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PROTOTYPE IoT-BASED AIRFIELD LIGHTING ON/OFF MONITORING SYSTEM (ALMOS) USING ESP32 MICROCONTROLLER

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Abstract

Airfield Lighting (AFL) systems play a crucial role in ensuring safe aircraft operations, particularly during low visibility, night operations, and adverse weather conditions; however, at Radin Inten II Lampung Airport, inspections are still conducted manually, relying on visual observation that often leads to delays in detecting lamp failures, longer maintenance times, and increased operational costs. This study aims to design and develop a prototype of an IoT-based Airfield Lighting On/Off Monitoring System (ALMOS) capable of real-time monitoring of AFL lamp status to improve maintenance efficiency and reliability. Using the Research and Development (R&D) method with a simplified Borg and Gall model, the prototype integrates the ACS712-30A current sensor to detect electrical flow, the Arduino Uno ATMega328P for initial data processing, and the Power Line Carrier Communication (PLCC) KQ330 module as a medium for transmitting data through existing power lines, while the ESP32 microcontroller receives and displays the data on a web-based monitoring interface. The experimental results show that ALMOS accurately detects current variations corresponding to on/off conditions and transmits data stably via PLCC and Wi-Fi networks, proving its effectiveness in real-time monitoring. The novelty of this research lies in the integration of IoT and PLCC technologies to simulate advanced systems like AGLAS into a simpler, low-cost, and educational prototype. This study contributes to airport engineering technology by providing a scalable reference model for developing automated AFL monitoring systems that enhance operational efficiency, minimize manual inspections, and serve as a practical learning medium for aviation technology students.

Keywords: *airfield lighting, current sensor ACS712, monitoring system, iot, microcontroller ESP32, power-line carrier communication.*

Introduction

Airfield Lighting (AFL) systems represent one of the most critical visual navigation aids in ensuring safe aircraft operations, especially during takeoff and landing phases under low-visibility conditions caused by night or adverse weather (Arya A. et al., 2020). According to *Annex 14 – Aerodromes* by the International Civil Aviation Organization (ICAO), the AFL system consists of a series of lighting units such as runway edge lights, taxiway edge lights, threshold and approach lights, and Precision Approach Path Indicators (PAPI), all designed to provide visual guidance for pilots (Putra et al., 2020). These systems play a vital role in maintaining visual orientation, ensuring smooth traffic flow, and reducing the risk of runway incursions and flight delays (Husaini et al., 2023; Wijaya, 2019).

The reliability of AFL infrastructure directly influences aviation safety and operational continuity, making its maintenance and monitoring an essential component of airside management (Susanto et al., 2020). According to the *Manual of Standard CASR Part 139* (KP 39/2015) and *SKEP/157/IX/03*, preventive maintenance of visual landing aids is a mandatory activity conducted daily by authorized airport technical units to ensure the functionality of all airfield lighting elements (Setyawan & Nafi, 2021). However, in practice, many Indonesian airports still rely on manual inspection methods involving physical observation and circuit-based control systems, which lack precise fault localization. This limitation often delays the detection of failures and leads to increased inspection time and operational costs (Salsabila, 2020).

Field observations at Radin Inten II Airport in Lampung reveal that the Electrical, Mechanical, and Equipment Facilities (EMEF) unit performs manual inspections by driving along the 3,000-meter runway and 450-meter approach area using maintenance vehicles to locate failed lamps. The process requires 24–45 minutes at night and up to 60 minutes during the day, depending on visibility conditions. Based on (Yusril et al. 2023), such manual operations not only consume significant time and fuel but also strain limited human resources, as only a few technical personnel are available per shift by Aerodrome Manual, These findings indicate the inefficiency and vulnerability of manual inspection systems, especially for large-scale airfields with extensive lighting networks.

Globally, automation and digitalization have become central to airport operation optimization (Sudjoko et al., 2021). Technologies such as the *Airfield Ground Lighting Automation System (AGLAS)*, developed by ADB safe-gate, have been implemented in several international airports to provide real-time monitoring and control of individual AFL units. Using Power Line Carrier Communication (PLCC) and Ethernet-based data transmission, AGLAS allows precise fault localization and centralized management via a computer dashboard (ADB Safegate, 2024). However, despite its advantages, AGLAS has not yet been adopted in Indonesian airports due to the high investment cost and the need for specialized infrastructure and personnel training (Simanjuntak et al., 2022).

