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Design and Experimental Analysis of an Arduino-Based IOT Smart Street-Lighting System with Adaptive Brightness Control

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Abstract: ***Conventional street-lighting systems may operate at a fixed output level or rely on time-based switching, leading to unnecessary energy use when ambient light is sufficient or road-user activity is low. This paper proposes a low-cost Arduino-based Internet of Things (IoT) street-lighting prototype combining ambient-light sensing, motion detection, adaptive brightness control, and remote monitoring. An LDR measures ambient illumination, while a passive infrared (PIR) sensor detects motion near the lighting zone. An Arduino Uno applies a three-state strategy: OFF during daylight, DIM during darkness without recent motion, and BRIGHT when motion is detected. An ESP8266 Wi-Fi module sends sensor readings and lamp status to an IoT dashboard. A repeatable experimental protocol is defined to evaluate response time, sensor behaviour, communication reliability, power consumption, and energy savings against an always-on full-brightness baseline. Since prototype measurements have not been supplied, quantitative results are intentionally left for completion after testing. The work is intended as a reproducible educational and small-scale research platform.***

Index Terms: ***Arduino Uno, Internet of Things, smart street lighting, adaptive brightness, LDR, PIR sensor, ESP8266, energy efficiency.***

I. INTRODUCTION

Street lighting supports road visibility and pedestrian safety, but fixed-output operation may consume energy even when full illumination is unnecessary. Combining ambient-light sensing with motion detection enables the lamp output to respond to operating conditions. IoT connectivity adds remote monitoring, event logging, and maintenance visibility. Low-cost microcontroller platforms provide accessible tools for prototyping these functions.

Prior work has investigated Arduino- and ESP8266-based street-light automation, motion-aware intensity regulation, and networked lighting management [1]–[5]. Because the general concept is already established, a credible contribution should emphasize a transparent experimental protocol, comparative energy measurements, repeatability, and limitations rather than claiming novelty from sensor integration alone. The objective of this work is to design and evaluate a prototype that adjusts brightness according to ambient illumination and motion while reporting measured energy use and operational performance.

II. OBJECTIVES AND PROPOSED CONTRIBUTION

1) Integrate an Arduino Uno, LDR, PIR sensor, PWM-compatible LED driver, and ESP8266 Wi-Fi connectivity.
2) Implement OFF, DIM, and BRIGHT control states using ambient-light gating and motion-based activation.
3) Log sensor values, control state, lamp output, and communication status through an IoT dashboard.
4) Compare energy consumption against an always-on full-brightness baseline using the same test duration and activity sequence.
5) Measure response time, motion-detection performance, false triggers, communication reliability, and repeatability.

III. RELATED WORK

An IEEE conference paper describes a solar-powered smart street-lighting system using NodeMCU/ESP8266, LDR, and motion sensing [1]. Other work explores Arduino-based automatic intensity regulation with ambient-light and motion sensors [2]. An IoT street-light control study describes dimming in the absence of traffic and remote status reporting [3]. More recent research examines LoRaWAN for longer-range monitoring [5]. These studies inform component selection and evaluation metrics. The present manuscript emphasizes a repeatable comparison against a defined full-brightness baseline. A novelty claim should be made only after a broader literature review and direct comparison with current studies.

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IV. PROPOSED SYSTEM ARCHITECTURE

The system contains a sensing layer, local control layer, lighting actuation layer, and IoT monitoring layer. The LDR supplies an analog ambient-light reading and the PIR supplies a digital motion signal. The Arduino filters readings, applies threshold and hold-time logic, and generates a PWM command for a low-voltage LED demonstration load. The ESP8266 forwards telemetry to a cloud or local server. The dashboard displays ambient-light values, motion events, control state, and lamp status. The overall architecture is shown in Fig. 1.

