sensors, and MG995 servo motors to enhance energy efficiency and improve road safety. It also utilises Internet of Things (IoT) platforms such as Adafruit IO to facilitate fault detection with a status indicator, and GPS-based location tracking which enables prompt restoration, resulting in a reduction of energy consumption compared to conventional systems. Real testing has demonstrated the system's reliability, addressing the limitations of conventional street lighting and setting the stage for smarter urban infrastructure.

## 1 INTRODUCTION

Urban street lighting plays a critical role in ensuring public safety and improving the quality of life. However, traditional streetlight systems are plagued by inefficiencies such as high energy consumption, frequent bulb failures, and delayed maintenance, which contribute to unsafe road conditions and increased operational costs. According to the World Health Organization (WHO), over 1.25 million deaths and 50 million injuries occur annually due to road traffic accidents, many of which are exacerbated by poor lighting conditions[1]. In addition, research by Darma et al.[2] shows that 66% of deaths occurred in rural areas, while 34% occurred in urban areas. Based on these percentages, 11.25% of road deaths are related to road damage,

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while 46% are related to inadequate road lighting. This demonstrates that road lighting contributes significantly to road fatalities.

To address these challenges, this project proposes an autonomous streetlight system that dynamically adjusts brightness and angular coverage based on real-time environmental and traffic conditions. The system utilises a Raspberry Pi Pico 2 W microcontroller, Light Dependent Resistor (LDR) sensors, piezoelectric sensors, and MG995 servo motors. This system utilises the MG995 servo to adjust the angle of the streetlight, ensuring precise control for excellent illumination coverage. The MG995 is recognised for its substantial torque, low-cost and endurance, frequently utilised in robotics, remote-controlled vehicles, and automation systems, rendering it a dependable option for motion control projects[3]. Within this system, the ability for automatic adjustment of the angle of the streetlight is essential for providing sufficient lighting in poorly lit areas, hence significantly improving streetlight efficacy as temporary lighting solution when required. Besides, the integration of Internet of Things (IoT) platforms like Adafruit IO has proven to support real-time monitoring and control, GPS-based location tracking, and remote-control capabilities, thereby significantly reducing maintenance response times.

## 2 LITERATURE REVIEW

Transportation is vital for modern society; however, road safety continues to be a major issue, particularly during night-time. Driving on inadequately illuminated roads or in areas with malfunctioning streetlights increases the likelihood of accidents and vehicle damage[4]. This contributes to hazardous conditions for both drivers and pedestrians. For instance, in Sibu, Malaysia, on December 15, 2023, two streetlight maintenance workers lost their lives when a four-wheel-drive vehicle lost control and hit them at the Jalan Sibu-Bintulu roundabout[5]. The workers were repairing a lamp post that had been damaged in an earlier accident. Furthermore, a study conducted in a Chinese city between 2014 and 2016 analysed 2,106 night-time vehicle accidents, discovered that 1,969 incidents occurred on poorly lit roads. These accidents resulted in 183 fatal crashes and 621 deaths, highlighting the increased frequency and severity of collisions in poorly illuminated environments[4]. Apart from the risk of road safety, lighting accounts for 10-38% of total electricity consumption in urban areas worldwide[6]. Cho and Dhingra[7] indicates that approximately 30% of a nation's overall electricity consumption is linked to street and road lighting.

Considering these issues, efficient street lighting is crucial for improving road safety and mitigating accident risks, especially at night. Well-lit roads enhance visibility for drivers, enabling them to see obstructions, pedestrians, and other cars with better clarity, thereby decreasing the probability of collisions. Likewise, sufficient street illumination enhances pedestrian safety by increasing the visibility of crosswalks and sidewalks, hence reducing the likelihood of accidents involving vulnerable road users. In addition to safety, effective street lighting is vital for urban sustainability, as its optimisation can greatly decrease energy usage and minimise carbon emissions[8].

The integration of IoT-based smart public street lighting systems has been extensively studied, with a focus on enhancing energy efficiency, safety, and sustainability in urban environments. Recent advancements in LED technology, coupled with IoT-enabled sensors and communication networks, have significantly improved the functionality of smart street lighting systems. Studies have demonstrated that replacing traditional lighting with LED technology can lead to substantial energy savings, reducing electricity consumption by up to 50%[9]. Moreover, the incorporation of smart sensors and wireless communication protocols, such as ZigBee and LoRa, allows for dynamic control of lighting intensity based on real-time data, such as traffic flow and weather conditions. This not only optimises energy usage but also enhances public safety and reduces maintenance costs. Also, the deployment of IoT-based monitoring units enables remote management and predictive maintenance, ensuring the reliability and longevity of the lighting infrastructure. These developments highlight the potential of smart street lighting systems to contribute to the broader goals of smart cities, including energy conservation, environmental sustainability, and an improved quality of life for urban residents.

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In recent years, the integration of IoT technologies into street lighting systems has gained significant attention due to their potential to enhance energy efficiency and urban management. Research by Sun et al.[10] proposed a smart streetlight management system utilising NB-IoT and LoRa technologies, which enable real-time data collection, remote monitoring, and fault detection through a cloud-based platform. Their system incorporates multiple sensors, including temperature, humidity, and light intensity sensors, to dynamically adjust streetlight operations based on environmental conditions. Over and above that, the integration of WEBGIS technology allows for the visualisation of streetlight data on electronic maps, facilitating efficient maintenance and management. While this approach demonstrates significant advancements in energy conservation and fault detection, it lacks features such as angle adjustment and real-time vehicle detection, which are crucial for improving road safety. Nevertheless, the use of advanced IoT technologies like NB-IoT and LoRa highlights the potential for scalable and efficient urban lighting solutions, offering valuable insights for future smart city infrastructure development.

