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Design and Development of the Mechanical Structures for Smart Street Light Control

Preethi K[1], Shivappa H.A[2], Srinivasu N[3], Tejesh S[4], Manjunath T.C[5] and Shashidhar V[6]
[1-4]Assistant Professor, Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India
[5]Dean Research (R & D), Professor, Computer Science & Engineering, Rajarajeswari College of Engineering, Bangalore, Karnataka
Email: tcmanju@iitbombay.org
[6]Associate Professor & HoD, Computer Science & Engineering Department (IoT, CS, BCT) Rajarajeswari College of Engineering, Bangalore, Karnataka

***Abstract*— The rapid growth of urbanization has increased the demand for energy-efficient infrastructure, particularly in street lighting, which often operates at full capacity regardless of actual need, leading to significant energy wastage. This project proposes a smart, low-cost street light control system designed to address these inefficiencies by automating lighting operations using an Arduino Uno microcontroller. The system utilizes a Light Dependent Resistor (LDR) to detect ambient light levels, ensuring that lights only turn on during the night or in low-light, cloudy conditions.**

To further optimize power consumption, Passive Infrared (PIR) sensors or IR sensors are deployed to detect the motion of vehicles or pedestrians. When motion is detected, the lights operate at 100% intensity; otherwise, they dim to a lower power state (e.g., 10%–20%) or turn off completely.

Key components include the Arduino microcontroller, LDR sensor, IR/PIR sensors, relay modules (for controlling high-voltage AC lights), and LED luminaires. In some implementations, a Real-Time Clock (RTC) module is integrated to ensure precise scheduling. Experimental results indicate that this system can reduce energy consumption by up to 65% compared to conventional, always-on lighting systems. Furthermore, the system enhances safety by ensuring adequate lighting when needed and reduces maintenance costs by extending the lifespan of the lamps.

***Index Terms*— Mechanical, Control, Arduino, Light, Time, Clock.**

I. Introduction

Smart street light using Arduino is an energy-efficient lighting system that automatically adjusts brightness or turns lights on/off based on ambient light (LDR sensors) and detected motion (IR/PIR sensors), controlled by an Arduino microcontroller, significantly reducing power wastage by illuminating only when needed, saving costs, and extending bulb life.

It combines sensors, LEDs, and the Arduino to create adaptive, cost-effective lighting for streets and outdoor areas [1].

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II. Core Components

The system is built around an Arduino board, such as the Uno, which serves as the central controller or "brain" of the setup. It is responsible for receiving input signals from various sensors, processing the data based on the programmed logic, and controlling the operation of the lighting elements accordingly. The decision-making capability of the system is driven by real-time sensor inputs, enabling intelligent and automated functionality.
A Light Dependent Resistor (LDR) is used to monitor ambient light conditions. It exhibits low resistance during bright conditions, such as daytime, and high resistance in dark conditions, such as nighttime. This variation in resistance allows the Arduino to determine whether the lights should remain off or be activated. To detect movement, Infrared (IR) or Passive Infrared (PIR) sensors are incorporated into the system. These sensors identify the presence of vehicles or pedestrians and send corresponding signals to the Arduino, enabling dynamic control of lighting intensity. The lighting component of the system is implemented using LEDs, which are energy-efficient and suitable for adaptive illumination. These LEDs are often connected to Pulse Width Modulation (PWM) pins of the Arduino, allowing brightness control based on the situation, such as dim lighting during inactivity and full brightness when motion is detected. Additionally, for applications involving higher power loads or real street lighting systems, a relay or solid-state relay (SSR) is used. This component acts as a switching interface, enabling the low-voltage Arduino to safely control high-power lighting circuits. Together, these components form a cohesive and efficient smart lighting system [2][20].

III. Objective / Aim

Smart street light using Arduino is an energy-efficient lighting system that automatically adjusts brightness or turns lights on/off based on ambient light (LDR sensors) and detected motion (IR/PIR sensors), controlled by an Arduino microcontroller, significantly reducing power wastage by illuminating only when needed, saving costs, and extending bulb life. It combines sensors, LEDs, and the Arduino to create adaptive, cost-effective lighting for streets and outdoor areas [3][19].

IV. Problem Statement Definition and Motivation

- The motivation for an Arduino automatic street light project stems from energy wastage and inefficiency in manual systems, with the core problem being lights staying on during the day or off during the night. The project aims to save power and improve safety by using sensors (like LDRs for light, PIR/IR for motion) and an Arduino to automatically switch lights on/off based on darkness or vehicle presence, reducing human intervention and costs.
- Energy Conservation: Traditional streetlights often remain on unnecessarily (e.g., all day), wasting significant power, especially as non-renewable sources dwindle.
- Cost Reduction: Automating lights reduces operational costs associated with manual switching and extends bulb life.
- Improved Efficiency: Ensures lights are on only when needed (darkness, traffic), optimizing illumination.
- Sustainability: Promotes smart city initiatives and responsible energy use.

