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ORIGINAL CONTRIBUTION

ENERGY EFFICIENT SMART STREET LIGHTING SYSTEM USING ARDUINO

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ABSTRACT

Conventional Street lights waste significant power by running at maximum output all night, regardless of actual road activity. To solve this, we developed a budget-friendly, adaptive smart lighting system using an Arduino Uno integrated with an LDR, PIR, and ultrasonic sensors. The LDR disables operation during daylight. At night, the system keeps LED lights dimmed at PWM 80. When approaching traffic or pedestrians are detected within a 120 cm range, the Arduino dynamically scales brightness to full capacity (PWM 255) and triggers an alert. Simulation results confirm seamless transition between idle and active states. By aligning illumination with real-time need, this solution slashes energy overhead, reduces operating costs, and enhances municipal safety across urban and residential areas.

KEYWORDS: Energy Efficiency, Intelligent Lighting, Adaptive Illumination, Arduino, Automated Lighting Control.

1. INTRODUCTION

Smart street lighting has become an essential pillar of modern urban infrastructure, playing a crucial role in maintaining road safety and driver visibility while optimizing municipal power usage [1], [2]. Historically, public lighting designs focused primarily on balancing energy savings with visual comfort and strict safety guidelines [3]. Kostic and Djokic emphasized that energy-efficiency measures must not compromise driver visibility or pedestrian safety, advocating for adaptive lighting criteria tailored to real-time road conditions [3]. Despite these recommendations, conventional street lighting networks still largely rely on fixed-intensity lamps operating on static timer schedules regardless of actual traffic density or natural daylight [2], [4]. This static operation leads to excessive energy waste, accelerated hardware degradation, and elevated operational costs [2], [4].

To overcome these traditional limitations, significant research has focused on intelligent, responsive lighting architectures [4], [5]. Early networked approaches, such as the ZigBee-based remote control system developed by Leccese, demonstrated how wireless sensor networks

(WSNs) can enable real-time monitoring and centralized lamp control to lower energy consumption [6]. To handle more complex traffic patterns, Zhang *et al.* proposed a group decision-making model that aggregates data across distributed sensors to autonomously regulate streetlights based on collective environmental feedback rather than isolated triggers [7]. Building on these concepts, modern adaptive street lighting frameworks combine low-power microcontrollers with ambient light and motion sensors to deliver full illumination when activity is present and dim during low-demand periods [1], [5], [8], [9].

In practical field observations of secondary roadways, university campuses, and isolated highways, traffic drops significantly during late-night hours. Operating conventional fixtures at maximum brightness during these idle periods represents a continuous drain on power grids [1], [2]. While advanced wireless mesh networks [6] and distributed decision models [7] offer robust capabilities, they often introduce higher installation costs and network overheads. This highlights the need for low-cost, decentralized architectures that provide immediate, adaptive responsiveness for localized deployments [1], [5].

To address these practical constraints, this paper presents a budget-friendly, energy-efficient smart street lighting system that automatically controls LED intensity using an Arduino Uno microcontroller integrated with Light Dependent Resistors (LDR), Passive Infrared (PIR) sensors, and ultrasonic sensors [1], [8]. During daylight hours, the system keeps the lights completely powered off (PWM = 0). At night, the system defaults to an energy-saving standby mode (PWM = 80). When an approaching vehicle or pedestrian is detected within a designated 120 cm range, the controller rapidly scales illumination to full capacity (PWM = 255) and triggers an alert [1], [8]. By matching light output directly to real-time road demand, the proposed framework significantly cuts electricity consumption while maintaining public safety and visual standards [1], [3].

2. DESIGN METHODOLOGY

This system is developed to control the street light according to the surrounding light condition and the presence of a nearby object. The Arduino Uno R3 is used as the main controller, while different sensors provide the information required for controlling the light. The working process of the system is carried out continuously so that the brightness can change whenever the surrounding condition changes. Arduino Uno R3 is used as the main controller in the system. An LDR detects the ambient light level and controls the day/night operation. A PIR sensor and ultrasonic sensor detect movement and objects within a predefined distance of 120 cm. When an object is detected, the Arduino increases the LED intensity using

PWM from 80 to 255. A 16×2 LCD displays the system status, while a buzzer provides an audio indication during detection. Thus, the system combines light sensing, motion detection, distance measurement, and PWM-based control to provide adaptive street lighting and reduce unnecessary energy consumption.

