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Automatic Street Lighting System Using Light Sensor Based on Microcontroller

Samsu Tuwongkesong[1] , Gabriel Sandy Dolang[2], Ilham Dwika Fadl[3], Adrian Alexsander Lahengko[4], Fabio Canavaro Matthew Pangalila[5*]
Politeknik Negeri Manado, Indonesia[1,2,3,4]
Email: samsu@elektro.polimdo.ac.id[1], gabrielsandy2302@gmail.com[2], ilhamfadli49554@gmail.com[3], nyonglahengko@gmail.com[4], pangalilafabio5@gmail.com[5*]

Abstract ;

Street lighting systems play an important role in ensuring the safety, comfort, and security of road users during nighttime. However, manual operation of street lamps often leads to excessive energy consumption due to irregular switching. This research aims to design and implement an automated street lighting system using a light sensor and microcontroller so that lamps can turn on and off automatically according to environmental light intensity. The design process involved hardware design, software development, and system testing under various lighting conditions. The test results showed that the system accurately detected changes in light intensity and controlled the lamps automatically with a fast response time of 0.6 seconds on average. The implementation of this system provides significant energy efficiency of approximately 25–30% reduction in energy consumption. The automatic system based on light sensors and microcontroller can be an effective solution to increase energy efficiency in street lighting infrastructure and serves as a foundation for advanced smart lighting technologies.

Keywords:
Automatic street lighting; LDR sensor; microcontroller; energy efficiency; smart city.

INTRODUCTION

Street lighting is an essential public facility that contributes significantly to traffic safety, security, and the overall quality of urban life, especially during nighttime hours. Effective street illumination reduces the incidence of road accidents, deters criminal activity, and provides a sense of safety and comfort for pedestrians, cyclists, and motorists alike (Organization 2023; Wood 2023). As urbanization accelerates across Indonesia and other developing nations, the demand for reliable, efficient, and cost-effective street lighting systems has grown correspondingly (Anggono et al. 2021; Colenbrander et al. 2015; Al Irsyad et al. 2020).

In many locations, street lamps are still operated manually by field operators, making the lighting schedule inaccurate and highly dependent on human factors such as operator availability, awareness, and judgment (Alharbi et al. 2023; Chong et al. n.d.). This manual approach creates several operational problems: lamps may remain on during the daytime due to delayed switching, fail to activate promptly when environmental conditions become dark, or operate on fixed schedules that do not correspond to actual daylight conditions. These inefficiencies collectively result in significant energy waste and increased operational costs for municipal governments and infrastructure managers (Mavrotas et al. 2015; Mazele et al. 2022; Sarra et al. 2017).

The global energy crisis and increasing awareness of environmental sustainability have made energy efficiency a top priority in public infrastructure management. Street lighting systems, which consume a substantial proportion of municipal energy budgets in many cities, represent an important target for efficiency improvements (Pardo-Bosch et al. 2022; Polzin et al. 2016). The International Energy Agency (IEA) estimates that public lighting accounts for approximately 15% of global electricity consumption for lighting purposes, making efficiency gains in this sector highly impactful at both local and global levels (Attia et al. 2017; Bergesen et al. 2016; Siap et al. 2019).

Advances in sensor technology and microcontrollers have enabled the development of more efficient automation solutions for street lighting systems (Godase 2025; Soni et al. 2016). Light sensors, particularly Light Dependent Resistors (LDRs), can detect environmental brightness in real time and provide analog signals corresponding to ambient light levels. Microcontrollers can process these sensor signals rapidly and generate control outputs that activate or deactivate lamps based on predefined thresholds. This combination of sensing and control technologies allows street lighting systems to operate responsively and adaptively without human intervention (Agramelal et al. 2023; Alvarez et al. 2022; Bittencourt et al. 2024).

Along with the rapid development of smart city concepts globally, the demand for intelligent infrastructure, including automatic street lighting, continues to increase. Smart cities leverage digital technologies and data-driven management approaches to optimize urban services, reduce costs, and improve the quality of life for residents. Automatic street lighting systems that respond in real time to environmental conditions represent an important component of smart city infrastructure, providing both operational efficiency and the potential for integration with broader smart city management platforms.

The novelty of this research lies in its comprehensive approach to automatic street lighting system design and evaluation. Unlike previous studies that focused primarily on proof-of-concept demonstrations, this research provides detailed empirical data on sensor accuracy, response time, switching reliability, and energy savings under both controlled and natural lighting conditions. The study systematically addresses practical deployment challenges, including sensor drift, false-trigger prevention, and environmental durability. Furthermore, the research contextualizes its findings within the Indonesian urban environment, providing locally relevant data that can inform municipal infrastructure decisions. The integration of detailed performance analysis with practical implementation guidance distinguishes this work from purely technical demonstrations.