In addition, Sajonia and Dagsa[11] developed an IoT-based smart streetlight monitoring system utilising Kalman Filter Estimation to enhance the accuracy of sensor readings, particularly for battery voltage and load current in solar-powered streetlights. Their system integrates GSM technology for data transmission and a web-based dashboard for real-time monitoring, enabling remote management of streetlights in rural areas. The study highlights the importance of energy efficiency and maintenance cost reduction, with the Kalman Filter effectively reducing sensor noise and improving data reliability. While the system focuses on solar energy and remote monitoring, it does not address dynamic brightness or angle adjustments, which are crucial for urban road safety. Nonetheless, the integration of advanced filtering techniques and IoT-based remote monitoring offers valuable insights for improving the reliability and efficiency of smart street lighting systems, particularly in areas with limited infrastructure.

Furthermore, Sujatha et al.[12] proposed an IoT-based Smart Street Light Controlling and Monitoring System that integrates LDR sensors, Arduino UNO microcontrollers, and ESP8266 Wi-Fi modules to dynamically adjust street lighting based on real-time environmental conditions. The system utilises the ThingSpeak API for cloud-based data monitoring and visualisation, enabling remote control and maintenance of streetlights. By automating lighting adjustments based on ambient light levels and motion detection, the system significantly reduces energy consumption and enhances urban safety. However, the study does not address angle adjustment or advanced fault detection mechanisms, which are critical for optimising illumination in poorly lit areas. Nonetheless, the integration of IoT and cloud-based monitoring offers a scalable and efficient solution for smart urban lighting, contributing to energy conservation and improved maintenance practices.

Another IoT-based Smart Street Light Management System was proposed by Dheena et al.[13] that leverages Arduino Nano, LDR sensors, and ESP8266 Wi-Fi modules to automate street lighting and reduce energy consumption. The system dynamically adjusts light intensity based on ambient light levels detected by LDR sensors and incorporates a DHT11 temperature-humidity sensor to monitor environmental conditions. By replacing traditional HID lamps with energy-efficient LEDs, the system significantly reduces power usage and maintenance costs. Not only that, the integration of IoT enables remote monitoring and control through a web interface, allowing for real-time updates and centralised management. While the system focuses on energy efficiency and environmental monitoring, it does not address angle adjustment or advanced fault detection mechanisms, which are crucial for optimising illumination in poorly lit areas. Even so, the use of IoT and cost-effective components offers a scalable solution for smart urban lighting, contributing to energy conservation and improved maintenance practices.

Additionally, Sorif et al.[14] proposed a smart streetlight management system using the Bolt IoT platform, integrating LDR sensors and IR sensors to dynamically adjust streetlight brightness based on ambient light levels and vehicle movement. The system employs LED lights for energy efficiency, reducing electricity consumption by automatically dimming lights to 40% brightness during low-traffic periods and increasing it to 100% when vehicles or pedestrians are detected. The Bolt IoT platform enables remote

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monitoring and control, allowing authorities to manage streetlights via a cloud-based dashboard and receive real-time alerts. This system not only reduces energy wastage and maintenance costs but also enhances road safety by ensuring optimal illumination. While the system is cost-effective and scalable, it does not address angle adjustment or advanced fault detection, which are critical for further optimisation in urban lighting systems.

The integration of smart technologies in urban street lighting has been a focal point of recent research, with various studies exploring energy-efficient solutions to address the limitations of traditional systems. For instance, Mehra et al.[15] proposed an Arduino-based smart streetlight system that utilises PIR sensors for motion detection and LDR modules for ambient light measurement, enabling dynamic control of LED brightness. This system significantly reduces energy consumption by activating lights only when necessary, achieving up to 75% energy savings compared to conventional methods. The study highlights the potential of combining sensor-based automation with microcontrollers like Arduino to create adaptable and sustainable urban lighting infrastructure. Such innovations align with the broader goal of enhancing road safety and energy efficiency, as discussed in earlier research, while addressing the challenges posed by rapid urbanisation and increasing energy demands.

Recent advancements in smart lighting systems have focused on energy efficiency and real-time monitoring, particularly in hazardous areas such as road intersections and pedestrian crossings. Buretea et al.[16] proposed a cost-effective, microcontroller-based solution for monitoring streetlamp states, utilising current sensors and low-power communication modules like nRF24 and LoRa. Their system minimises energy consumption by activating only during state changes, significantly extending battery life compared to traditional sleep-mode approaches. This research also highlights the importance of flexible, low-power solutions that can be integrated into existing infrastructure without extensive modifications, offering a practical approach to enhance the reliability and efficiency of urban lighting systems. Such innovations align with the broader goal of reducing energy waste and improving safety in urban environments. A study by Dheena et al.[13] presented a smart streetlight management system utilising Arduino in which the LDR detects inadequate illumination and uses a relay to activate and deactivate the streetlight. This project has the potential to conserve energy, yet it may entail substantial installation and maintenance expenses. Streetlamp control introduced by Ouerhani et al.[17] utilises the Zigbee remote module, microcontroller, LDR, and transmission modules. Wireless communication was accomplished using the Zigbee light module. However, the initiative is limited by the small range of the Zigbee network.

Conversely, Suseendran et al.[18] utilised a Raspberry Pi 3 with Python programming to regulate the light intensity of the LDR, while still utilising a Zigbee remote module for wireless communication. Although it promotes a reduction in power usage, the design is relatively complicated. Additional research has been undertaken by Archibong et al.[19] who utilised the Arduino Wi-Fi Module, IoT module, Flying Fish IR sensor, driver IC, LED array, 18650 cylindrical lithium-ion batteries rated at 3.7 V and 2,200 mAh, LDR, SARODA SP09-05 model solar PV module rated at 18 V and 20 W, along with a wireless router and computer to facilitate the solar panel-powered streetlamp control. The research demonstrates substantial power savings, but it still incurs high installation costs due to the components involved.