First, the Arduino Uno R3 is connected to the LDR, PIR sensor, ultrasonic sensor, LED street light, 16×2 LCD, and a buzzer. Each component performs a specific function in the system. The sensors provide input to the Arduino, and the Arduino processes these inputs before deciding the required light intensity. The LDR is used to determine the amount of light present around the street light. Its reading is continuously monitored by the Arduino. When the surrounding light is sufficient, the system considers it as daytime and keeps the LED switched OFF. When the light level decreases, the system changes to night operation. After entering night mode, the LED does not immediately operate at its maximum brightness. Instead, it is kept at a lower intensity using PWM. In the developed system, the initial PWM value is 80. This provides basic illumination while avoiding the need to operate the light at full brightness when there is no nearby traffic. During night operation, the PIR sensor is used to sense movement in the surrounding area. The ultrasonic sensor is used along with it to determine whether an object is within the selected detection range. In this work, the distance limit is set to 120 cm. These sensors help the controller identify when a vehicle or moving object approaches the street light.

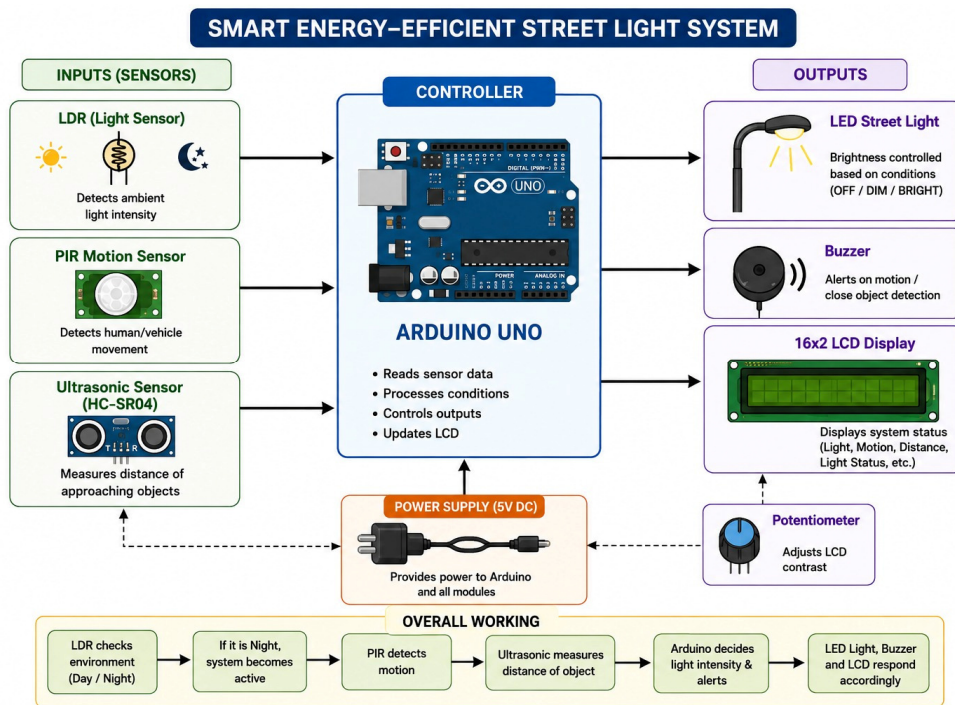


Figure 1: Block Diagram of the Proposed Smart Energy-Efficient Street Light System