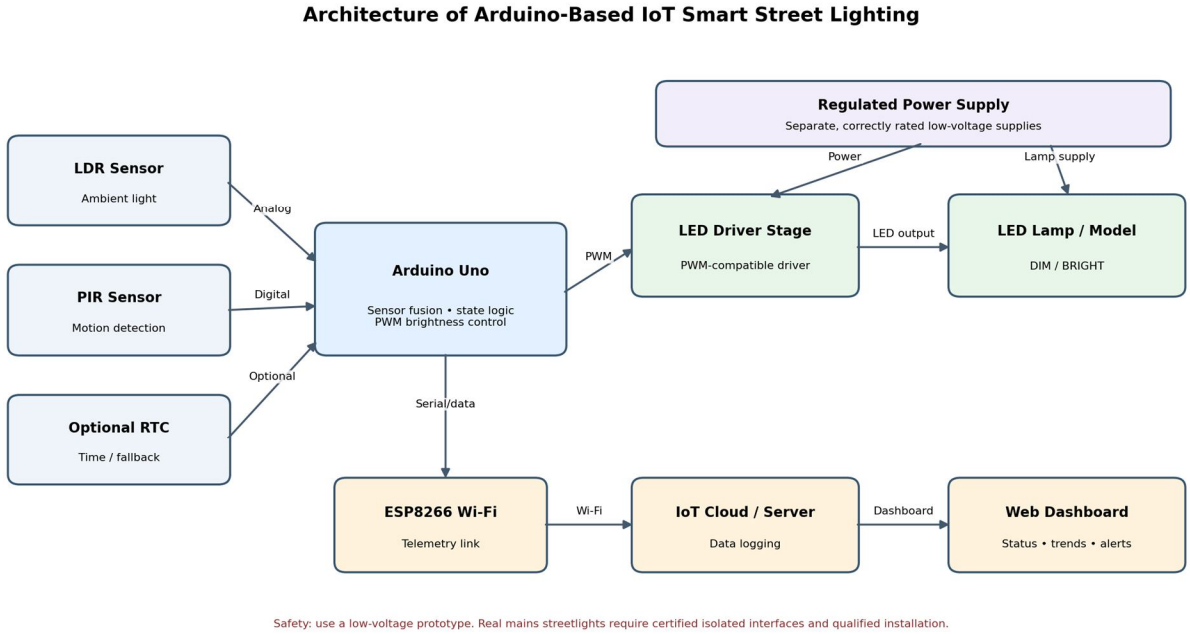


Fig. 1 Proposed architecture of the Arduino-based IoT smart street-lighting system

A. Hardware Components

The hardware components of the prototype, their functions and the main design considerations are listed in Table 1.

Table 1 Hardware components and design notes

Component	Function	Design note
Arduino Uno	Local processing and PWM control	Confirm selected PWM pin and timer requirements.
LDR + voltage divider	Ambient-light measurement	Calibrate threshold and add hysteresis.
PIR sensor	Motion detection	Tune sensitivity and hold time; placement affects detection.
ESP8266 Wi-Fi	Telemetry	Use 3.3 V logic and suitable power/level shifting.
PWM-compatible LED driver	Lamp intensity control	Match driver to LED current and voltage.
IoT dashboard/server	Data logging and monitoring	Use authenticated communication; protect credentials.
Regulated supply	Power controller and lamp	Use properly rated and protected supplies.

B. Control Strategy

Daylight gating prevents unnecessary lamp activation. If ambient light is above the calibrated daylight threshold, the output is OFF. At night, the output is DIM when no motion has been detected during the configured hold interval. When motion is detected, the output becomes BRIGHT for a defined hold period before returning to DIM. Hysteresis around the light threshold helps prevent rapid toggling near dusk and dawn.

The resulting control states are summarised in Table 2. The PWM values shown are illustrative and must be calibrated for the selected LED and driver.

Table 2 Control states and illustrative PWM values

Ambient condition	Motion	State	Illustrative PWM
Daylight	Any	OFF	0
Dark	No recent motion	DIM	80/255 (~31%)
Dark	Motion / hold timer active	BRIGHT	255/255 (100%)

PWM duty cycle is not necessarily proportional to luminous output. Measure illuminance with a lux meter if available.