The literature review highlights the critical role of smart street lighting systems in enhancing road safety, reducing energy consumption, and promoting urban sustainability. While existing systems have made significant strides in energy efficiency and automation, they often fall short of addressing key challenges such as dynamic angle adjustment, real-time fault detection, and adaptability to varying environmental conditions. The proposed autonomous streetlight system aims to bridge these gaps by integrating features such as real-time monitoring, adaptive lighting control, and predictive maintenance. By doing so, it seeks to provide a more efficient, cost-effective, and reliable solution for urban lighting, ultimately contributing to safer roads, reduced energy usage, and smarter city infrastructure.

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## 3 METHODOLOGY

The autonomous streetlight system is developed and evaluated as a prototype under controlled conditions for the purpose of the study. A proof of concept for potential scalability in smart urban infrastructure was established by designing the system as a small-scale prototype that controlled three streetlights. The Raspberry Pi Pico 2 W served as the primary controller for the prototype, which also included two sensors: a piezoelectric sensor and an LDR sensor. In addition to these sensors, the system also incorporated the MG995 servo motor, GPS NEO-6M module, PCA9685 16-channel, 12-bit Pulse Width Modulation (PWM), OLED SSD1306, LEDs, push buttons, and LM2596 DC-DC buck converter, which served to step down DC voltage from a higher input level to a stable lower output level. The overall circuit diagram designed using the Fritzing application is presented in Fig. 1.

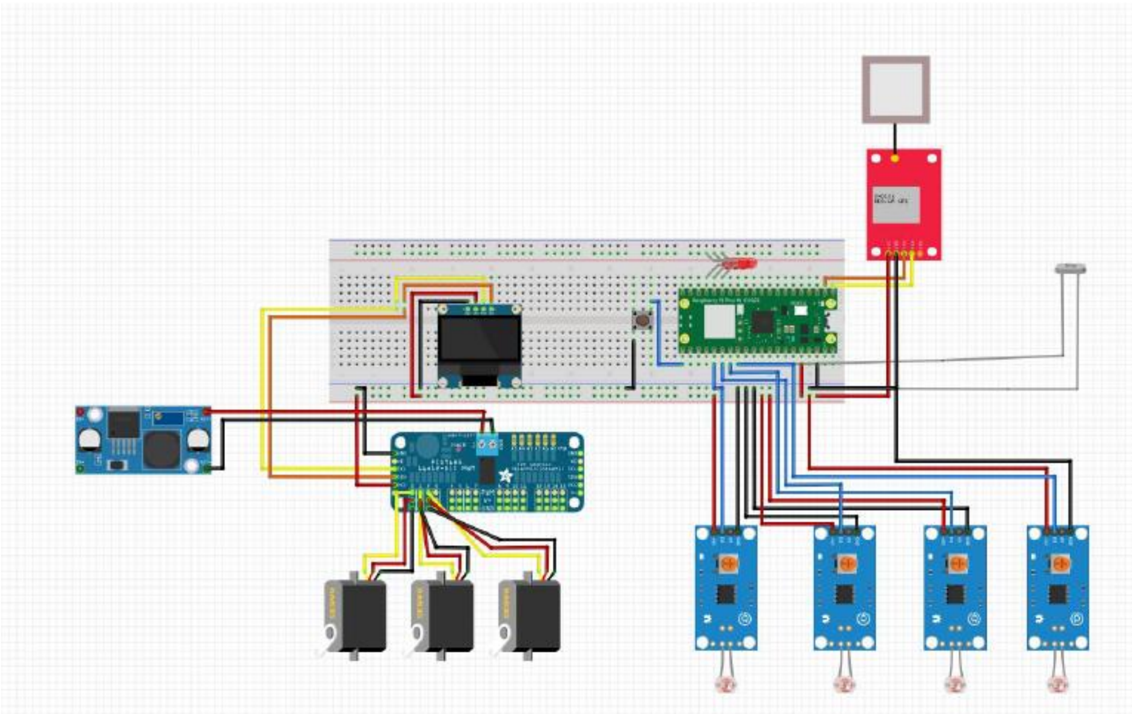

Fig. 1. Autonomous streetlight brightness and angle adjustment.

Fig. 2 illustrates the system block diagram. The Raspberry Pi Pico 2 W was integrated as the main controller for the entire system. It processed inputs from the LDR and piezoelectric sensors, controlled the servo motor for angle adjustment, managed brightness levels, received signals from the GPS module, as well as sent and received data via Adafruit IO. The Raspberry Pi Pico 2 W was equipped with a Wi-Fi module that facilitated real-time updates and GPS tracking by connecting the system to Adafruit IO.

The LDR sensor was employed to measure the lighting conditions, while a piezoelectric sensor was utilised to detect the presence of a vehicle through vibration. The LDR assessed ambient light levels and determined if it was sufficiently dark to activate the servo motor, illuminating a dark area. The LED streetlights automatically adjusted their brightness according to real-time light conditions and motion detection. The brightness control system enhanced energy efficiency by adjusting to environmental conditions, including precipitation and darkness, to provide optimal lighting. During low traffic intervals, the lights reduced in brightness to conserve energy, and upon detecting vehicle presence, they automatically intensified to ensure optimal illumination. This system optimised power efficiency and enhanced street safety.

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The microcontroller's built-in Wi-Fi allowed the Raspberry Pi Pico 2 W to interface with Adafruit IO. This platform was designed to display sensor data and monitor outputs, enabling the monitoring of light intensity levels, location, motion status, and manual servo control. This system provided cost-effective street lighting management, thereby enhancing safety, conserving energy, providing immediate feedback to traffic maintenance workers, and offering short-term solutions.