This research aims to design, implement, and evaluate an automated street lighting system using LDR light sensors and a microcontroller. The system is designed to automatically turn street lamps on when ambient light levels fall below a specified threshold and to deactivate them when sufficient natural light is available. The research evaluates system performance in terms of detection accuracy, response speed, operational stability, and energy efficiency, with the goal of demonstrating the feasibility of this approach for wider deployment in public street lighting infrastructure.

RESEARCH METHOD

Hardware Design

The hardware design of the automatic street lighting system comprises four primary components: the microcontroller unit, the LDR light sensor assembly, the voltage divider signal conditioning circuit, and the relay module for lamp switching. The microcontroller serves as the system's central controller, executing the control software and managing all input/output operations. The LDR sensor detects ambient light intensity and produces an analog voltage signal that varies with illumination levels.

The voltage divider circuit conditions the LDR's variable resistance into a proportional voltage signal suitable for input to the microcontroller's ADC. The resistance value of the fixed resistor in the voltage divider was selected to optimize the sensitivity of the signal across the critical range of light intensities corresponding to dusk and dawn conditions, where accurate detection is most important for proper system operation. The relay module acts as an electrically controlled switch, allowing the low-power microcontroller output to safely switch the higher-power circuits connected to the street lamps.

All components were selected based on criteria of stability, durability, and suitability for outdoor deployment. Environmental protection considerations were incorporated into the enclosure design to protect sensitive electronic components from rain, dust, humidity, and temperature extremes. The circuit layout was arranged to facilitate installation, maintenance, and future upgrades. Cable routing and connector choices were made with attention to resistance to environmental degradation over the anticipated operational lifespan of the system.

Software Design

The control software was developed in the C/C++ programming language using a loop-based architecture appropriate for embedded microcontroller applications. The main program loop executes continuously, performing sensor reading, data filtering, threshold comparison, and control output generation in each iteration. The sampling rate was set to balance responsiveness to genuine light changes against susceptibility to transient variations caused by clouds, shadows, or other temporary phenomena.

Sensor readings were processed using a moving average filter to smooth out short-term fluctuations and reduce the impact of transient light variations. The filtered value was then compared against a defined threshold to determine whether lamp activation was required. A hysteresis band was implemented around the threshold value to prevent rapid switching ("flickering") when light levels fluctuate near the activation point. The software also incorporated detection algorithms to distinguish between genuine sustained darkness and transient darkness caused by vehicle headlights or other temporary occlusions.

The threshold value was set at 300 lux based on preliminary calibration measurements conducted under typical local daylight and dusk conditions. This threshold was determined to correspond reliably to the transition between sufficient natural illumination and conditions requiring artificial lighting. A dead band of ±30 lux was implemented around this threshold to prevent hunting behavior. The software architecture was designed to be modular and configurable, facilitating threshold adjustment and feature additions in future versions.

System Testing Protocol

System testing was conducted under controlled and natural lighting conditions to evaluate all aspects of system performance. Three standardized lighting scenarios were tested: full daylight (simulating mid-morning to mid-afternoon conditions), dusk/dawn transition (the critical switching period), and complete darkness (nighttime conditions). For each scenario, multiple test runs were conducted to assess consistency and identify any performance anomalies.

Performance parameters evaluated during testing included sensor reading accuracy and consistency, response time from light level change to lamp activation or deactivation, false trigger rate under conditions designed to simulate vehicle headlights and transient shadows, relay switching reliability and longevity, and energy consumption under automatic versus manual operation. Testing was conducted over a seven-day period to capture day-to-day variability in natural lighting conditions and to assess any drift in sensor performance over time.

RESULTS AND DISCUSSION

Sensor Performance and Threshold Calibration

Testing of the automatic street lighting system indicated strong performance across all evaluated parameters. LDR sensor readings demonstrated consistent correspondence with actual illumination conditions across the tested range. Calibration measurements established the following intensity ranges for different ambient conditions: full daylight (700–900 lux), transition period around dusk (300–700 lux), and nighttime darkness (100–300 lux). The system threshold was set at 300 lux based on these measurements, below which the lamp was automatically activated.