This technological gap presents an opportunity to explore a more accessible, low-cost, and educational solution through the development of an IoT-based *Airfield Lighting On/Off Monitoring System (ALMOS)* prototype. Unlike previous studies—such as (Setyawan & Nafi 2021), who utilized GSM modules for fault notification, or (Nugroho 2021), who designed IoT-based mockups for educational purposes—IoT technology is chosen because it enables real-time monitoring, remote accessibility, and efficient data integration without requiring complex infrastructure (Herlina et al., 2022; Rizky et al., 2020; Sun et al., 2021). Accordingly, this research integrates IoT technology with PLCC-based communication to transmit current data representing the on/off status of each lamp. The prototype employs an ACS712-30A current sensor to detect electrical flow, an Arduino Uno ATMega328P for initial data processing (Gadekar et al., 2021), and an ESP32 microcontroller as a data receiver that visualizes information via a local web-based monitoring interface (Tran et al., 2024).

The main objective of this research is to design and develop a functional prototype that can simulate real-time AFL lamp monitoring using IoT and PLCC technologies (Yang et al., 2021). The system aims to provide an alternative monitoring approach that improves maintenance efficiency (Bahtiyar, 2020). reduces inspection time, and enhances operational reliability.

The urgency of this study is underscored by the increasing need for digital transformation within Indonesia's aviation infrastructure. Manual inspection systems are no longer sufficient to support modern safety and maintenance standards. The integration of IoT and PLCC in the ALMOS prototype provides a foundation for developing affordable automation solutions suitable for small to medium-sized airports that lack advanced systems like AGLAS. The novelty of this research lies in combining IoT-based sensor monitoring with PLCC transmission technology within a compact prototype framework. While previous works have relied primarily on GSM, Wi-Fi, or relay-based systems, this study successfully demonstrates the potential of PLCC to transmit monitoring data over existing power lines—eliminating the need for additional communication cables. This hybrid design not only reduces implementation costs but also enhances system scalability.

From a theoretical standpoint, the study extends the application of IoT technology in airport engineering and electrical systems by providing a model for real-time data acquisition and networked monitoring of distributed infrastructure (Lahna et al., 2023). Practically, the ALMOS prototype demonstrates a feasible and replicable approach for airport maintenance teams to monitor lighting systems more efficiently, reducing human workload and operational costs. It also offers an educational model that can be integrated into laboratory learning for students in aviation engineering programs. In conclusion, this research contributes to the advancement of airport engineering technology by introducing an innovative and cost-efficient IoT-based monitoring prototype for Airfield Lighting Systems. The ALMOS model bridges the technological gap between conventional manual inspection and high-cost automation systems, offering both academic and practical value. The system's design concept can serve as a scalable reference for future developments in smart airport infrastructure, supporting Indonesia's ongoing efforts to modernize its aviation maintenance systems and align with global safety and operational standards.

Methods

This study employed a Research and Development (R&D) design using a simplified Borg and Gall model, focusing on the stages of research, prototype design, expert validation, and functional testing (Sugiyono, 2022). The research approach combined qualitative and quantitative methods: the qualitative phase explored the operational characteristics of the AFL inspection process and system requirements, while the quantitative phase tested the prototype's technical performance, including current detection, data transmission, and monitoring accuracy.