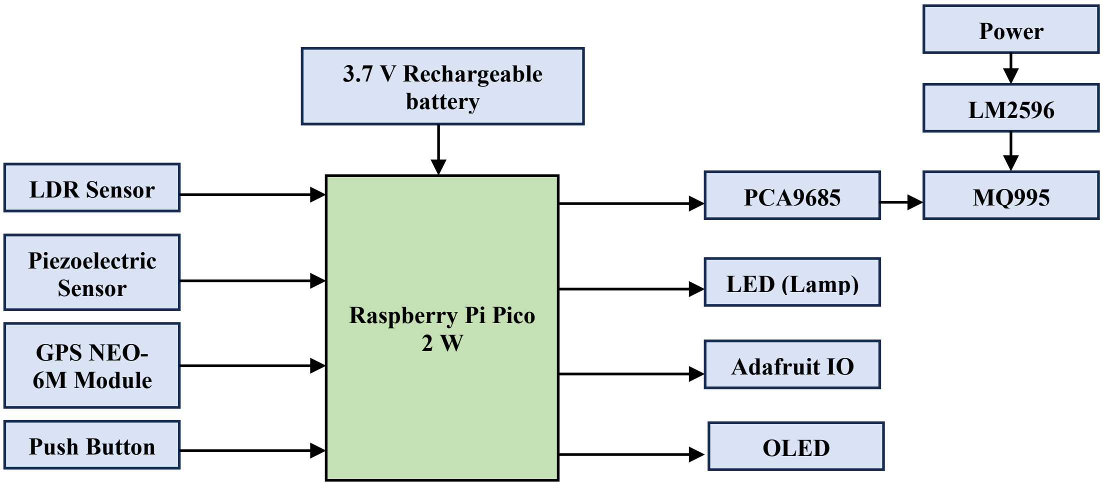


Fig. 2. System block diagram.

The comprehensive system flowchart is illustrated in Fig. 3. It began by interpreting the input from the LDR, which generated a digital signal corresponding to ambient light intensity. Upon detection of darkness, the servo motor was activated to adjust the streetlight position to illuminate the dark area. The OLED panel displayed the current servo angle for monitoring and feedback purposes. The operation continued until the main switch was turned off. The second process involved adjusting LED brightness in response to vehicle detection. It continuously monitored the ambient light and automatically reduced the LED brightness to half when darkness was detected. A piezoelectric sensor detected approaching vehicles, prompting the system to increase the LED brightness to maximum intensity for improved visibility. The present LED brightness, indicated by the duty cycle, was displayed on the OLED screen. The LED returned to half intensity to save energy when no vehicles were detected. To ensure uninterrupted and delay-free real-time vehicle identification and LED brightness adjustments, this process operated concurrently with other system functions.

The following procedure involved updating GPS locations to Adafruit IO by integrating GPS abilities for remote monitoring and maintenance. Upon detection of darkness by the LDR, the system acquired the streetlight's GPS coordinates (latitude and longitude) and transmitted this information to Adafruit IO, enabling users to monitor the location of the streetlight. The successful transmission of the location data was confirmed by a status indicator on Adafruit IO, and the process was completed when the update was successful. This feature enhanced operational efficiency by allowing maintenance teams to promptly identify and locate fixtures that required attention, thereby streamlining the maintenance process and guaranteeing timely interventions.

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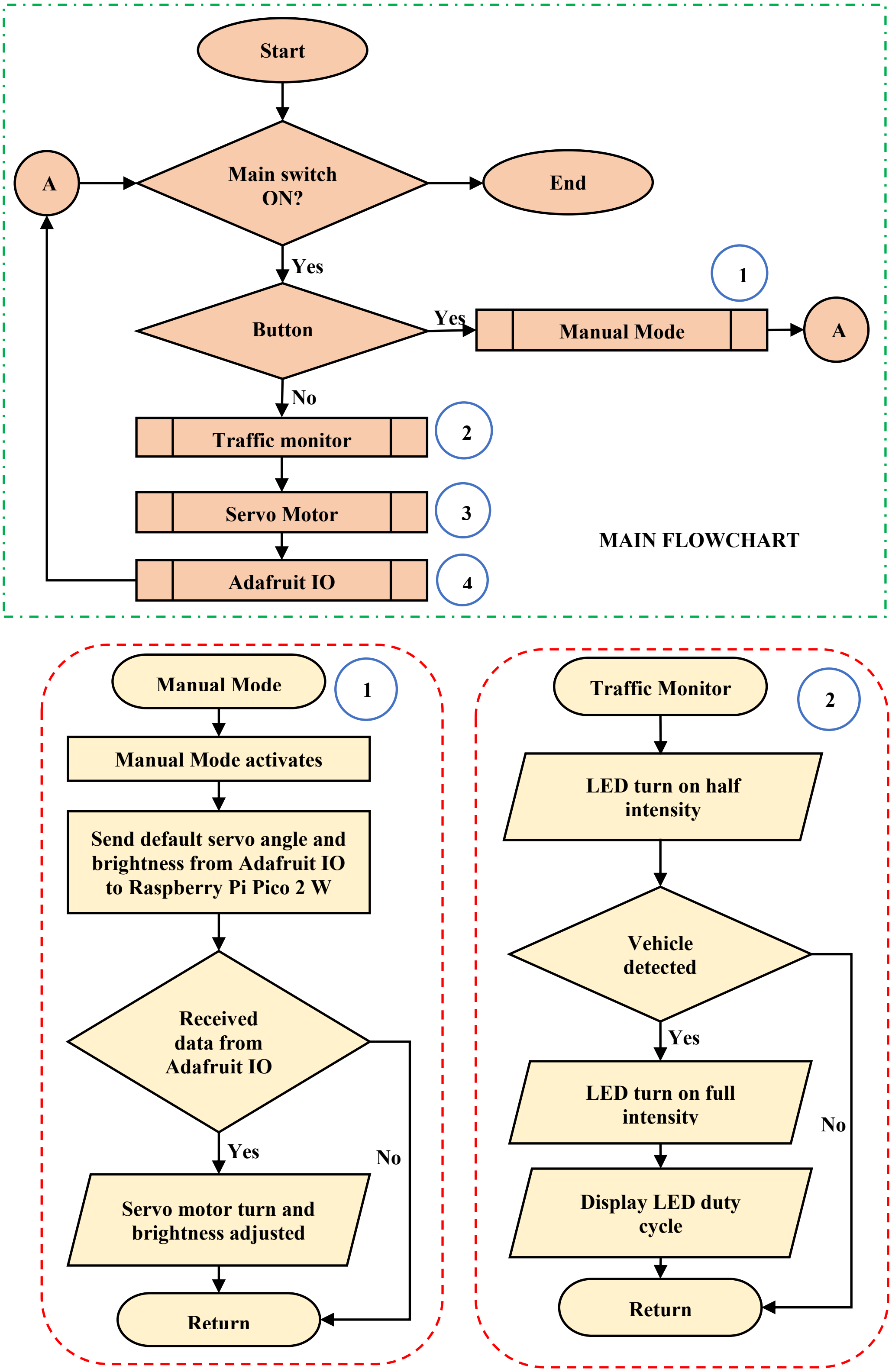