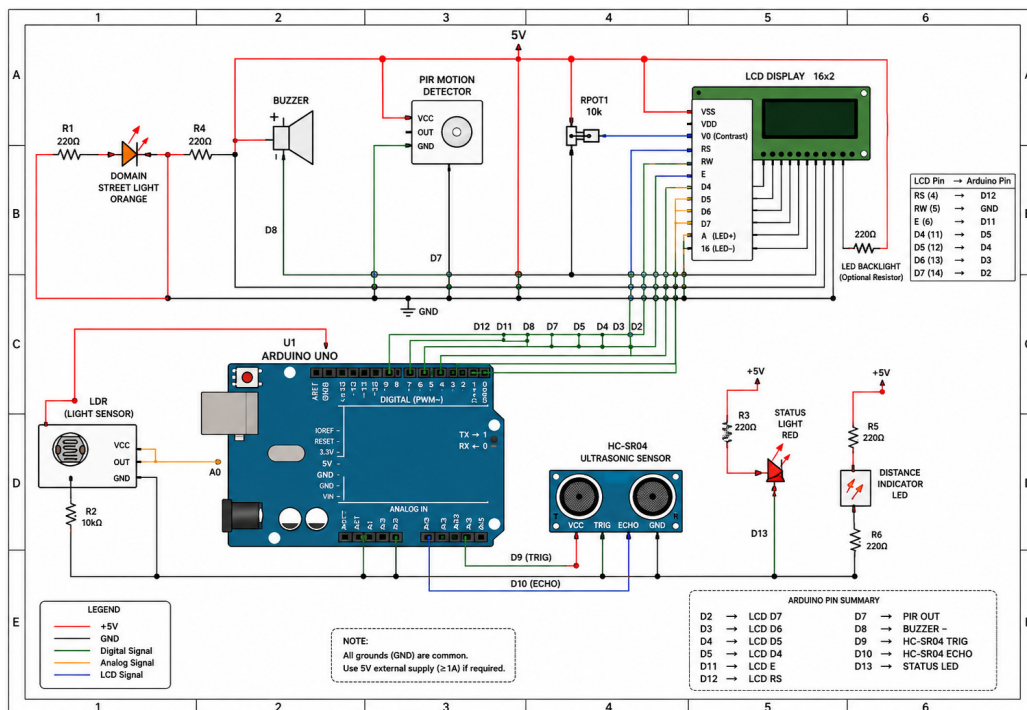


Figure 2: Detailed Circuit Connection Diagram of the Proposed Smart Street Light System

When the sensors detect an object within the specified range, the Arduino changes the PWM value of the LED from 80 to 255. As a result, the street light reaches its maximum brightness and provides better visibility for the detected object. Once the object moves away from the detection range, the system returns the LED to its lower

brightness level. The 16x2 LCD is used to show the current condition of the system. It can indicate whether the system is operating in day mode, night mode, or detecting an object. The piezoelectric buzzer provides an additional indication when the required detection condition occurs. This makes it easier to observe the

response of the system during testing. After completing one sensing and control cycle, the Arduino again reads the sensor values and repeats the same process. Therefore, the street light does not depend on a fixed operating schedule. Its condition changes according to the actual readings received from the sensors. Through this continuous process, the system provides higher brightness when required and lower brightness when the road is clear, helping to reduce unnecessary energy consumption.

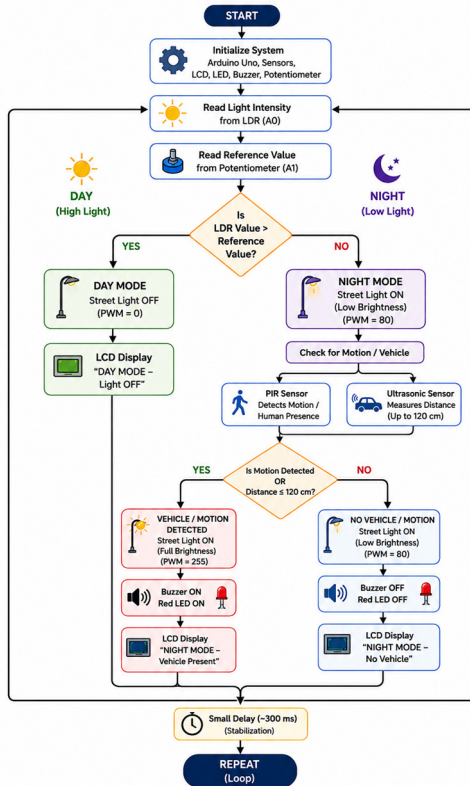


Figure 3: Control Flowchart of the Smart Energy-Efficient Street Light System

The block diagram in Figure 1 shows the main components and signal flow of the proposed smart street light system. The LDR, PIR, and ultrasonic sensors provide the required input to the Arduino Uno for checking light conditions, movement, and object distance. Based on these inputs, the Arduino controls the LED street light using PWM. The 16×2 LCD displays the system status, while the buzzer gives an alert during detection. A 5V supply powers the circuit, and the potentiometer is used for LCD contrast adjustment. Overall, the diagram gives a simple view of how the different parts work together. Figure 2 shows the circuit connections used for our work. The Arduino Uno is connected to the