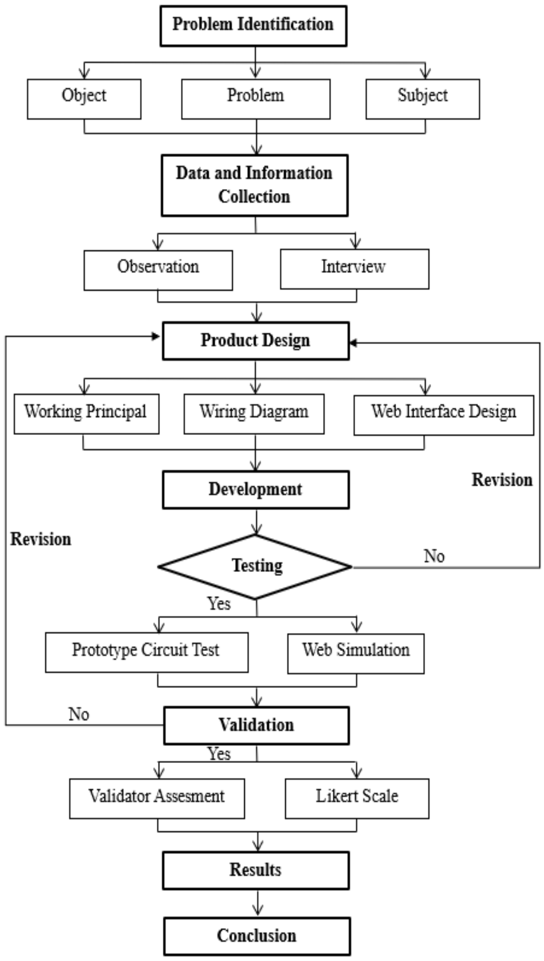


Figure 1. Research Flow Diagram

The object of the study was a prototype of the *ALMOS*, designed to simulate real-time monitoring of airfield lamps. The prototype consisted of a circuit equipped with an ACS712-30A current sensor to detect electrical flow, an Arduino Uno ATMega328P for signal processing, a PLCC KQ330 module for data transmission over existing power lines, and an ESP32 microcontroller for receiving and displaying monitoring data on a web-based interface. The sample circuit simulated three 150W halogen lamps (6.6A) representing runway edge lights typically found in airport lighting systems.

The research was conducted at the Laboratory of the Airport Engineering Technology Study Program, Palembang Aviation Polytechnic, from February to June 2024, with field data references obtained from the Electrical, Mechanical, and EMEF Unit at Radin Inten II Airport, Lampung, which performs manual inspection of AFL. Data collection techniques included: 1) Observation, to identify current inspection practices and limitations at Radin Inten II Airport; 2) Interviews, with technical personnel and academic experts to gather insights regarding system design and feasibility; 3) Documentation, using official references such as *Aerodrome Manual (2024)* and *CASR Part 139*; and 4) Prototype testing, involving measurement of current sensor accuracy, communication stability via PLCC, and real-time data transmission performance between transmitter and receiver modules.

Data analysis was carried out using descriptive qualitative interpretation supported by quantitative performance evaluation. Qualitative analysis interpreted system functions, performance behavior, and user responses during prototype testing, while quantitative analysis compared current sensor readings, voltage levels, and communication delays to determine the accuracy and reliability of the prototype.

To ensure data validity and reliability, two levels of validation were performed: 1) Expert validation (expert judgment) by lecturers and airport technicians, assessing circuit design, component configuration, and software interface; and 2) Functional validation, testing the system's capability to detect on/off status and the accuracy of data transmission through PLCC. Triangulation was applied by comparing interview results, prototype test data, and supporting documents to enhance data credibility.

Through this methodological process, both contextual (airport operational) and technical (system performance) aspects were comprehensively analyzed. The validated ALMOS prototype demonstrates how IoT and PLCC technologies can be effectively integrated into a low-cost, real-time airfield lighting monitoring system suitable for educational and operational applications in airport engineering.

Results and Discussions

The *Airfield Lighting On/Off Monitoring System (ALMOS)* prototype was designed to simulate real-time monitoring of Airfield Lighting (AFL) circuits through the integration of IoT and Power Line Carrier Communication (PLCC) technologies. The prototype comprised three main subsystems: 1) Sensor and transmitter circuit, consisting of an ACS712-30A current sensor connected to an Arduino Uno microcontroller that converts analog current signals into digital data; 2) Data communication circuit, utilizing the PLCC 12V KQ330 module to transmit data through the existing power line network; and 3) Receiver and monitoring circuit, employing an ESP32 microcontroller connected to a web-based localhost interface that displays the operational status of the lights in real time.

The simulation used three 150W/6.6A halogen lamps as representative loads for runway edge lights. The monitoring webpage displayed the lamp condition with a green indicator for ON and red indicator for OFF status. The overall configuration of the ALMOS prototype is shown in Figure 1, which illustrates the main components and data flow between the transmitter and receiver modules.