V. EXPERIMENTAL METHODOLOGY

A. *Prototype and Test Environment*

Construct a low-voltage scaled street-light model using an LED or LED strip and a suitable PWM driver. Place the LDR so it measures ambient light without being strongly affected by the controlled lamp. Position the PIR sensor to cover the test path. Connect the ESP8266 to Wi-Fi and configure a dashboard/server endpoint for timestamped telemetry. Measure lamp electrical power with a suitable power meter or calibrated voltage/current setup.

Safety: never connect a mains streetlight directly to Arduino pins or an unisolated hobby circuit. A real streetlight installation requires a certified, correctly rated isolated interface and qualified electrical installation. Low-voltage testing is sufficient for the proposed experiments.

B. *Test Scenarios*

1) Daylight: vary ambient illumination above the threshold and verify OFF state.
2) Night without motion: ambient light below threshold, detection zone clear; verify DIM state.
3) Night with motion: introduce a moving target and measure detection-to-BRIGHT response time.
4) Motion stops: measure hold time and return-to-DIM delay.
5) Threshold stability: vary light near the threshold and check for unwanted rapid switching.
6) Network disruption: disconnect Wi-Fi and verify local lighting control continues.
7) Repeatability: conduct at least 20 motion-response trials and record failures as well as successes.

C. *Evaluation Metrics*

Record mean and maximum response time, successful motion detections divided by test events, false triggers per hour, telemetry delivery ratio, mean power in each state, and total energy over a fixed period. Compare adaptive operation with the same lamp running at full brightness for the same duration and activity sequence. Energy is calculated using (1):

$$E = \Sigma(P_i \times t_i) / 1000 \quad (1)$$

where E is energy in kWh, P_i is measured power in watts in state i, and t_i is time in hours. The energy saving is calculated using (2):

$$\text{Energy saving (\%)} = [(E_baseline - E_adaptive) / E_baseline] \times 100 \quad (2)$$

Measure actual power in each state; do not assume power is linear with PWM duty cycle. State whether results come from a scaled low-voltage prototype or a full-size installation.

VI. RESULTS AND DISCUSSION

No measured results are asserted in this draft. Populate Table 3 from the test log, include the number of trials and measurement uncertainty where possible, and discuss unsuccessful events as well as successful operation.

Table 3 Comparison of baseline and adaptive operation (to be completed after testing)

Metric	Baseline	Adaptive system	Measured result / notes
Average lamp power (W)	Measure	Measure	[Insert]
Energy over fixed test period	Calculate	Calculate	[Insert]
Motion response time (s)	N/A	Measure	[Mean / max / sample count]
Detection success (%)	N/A	Measure	[Insert]
False triggers per hour	N/A	Measure	[Insert]
Telemetry delivery ratio (%)	N/A	Measure	[Insert]

Discuss the measured energy difference under identical test schedules. Include limitations such as PIR placement, LDR calibration, network coverage, and differences between a laboratory LED and outdoor streetlighting.

VII. LIMITATIONS

1) PIR sensors can miss slow or stationary targets and performance depends on placement and thermal conditions.
2) LDR readings vary with tolerance, mounting, weather, and light from the controlled lamp.
3) Wi-Fi may not suit all municipal deployments; longer-range or wired communication may be needed.
4) A prototype does not establish compliance with outdoor lighting standards, ingress protection, electrical safety, or cybersecurity requirements.
5) Energy savings depend on traffic patterns, dim level, hold time, driver efficiency, and the baseline definition.

VIII. CONCLUSION

This paper proposes an Arduino-based IoT smart street-lighting system combining ambient-light sensing, PIR motion detection, state-based brightness control, and ESP8266 remote monitoring. The experimental protocol defines a comparison with an always-on full-brightness baseline and measures energy use, response time, detection performance, and telemetry reliability. Quantitative conclusions should be added only after the prototype has been tested and the data checked.