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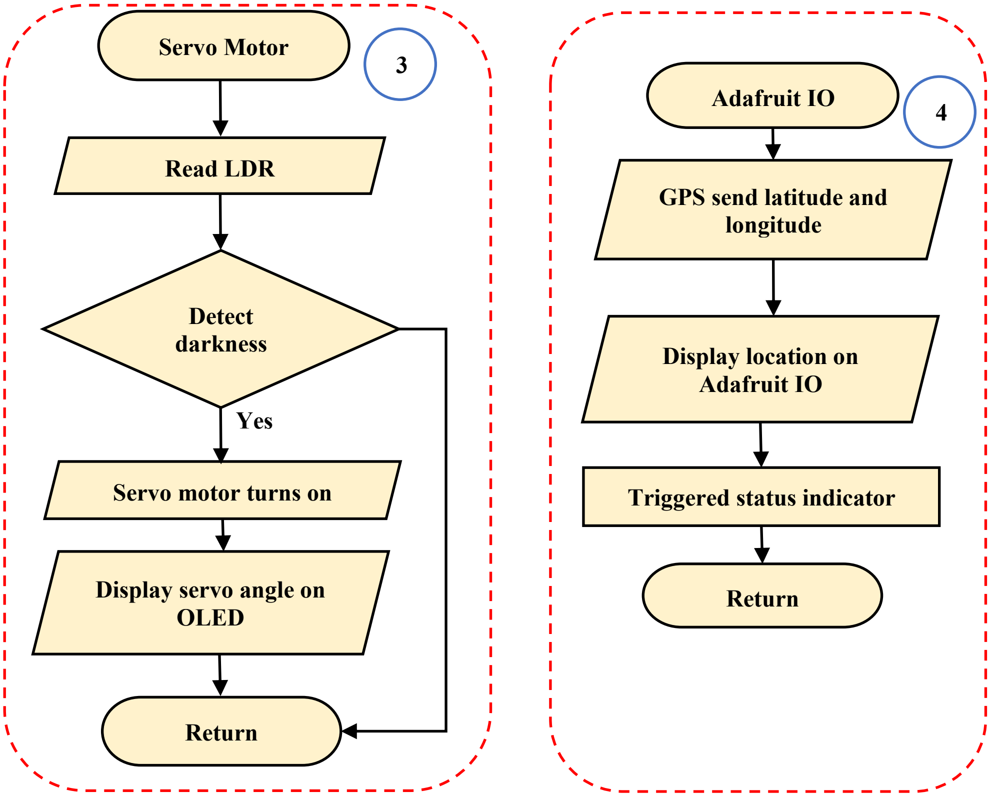


Fig. 2. Autonomous streetlight brightness and angle adjustment flowchart.

The fourth procedure, manual override via Adafruit IO, allowed users to remotely manage the streetlight system. The system generally operated in automatic mode; however, pressing a button on Adafruit IO activated the manual override, transitioning the system to manual mode. In this mode, Adafruit IO transmitted preset servo angles and LED brightness values to the Raspberry Pi Pico 2 W, allowing users to modify these parameters as desired. The system executed the customised values instantaneously. Once the manual adjustments were finalised, the process ended, and the system resumed automatic operation. This feature improved flexibility, enabling users to intervene during emergencies or exceptional situations while maintaining the system's overall efficiency.

## 4 RESULT AND DISCUSSION

The prototype development of this autonomous streetlight brightness and angle adjustment system was conducted using Proteus software to create the final PCB layout, as illustrated in Fig. 4.