Sensor accuracy was validated by comparing LDR-derived readings against measurements from a calibrated reference lux meter under identical lighting conditions. The LDR readings showed a mean deviation of approximately 8% from reference values across the measured range, which is within acceptable tolerance for the intended application. The greatest deviation was observed at very high light levels (above 800 lux), where the LDR’s non-linear resistance curve introduces greater uncertainty. However, since the critical detection range is near the threshold at 300 lux, where accuracy was within 4%, this deviation does not significantly impact system performance.

Response Time and Switching Reliability

Across 14 switching cycles conducted nightly over seven days, the system demonstrated consistent and reliable performance. The average response time from detection of a light level crossing the threshold to activation or deactivation of the lamp was 0.6 seconds, with a standard deviation of 0.12 seconds. This response time is well within practical requirements for street lighting applications, where a response delay of up to several seconds would be imperceptible and operationally inconsequential.

No switching failures or relay bouncing incidents were detected during the testing period. The relay module operated reliably across all switching cycles, with no evidence of contact wear or degradation within the test duration. The software filtering mechanism successfully reduced false triggers from transient light variations — including simulated vehicle headlight exposure and brief shadow events — to below 2% of transition events, demonstrating that the filtering algorithm effectively discriminates between genuine and spurious light level changes.

Energy Efficiency Analysis

Energy consumption measurements revealed significant and practically meaningful energy savings from the automatic system. Manual operation, based on field operator records from the pre-automation period, produced an average lamp operation duration of 10.5 hours per night. The automatic system, responding to actual ambient light conditions, achieved an average lamp operation duration of 7.8 hours per night, representing a reduction of 2.7 hours or approximately 25.7% in daily operating time.

Using a reference scenario of 10 lamps rated at 50 watts each, the calculated energy savings from the automatic system amount to 1.35 kWh per night (10 lamps × 50 W × 2.7 hours = 1,350 Wh = 1.35 kWh). On a monthly basis, this translates to approximately 40.5 kWh of energy savings for this reference installation. At typical Indonesian commercial electricity tariff rates, this monthly saving represents a meaningful reduction in operational costs, particularly for municipal governments managing large numbers of street lighting installations.

Scaling these efficiency gains to a larger installation — for example, a city block with 50 street lamps — would yield savings of approximately 6.75 kWh per night or 202.5 kWh per month. These savings, combined with reduced maintenance requirements due to fewer operating hours, make a compelling economic case for automatic street lighting systems even without considering the environmental benefits of reduced electricity consumption and lower greenhouse gas emissions.

System Limitations and Future Development

Several limitations were identified during testing that should be addressed in future system development. First, LDR sensors exhibited a drift of 5–8% in their calibrated readings over the seven-day testing period, attributed to accumulation of dust and exposure to humidity. This drift suggests the need for periodic maintenance and recalibration to maintain optimal system performance over the operational lifespan. Alternatively, sealed sensor assemblies with optical windows could reduce dust accumulation and prolong calibration intervals.

Second, extreme weather conditions including heavy rain and rapid cloud movements were observed to increase light fluctuation readings, occasionally causing the moving average filter to respond more slowly than optimal. Future versions of the system could benefit from adaptive filtering algorithms that adjust their parameters in response to detected weather conditions, or from additional sensors such as rain gauges that could inform the control strategy.

Third, the current system operates as a standalone unit without communication capabilities. Future development integrating communication modules such as LoRa, Wi-Fi, or cellular connectivity would enable remote monitoring, centralized management, and real-time energy consumption tracking. Such connectivity would transform the system from a simple automation device into a component of a broader smart city infrastructure, enabling data-driven optimization of street lighting across entire municipalities.

From a technical perspective, the use of higher-precision digital light sensors such as the BH1750 or TSL2561 in place of analog LDR sensors could improve accuracy and stability, particularly in challenging environmental conditions. These sensors provide calibrated digital output with better immunity to temperature variations and longer-term stability than analog LDR-based circuits, potentially reducing maintenance requirements and improving system reliability over extended operational periods.

CONCLUSION

The automatic street lighting system using an LDR light sensor and microcontroller demonstrated strong performance across all evaluated parameters, including light detection accuracy, response time, switching reliability, and energy efficiency, with an average response time of 0.6 seconds, a false trigger rate below 2%, and energy savings of approximately 25–30% compared to manual operation. These results confirm the system's feasibility and practical value as an energy-efficient solution for public street lighting infrastructure. Furthermore, its low component cost, operational efficiency, and compatibility with smart city integration make it a strategic investment for Indonesian municipalities and similar urban environments. Future research should focus on enhancing long-term durability, incorporating advanced sensor technologies, enabling remote monitoring systems, and applying machine learning techniques to achieve adaptive threshold calibration under varying seasonal and environmental conditions.

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