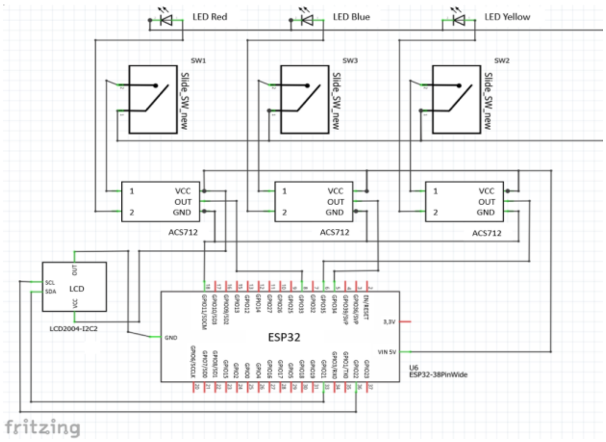
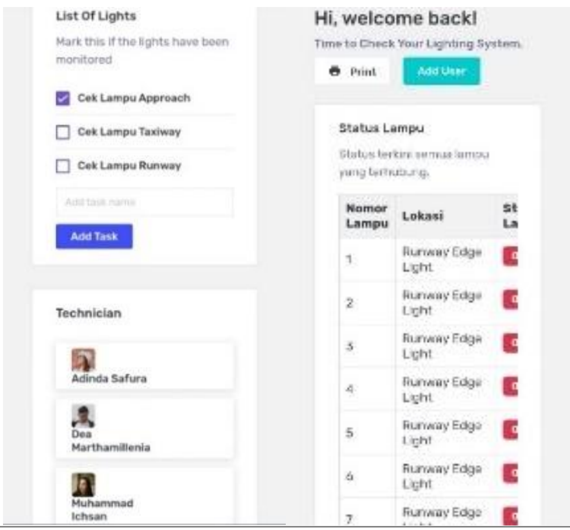
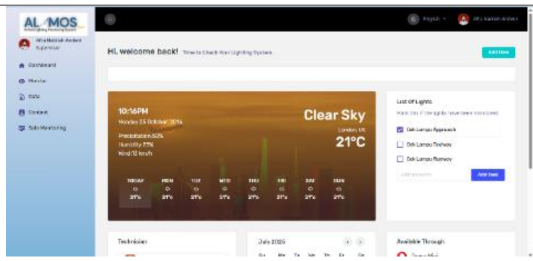


Figure 2. Wiring Diagram and Circuit Layout of the ALMOS Prototype

The system's circuit layout consisted of a power input connected to a series of halogen lamps representing AFL units. The current from each lamp was sensed by the ACS712-30A module, whose analog output was sent to the Arduino Uno. This Arduino was connected to a PLCC KQ330 transmitter module, which modulated the signal and injected it into the power line. At the receiver end, another PLCC KQ330 module decoded the signal and passed it to the ESP32 microcontroller, which then transmitted the processed data to a web-based monitoring dashboard accessible via local Wi-Fi. The ALMOS interface was develop using a web-based dashboard accessible via smartphones and PCs. Table 1. summarizes the main interface features.

Table 1. Visual Display of ALMOS

Smartphone View

Laptop/PC view

Dashboard The user enters the ALMOS main web page, which displays navigation buttons to various key features of the monitoring system.
Digital map Monitoring It shows a digital map of the lamp locations on the first prototype, complete with on/off status indicators represented by colors, lamp numbers, and positions.
Data (Monitoring Result) It also displays a table containing the lamp number, on/off status, current (A), as well as the date and time of monitoring. This data can be printed in PDF format for maintenance record purposes.

The monitoring dashboard displayed three virtual indicators corresponding to the three simulated lamps. Each indicator changed color dynamically: green represented a lamp in "ON" condition, and red indicated "OFF." The system refreshed automatically every 1–2 seconds, showing the real-time status of each circuit. The interface also contained textual status data (e.g., "Lamp 1: ON," "Lamp 2: OFF"), and the data were updated directly as current readings changed. This visualization successfully replicated a miniature version of commercial ALMOS used in modern airports.

Design validation was performed through expert assesments involving four validators: a field supervisor (AFL expert), an electrical technician, an instrumentation lecturer, and an IT specialist. Each validator assessed the prototype's functionality, realiability, usability, and compliance with operational needs using a Likert scale (1-5).

Table 2. Total Validation Assesment

Validators	**Score (%)**
Subject Expert	90
Field Technician	86
Tool Expert	88
Media Expert	92
Average	**89**

$$Feasibility\ Percent = \frac{356}{4}\ x\ 100\% = 89\%$$

Prototype testing focused on functional validation of the sensor, PLCC transmission stability, and web monitoring performance. Table 1 summarizes the measurement and observation data obtained during laboratory testing.