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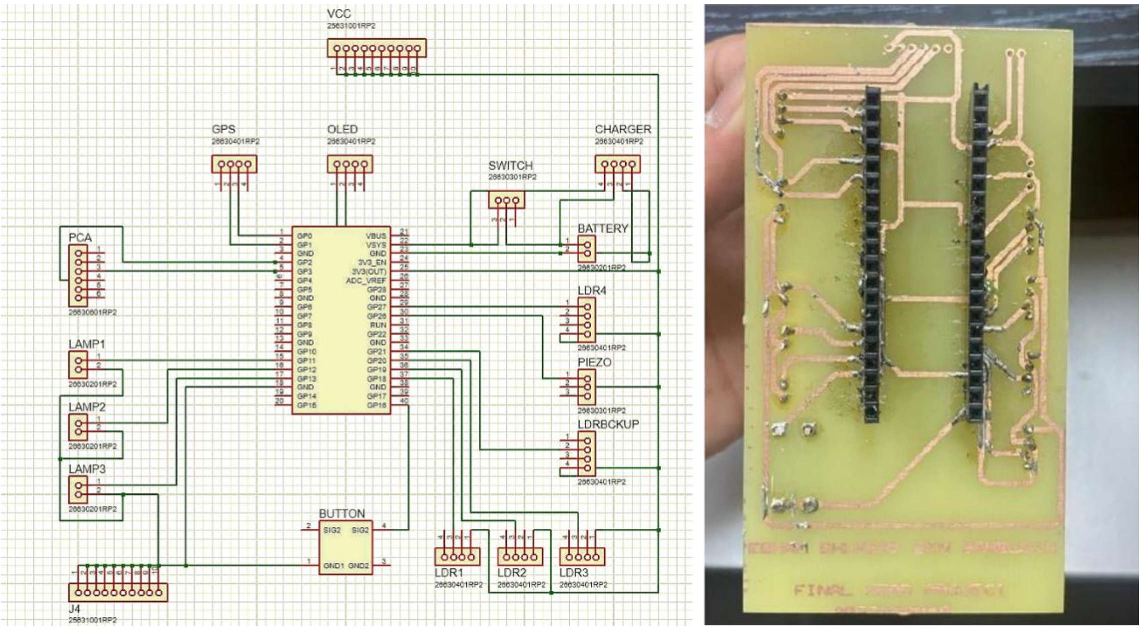
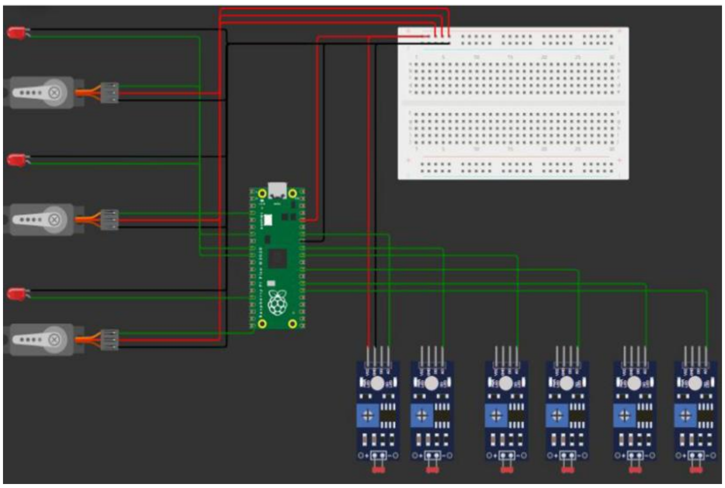



Fig. 4. Development of PCB layout using Proteus software.

Fig. 5 provides a visual representation of the simulation setup of the system and its initial operation. Fig. 5(a) shows the hardware connections of the Raspberry Pi Pico 2 W to the system components, while Fig. 5(b) illustrates the operation of the system during the initial simulation phase. This figure is essential for understanding how the system operates, particularly in terms of light detection, brightness adjustment, and angle control.



(a)

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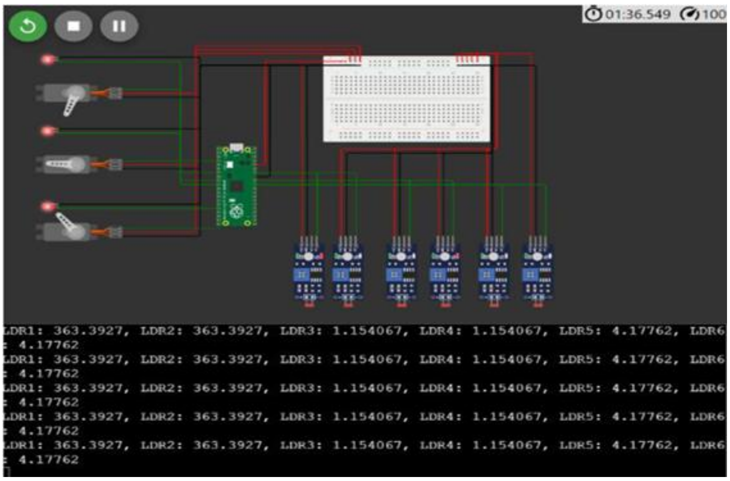


(b)

Fig. 5. Wokwi simulation. (a) Hardware connection in Wokwi. (b) Initial simulation in Wokwi.

Fig. 5(a) presents the hardware connections of the Raspberry Pi Pico 2 W microcontroller, which served as the central control unit for the system. It was connected to three servo motors, three LEDs (representing streetlights), and six LDR sensors. The LDR sensors were divided into two groups: three LDRs were used to control the brightness of the LEDs, while the other three LDRs were responsible for controlling the servo motors, which adjusted the angle of the streetlights. The integration of these components demonstrated the ability of the system to simultaneously detect and respond to environmental conditions. The LDR sensors measured ambient light levels, providing real-time data to the Raspberry Pi Pico 2 W. Based on this data, the system dynamically adjusted both the brightness of the LEDs and the angle of the streetlights to ensure optimal illumination. This dual functionality was a key feature of the system, as it allowed precise control over both light intensity and coverage, hence addressing the limitations of traditional streetlight systems.