LDR, PIR sensor, HC-SR04 ultrasonic sensor, LCD, buzzer, and LED indicators. The LDR is connected to A0, while the PIR output is connected to D7. The ultrasonic sensor uses D9 and D10 for trigger and echo. The LCD is connected through D2–D6, D11, and D12, and D8 is used for the buzzer. The circuit uses a common 5V supply and ground for the connected components. Figure 3 explains the control sequence used in the proposed street light system. The system first starts all the connected components and takes the LDR and potentiometer readings. These values are used to decide whether the surrounding condition is suitable for day mode or night mode. In day mode, the street light stays OFF. At night, the light is kept at a low level until the PIR or ultrasonic sensor detects a person or vehicle within 120 cm. When detection occurs, the light changes to full brightness (PWM 255) and the buzzer gives an indication. If nothing is detected, the light continues at PWM 80. The LCD also changes its message according to the current condition. After a short delay, the controller checks the sensors again and continues the same operation.

The following components were used to build and test the proposed street lighting system:

- Arduino Uno R3 – Main controller of the system.
- LDR – Detects the surrounding light level.
- 16×2 LCD – Displays the current system condition.
- 10 kΩ Potentiometer – Adjusts the LCD contrast.
- PIR Sensor – Detects movement in the monitored area.
- HC-SR04 Ultrasonic Sensor – Measures the distance of a nearby object.
- Orange LED – Represents the street light.
- Red LED – Provides system status indication.
- Piezo Buzzer – Gives an alert when detection occurs.
- 220 Ω Resistors – Used to limit current through the LEDs.
- 10 kΩ Resistor – Used with the LDR for voltage sensing.

3. RESULTS AND ANALYSIS

The circuit was tested in the simulation by changing the light condition and the position of the detected object. The main things checked were the street-light brightness, LCD message, buzzer response, and distance measured by the ultrasonic sensor. The results for the different conditions are given below.

(i) Day Condition: When enough light falls on the LDR, the system treats the condition as daytime. The street light stays OFF (PWM = 0). The LCD shows the day-mode message. This confirms that the light does not remain ON when natural light is already available.

(ii) Night Condition with No Vehicle: When the LDR reading indicates low light, the system changes to night mode. If there is no vehicle or moving object near the sensor, the street light stays at low brightness (PWM = 80). The buzzer is OFF and the LCD shows the corresponding night-mode status.

(iii) Vehicle Detection: A vehicle or object was placed within the detection range. When the distance became 120 cm or less, the system detected it and increased the street-light output to PWM = 255. At the same time, the buzzer turned ON and the LCD changed to the vehicle-detected message.

(iv) Distance Check: The HC-SR04 was used to check the distance of the object from the sensor. The measured distance was compared with the 120 cm limit set in the program. This allowed the Arduino to decide whether the light should remain dim or change to full brightness.