Tabel 1. Summary of ALMOS Prototype Test Result

No.	Test Parameter	Expected Condition	Observed Result	Remarks / Performance
1	Lamp ON (150W/6.6A) current reading	6.6 A	6.52 A – 6.58 A	Sensor accuracy ±1.2%
2	Lamp OFF current reading	0 A	0.02 A – 0.04 A	No false detection
3	PLCC data transmission success rate	≥ 95%	97.6% average	Stable within 15 m range
4	ESP32–Web data update delay	1 second	1.1 – 1.3 s	Acceptable for real-time display
5	Power supply stability	12 V ±5%	11.9 – 12.1 V	Stable
6	Web indicator response	Instant ON/OFF	< 2 s	Real-time status update successful

The results confirmed that the ALMOS system was able to detect current flow accurately using the ACS712 sensor, transmit data through power lines via PLCC, and display the lamp's operational status correctly on the web interface. The test results demonstrated that the ALMOS prototype operated effectively in detecting and transmitting real-time status of airfield lighting circuits. The ACS712 sensor accurately distinguished ON and OFF current conditions with minimal deviation, while the PLCC KQ330 module ensured stable data transmission through existing power lines without additional cables.

The ESP32-based web interface responded within approximately one second, confirming reliable synchronization between hardware and software. These outcomes indicate that IoT–PLCC integration can support simple yet effective automation for monitoring airfield lighting systems in laboratory or small-airport environments. The findings align with Setyawan and Nafi (2021) and Nugroho (2021), who emphasized the importance of IoT in airfield lighting automation. However, unlike previous designs that used GSM or Wi-Fi communication, this study employed PLCC, reducing wiring complexity and costs while maintaining accuracy. Additionally, the use of the ACS712 current sensor provides a reliable and low-cost method for detecting electrical current without requiring direct contact with high-voltage lines, ensuring operational safety and allowing precise monitoring of each lamp's on/off status. Compared to AGLAS by ADB Safegate, ALMOS offers a simplified educational alternative with practical applicability for low-budget or regional airports.

Academically, the ALMOS prototype provides a learning model for understanding IoT integration, data acquisition, and automation in airport electrical systems. Practically, it offers a low-cost monitoring method that enhances inspection efficiency, minimizes manual workload, and can be expanded into scalable real-world applications. The system's ability to operate through existing electrical lines demonstrates its potential for use in regional airports or educational facilities.

This study was limited to laboratory-scale testing under short-range (≤15 m) PLCC communication and simulated lighting loads. Environmental variables such as interference, voltage fluctuations, and large-scale runway circuits were not evaluated. Additionally, circuit disconnection was used to simulate faults rather than testing with actual field sensors, restricting direct generalization to operational environments. Overall, the ALMOS prototype successfully integrated IoT and PLCC technologies to achieve real-time airfield lighting monitoring without additional wiring. The system demonstrated stable performance and communication reliability, validating the feasibility of low-cost automation for airport lighting systems. These results suggest that ALMOS can serve as a reference model for smart airport technology, bridging the gap between manual inspection and advanced automation systems while contributing to academic learning and practical airport maintenance innovation.

Conclusion

This research successfully designed and developed a prototype of an IoT-based Airfield Lighting On/Off Monitoring System (ALMOS) integrated with Power Line Carrier Communication (PLCC) to support real-time monitoring of airfield lighting circuits. The experimental results demonstrate that the ACS712-30A current sensor was able to accurately distinguish ON and OFF conditions of simulated airfield lamps with minimal deviation, while the PLCC KQ330 module provided stable data transmission through existing power lines without requiring additional communication infrastructure. Furthermore, the ESP32-based web interface effectively visualized lamp status in near real time, confirming reliable synchronization between sensing, communication, and monitoring components. From an operational perspective, the ALMOS prototype shows strong potential to improve the efficiency of airfield lighting maintenance by reducing dependence on manual inspections, minimizing inspection time, and enabling faster identification of lamp failures. Compared to conventional manual inspection methods and high-cost commercial systems such as AGLAS, ALMOS offers a simpler, low-cost, and scalable alternative that is particularly suitable for small to medium-sized airports as well as educational and training environments. From an academic standpoint, this study contributes to the application of IoT and PLCC technologies in airport engineering by providing a practical reference model for integrating sensor-based monitoring, power-line communication, and web-based visualization. The prototype can also be utilized as a learning medium for aviation engineering students to better understand automation concepts in airfield electrical systems. Despite its promising performance, this study was limited to laboratory-scale testing with short-range PLCC communication and simulated lighting loads. Environmental factors such as electromagnetic interference, voltage fluctuations, long-distance runway circuits, and real operational conditions were not evaluated. Therefore, future research is recommended to implement the system in actual airport environments, expand it to multi-node and multi-circuit monitoring, integrate data logging and maintenance management features, and assess long-term reliability. Overall, the ALMOS prototype provides a valuable and cost-effective reference for the development of smart airfield lighting monitoring systems and supports ongoing digital transformation in airport maintenance and safety management.

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