Fig. 5(b) illustrates the operation of the system during the initial simulation phase. The simulation demonstrated how the system responded to low-light conditions by adjusting the brightness and angle of the streetlights. The three LDRs assigned to control the servo motors detected the dimly lit areas. When such area was detected, the system activated the servo motors to adjust the angle of the streetlights, directing illumination toward the area. This feature ensured that even in areas with inadequate or malfunctioning streetlights, sufficient illumination was provided to enhance road safety. Meanwhile, the other three LDRs, which controlled the brightness of the LEDs, detected the overall ambient light levels. When darkness was detected, they triggered an increase in the intensity of the LEDs, providing additional illumination to the area. This process worked in tandem with the angle adjustment, ensuring that both the brightness and coverage of the streetlights were optimised in real-time. The ability to adjust both brightness and angle concurrently was a significant improvement over traditional streetlight systems, which typically operated at fixed brightness levels and angles.

While the Wokwi simulation successfully demonstrated the ability of the system to adjust streetlight brightness and angle based on ambient light conditions, it is important to acknowledge that the piezoelectric sensor, a key component for vehicle detection, could not be integrated into the simulation due to platform limitations. This limitation, however, does not diminish the overall functionality or potential of the system, as the role of the piezoelectric sensor was validated through physical prototyping and testing outside the simulation environment. The Wokwi simulation platform, while highly effective for testing microcontroller-based systems, has certain limitations in terms of the components it can simulate.

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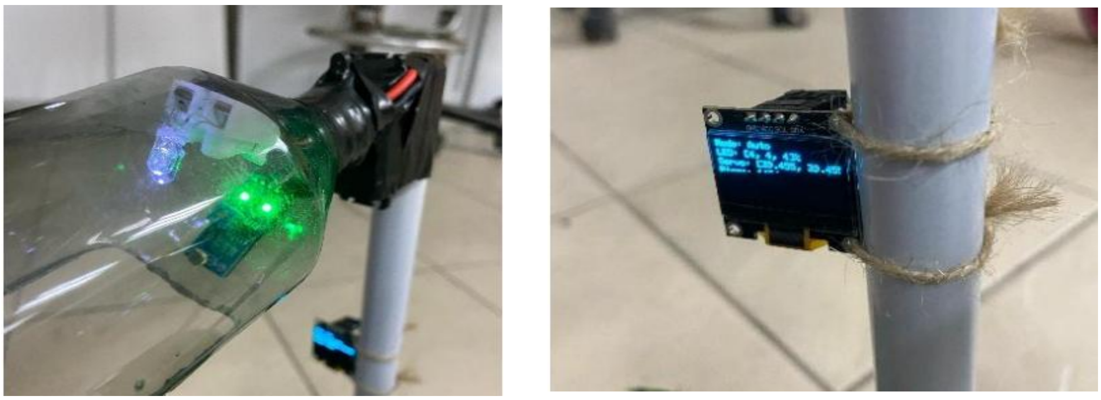
Specifically, it does not currently support the simulation of piezoelectric sensors, which depend on physical vibrations to generate signals. As a result, the simulation focused on validating the system's light detection and angle adjustment capabilities using LDR sensors and servo motors, which are fully supported by the platform.

To address the limitation of the Wokwi simulation, the functionality of the piezoelectric sensor was tested using the physical prototype. The results presented in Fig. 6 and Fig. 7 demonstrate the functionality of the Autonomous Streetlight Brightness and Angle Adjustment System. The OLED display provides real-time feedback on the system operation, including LED intensity, servo angle, and vehicle detection status. Servo angle adjustment is a critical feature of the system which ensures streetlights provide optimal illumination coverage, especially in areas with poor lighting or malfunctioning streetlights. The MG995 servo motors, controlled by the PCA9685 PWM driver, were able to precisely adjust the angle of the streetlights based on input from the LDR sensors. When the LDR sensors detected low ambient light levels, the servos re-positioned the streetlights to direct light toward the dark areas, thereby improving visibility and safety. The OLED display provided real-time feedback on the servo angle, showing the current angle of the streetlight. This feature allowed for easy monitoring and verification of the system's performance, ensuring that the servos were functioning as intended.

(a) (b)

Fig. 3. Full brightness mode. (a) Full brightness; (b) OLED display in full brightness.



(a) (b)

Fig. 4. Dim brightness mode. (a) Dim brightness: (b) OLED display in dim brightness.

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The LED full brightness mode was activated when the system detected the presence of a vehicle through the piezoelectric sensor. In this mode, the LEDs operated at maximum brightness to ensure optimal visibility for drivers and pedestrians. This feature is crucial for enhancing road safety, especially in low-traffic areas where vehicles are less frequent. The OLED display showed the LED intensity in real-time, indicating when the system entered full-brightness mode in response to vehicle detection. This provided clear feedback on the system's response to vehicle presence.

Meanwhile, the LED dim brightness mode was activated during periods of low traffic or when ambient light levels are sufficient. In this mode, the LEDs operated at half brightness, conserving energy while still providing adequate illumination for the surrounding area. This feature was particularly useful during late-night hours when traffic was minimal, or during twilight when natural light was present. The OLED display also provided real-time feedback on the LED intensity during dim mode, showing that the LEDs were operating at half brightness. This feature allowed for easy monitoring of the system's energy-saving mode, ensuring that the LEDs were functioning as intended. The vehicle detection status was another key feature of the system, which provided real-time feedback when a vehicle was detected by the piezoelectric sensor. The OLED display clearly indicated easy monitoring of the system's responsiveness to traffic conditions. The overall performance of the system is presented in Table 1.