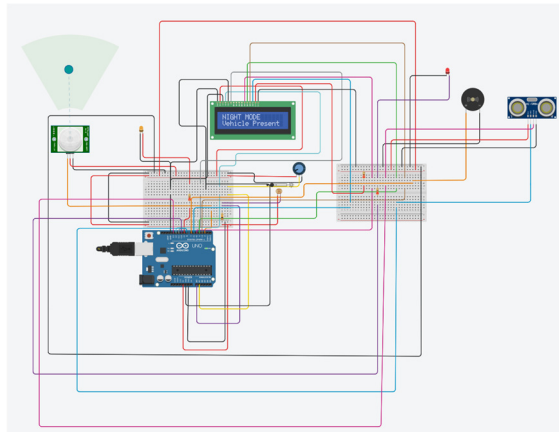


Figure 4: Simulation Result for Vehicle and Motion Detection

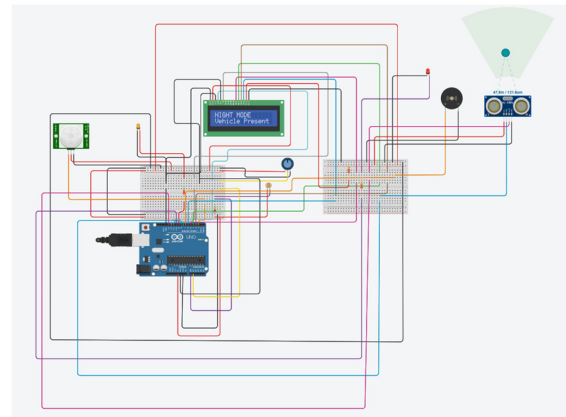


Figure 5: Simulation Result for Vehicle Detection with Distance Measurement

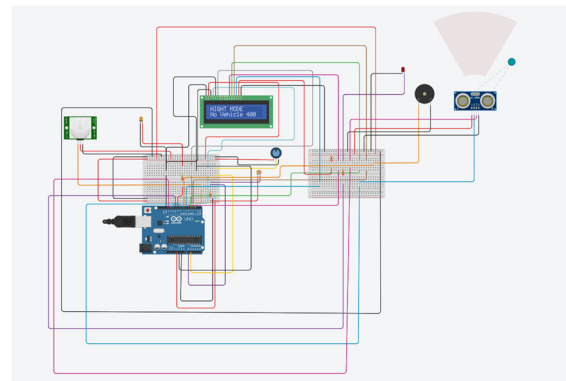


Figure 6: Simulation Result for Night Mode with No Vehicle

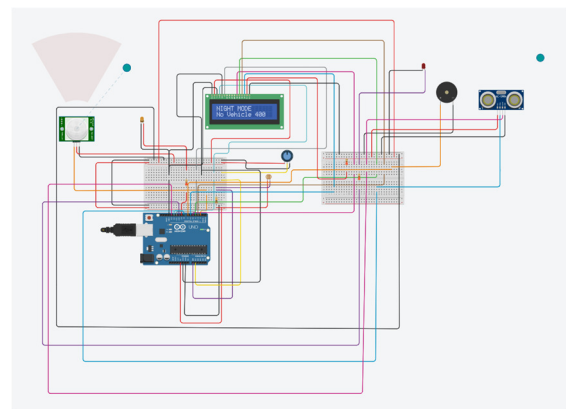


Figure 7: Simulation Result for Night Mode with No Motion Detection

Table 1: Observed Sensor Readings and System Response

SL. No.	LDR VALUE	Distance (cm)	Motion	Mode	LED PWM	Buzzer
1	950	400	No	Day	0	OFF
2	550	400	No	Night	80	OFF

SL. No.	LDR VALUE	Distance (cm)	Motion	Mode	LED PWM	Buzzer
3	400	150	No	Night	80	OFF
4	250	120	Yes	Night	255	ON
5	100	80	Yes	Night	255	ON
6	420	400	No	Night	80	OFF

The Table 1 gives the readings taken during different test conditions. In daylight, the street light stays OFF with PWM 0. At night, when no vehicle is present, the light works at PWM 80. When a vehicle or moving object comes within 120 cm, the light changes to PWM 255 and the buzzer turns ON. The readings show that the system changes the light intensity according to the surrounding condition and object detection. The characteristic curves shown in Fig. 8 are derived from the experimental dataset recorded in Table 1, illustrating how ambient lighting conditions and vehicle proximity influence the street light brightness.

Specifically, Fig. 8(a) highlights the relationship between the analog LDR reading and LED output. Under high ambient light conditions (LDR = 950), daylight is deemed sufficient, keeping the street light completely turned off (PWM = 0).

Once ambient light levels drop below the threshold value of 600, the system automatically transitions into night mode, setting the LED to an energy-saving standby intensity (PWM = 80). As ambient light decreases further, detecting motion triggers the system to scale the brightness up to its maximum capacity (PWM = 255).