IX. ACKNOWLEDGMENT

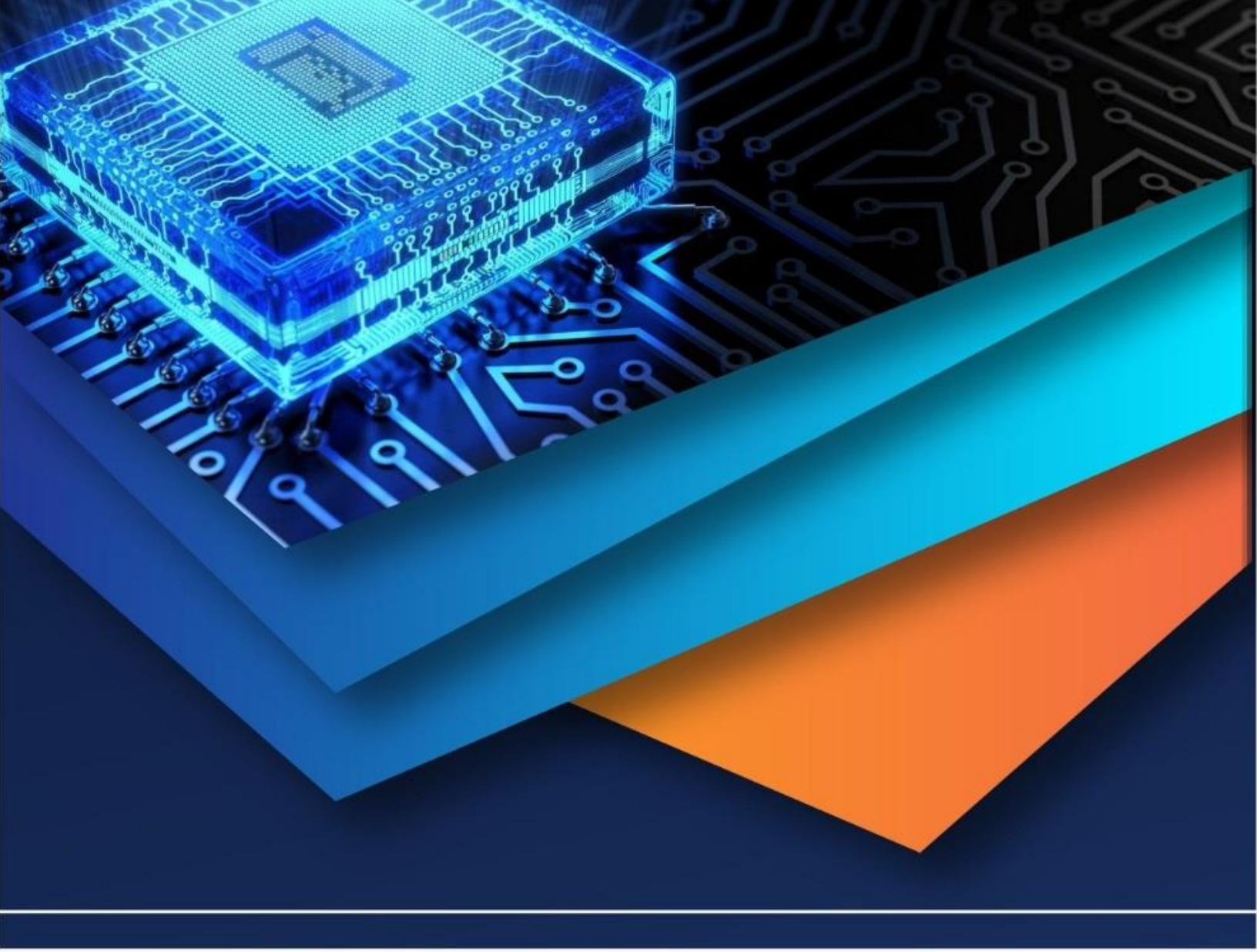
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