Table 1. Summary of system performance based on real-time OLED display data

| Feature | Result | OLED Display Data | Implications |
|---|---|---|---|
| Servo angle adjustment | Precise and responsive angle adjustment based on LDR sensor input. | Displays current servo angle (e.g., 45°, 90°, etc.). | Improved illumination coverage in dark areas, enhanced safety, and energy efficiency. |
| LED full brightness | LEDs operate at full brightness upon vehicle detection. | Displays LED intensity at 100% and "Vehicle Detected" status. | Enhanced visibility for drivers, reduced risk of accidents, and optimized energy usage. |
| LED dim brightness | LEDs operate at half brightness during low traffic or sufficient ambient light. | Displays LED intensity at 4% and "No Vehicle Detected" status. | Significant energy savings, extended LED lifespan, and adaptability to environmental conditions. |
| Vehicle detection | Piezoelectric sensor accurately detects vehicle presence. | Displays "Vehicle Detected" or "No Vehicle Detected" status in real-time. | Real-time feedback ensures quick system response, enhancing road safety. |

In addition, the integration with Adafruit IO enabled the display of the angle adjustment alongside the location of the streetlight through the GPS module, as demonstrated in Fig. 8. The Adafruit IO interface provided a user-friendly dashboard that displayed critical data, including light intensity levels, servo motor angles, and GPS coordinates of the streetlights. This integration was a key feature of the system, as it enabled remote monitoring, fault detection, and maintenance coordination. The integration of the system with Adafruit IO represented a significant step forward in the development of smart urban infrastructure. By providing real-time monitoring, remote control, and fault detection capabilities, the system enhanced the efficiency and reliability of streetlight management. This not only improved road safety but also reduced operational costs by optimising energy usage and streamlining maintenance processes. The ability to remotely monitor and control streetlights was particularly valuable in large urban areas, where manual inspection and maintenance could be time-consuming and resource intensive.

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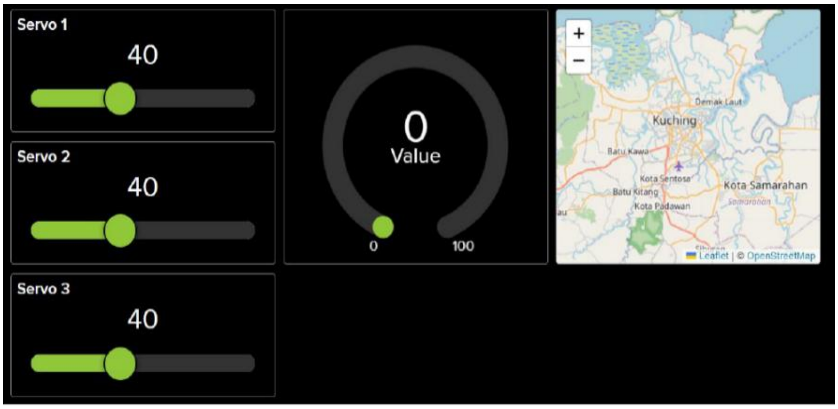


Fig. 5. Adafruit IO interface.

The final prototype of the system was presented in Fig. 9, showcasing the fully functional implementation of the Autonomous Streetlight Brightness and Angle Adjustment System. The prototype integrated all key components, including the Raspberry Pi Pico 2 W microcontroller, LDR sensors, piezoelectric sensors, MG995 servo motors, and LED streetlights, to demonstrate the system's ability to dynamically adjust brightness and angle based on real-time environmental and traffic conditions. The prototype successfully validated the system's core functionalities, such as adaptive brightness control, precise angle adjustment, and real-time vehicle detection, as well as its integration with IoT platforms like Adafruit IO for remote monitoring and control. This prototype served as a proof of concept, highlighting the potential of the system to enhance road safety, improve energy efficiency, and streamline maintenance processes in urban environments.

Fig. 6. Final prototype.

## 5 CONCLUSION

In conclusion, the prototype for an autonomous streetlight brightness and angle adjustment system successfully addressed the shortcomings of traditional street lighting, including energy inefficiency, limited bulb lifespan, and delayed maintenance. By using technologies such as the Raspberry Pi Pico 2 W, LDR sensors, IR sensors, and servo motors, the system demonstrated improved functionality, promoted road safety, and reduced energy usage. Incorporating Pulse Width Modulation (PWM) for brightness regulation

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and vibration sensing maximised energy efficiency, while the angle adjustment capability offered a temporary solution for dark zones caused by malfunctioning lights. Moreover, the integration of IoT facilitated instantaneous failure identification and accurate location tracking, optimising maintenance procedures and enhancing overall streetlight management.

The architecture of the system and functionality have been validated through simulation and testing on platforms like Proteus and Wokwi[20], proving its viability as a modern urban infrastructure solution. As a prototype, this project needs more testing to ensure long-term stability and dependability in real life. Long-term field testing should assess the system's performance in extreme weather, high traffic, and different metropolitan layouts. Scalability testing should also be carried out to determine its suitability for large-scale deployment. Addressing these issues will improve the system, enhance efficiency, and prepare it for widespread adoption.

## CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts, and declare the absence of conflicting interests with the funders.

## AUTHORS' CONTRIBUTIONS

Conceptualisation: E. S. Samsudin
Data curation: E. S. Samsudin
Methodology: E. S. Samsudin, M. F. Muhd Yusoff
Formal analysis: E. S. Samsudin
Visualization: E. S. Samsudin
Software: E. S. Samsudin
Writing (original draft): N. A. Abdul Rahman
Writing (review and editing): N. A. Abdul Rahman, H. Jumaat
Validation: M. F. Muhd Yusoff, H. Jumaat
Supervision: M. F. Muhd Yusoff
Funding acquisition: Not Applicable
Project administration: M. F. Muhd Yusoff, N. A. Abdul Rahman

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