Complementing this, Fig. 8(b) demonstrates how vehicle distance dictates LED illumination. When an approaching object enters the 120 cm threshold or closer, the Arduino immediately boosts the LED brightness to full capacity (PWM = 255) and activates the piezo-buzzer. Conversely, for distances exceeding 120 cm, the streetlight remains in its dimmed state (PWM = 80) with the buzzer disengaged. The red dashed boundary line in Fig. 8(b) explicitly marks this 120 cm detection cutoff.

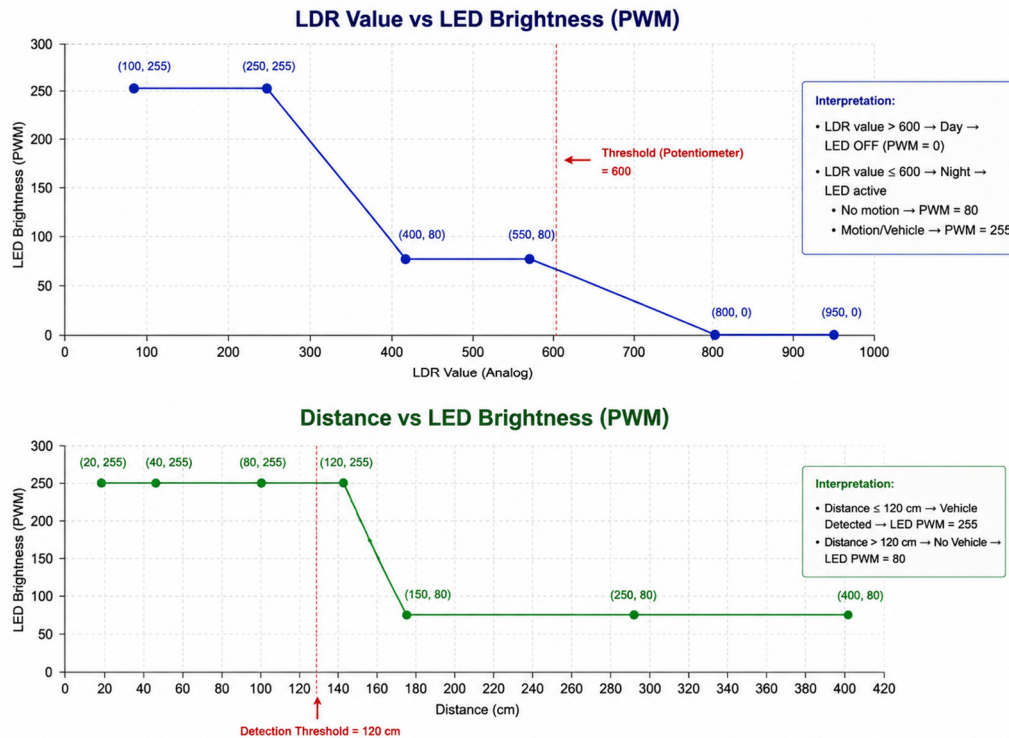


Figure 8: (a) Characteristics curve between variation of LED Brightness with LDR Value and (b) Characteristics curve between variation of LED Brightness with Distance of vehicle.

4. CONCLUSION

This work originated from observing a simple, widespread issue: standard streetlights waste vast amounts of energy by glowing at full power all night, even when roads are empty or daylight is present. To address this inefficiency, we developed an adaptive, smart lighting setup using an LDR for ambient light sensing, along with PIR and ultrasonic sensors for precise motion and proximity detection. Successfully simulated in Tinkercad, the Arduino UNO seamlessly coordinated sensor inputs with the LED, LCD, and buzzer outputs under varying conditions. By dynamically scaling brightness to actual demand, this design significantly cuts electricity waste, lowers operational expenses, and ensures safer, smarter public spaces.

Looking ahead, the system can be enhanced by integrating IoT and wireless protocols for remote monitoring and diagnostics. Incorporating solar panels and rechargeable batteries would enable sustainable off-grid operation. Furthermore,

deploying AI-driven algorithms could allow the lights to learn traffic patterns and proactively adjust illumination, while automated fault detection could instantly flag damaged units. Designed for versatility, this solution can easily scale beyond city streets to highways, campuses, parking lots, and parks—paving the way for more resilient and energy-conscious urban infrastructure.

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