V. Literature Survey

The literature survey on Arduino-based smart street lights reveals a focus on energy saving through automation, primarily using PIR (Passive Infrared) sensors for motion detection and LDR (Light Dependent Resistors) to sense ambient light, with Arduino acting as the controller to adjust LED brightness or turn lights on/off. Key research highlights include low-cost implementation, reduced power consumption, enhanced safety by only illuminating areas with movement (dimly at night, full brightness when motion detected), and integration with IoT for monitoring and management in smart cities, improving upon traditional, inefficient systems [4][18].

VI. Outcome of the Project

The outcome of an Arduino smart street light project is an energy-efficient, automated lighting system that significantly reduces power consumption by adjusting light levels based on ambient light (LDR sensors) and detecting motion (IR/Ultrasonic sensors) to brighten only when needed, offering dynamic illumination, lower costs, and potential for smart city integration (like IoT monitoring). The proposed system is built around the concept of adaptive illumination, where lighting is provided only when and where it is actually required, instead of maintaining full brightness throughout the night. This intelligent approach ensures that energy is not wasted during periods of inactivity. One of the key features of the system is its ability to automatically activate and deactivate based on environmental conditions. By continuously sensing natural light levels using an LDR, the system turns the lights ON at dusk and switches them OFF at dawn without any manual intervention, making the operation fully automated and efficient. Another important aspect is dynamic intensity management, where the brightness of the LEDs is adjusted in real time depending on the presence of movement. During low-traffic periods, the lights either remain dim or completely OFF to conserve energy. However, when a pedestrian or vehicle is detected through IR or PIR sensors, the system instantly increases the brightness to full intensity, ensuring proper visibility and safety. This seamless adjustment of lighting levels not only enhances user comfort but also significantly optimizes energy usage [5][17].

The effectiveness of the system is largely due to its sensor integration, where multiple sensors such as LDR, IR, and PIR work together to collect real-time data about ambient light and motion. This data is processed by the Arduino microcontroller, which makes intelligent decisions regarding lighting control. As a result, the system achieves high energy efficiency by delivering illumination strictly based on actual demand, thereby reducing overall electricity consumption compared to conventional street lighting systems. Furthermore, the system is designed with scalability in mind. It can be extended to include Internet of Things (IoT) capabilities by integrating Wi-Fi or Bluetooth modules. This allows for remote monitoring, fault detection, and performance analysis through cloud platforms or mobile applications. Such integration not only improves system management but also supports the development of smart city infrastructure by enabling data-driven optimization and efficient urban lighting solutions [6][16].

VII. TOOLS TO BE USED (H/W & S/W)

The proposed smart street lighting system requires a set of essential hardware components to ensure proper sensing, processing, and control. At the center of the system is the Arduino Uno board, which acts as the main microcontroller and serves as the brain of the entire setup. It continuously receives input signals from the sensors, processes the information according to the programmed logic, and controls the lighting output. To identify whether the environment is in daytime or nighttime, a Light Dependent Resistor (LDR) is used as the light-sensing element. This sensor measures the surrounding light intensity and helps the Arduino decide when the street lights should remain off or become active. The Fig. 1 shows the overall block diagram. In addition to the LDR, an IR or PIR motion sensor is included to detect the presence of pedestrians or vehicles. This motion detection capability allows the lights to glow at full brightness only when movement is detected, while keeping them dimmed or switched off when no activity is present, thereby improving energy efficiency [7][15].

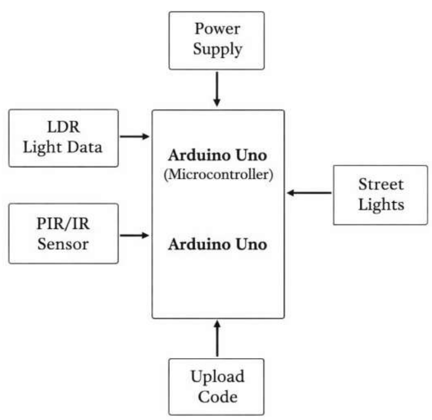

Figure 1. Overall block diagram

VIII. PROPOSED ALGORITHM / FLOW-CHART / DFD

The proposed algorithm for the smart street lighting system is based on two important sensing inputs, namely the Light Dependent Resistor (LDR) for identifying ambient light conditions and the IR or PIR sensor for detecting the presence of movement. The system begins with an initialization stage in which the Arduino microcontroller powers up and configures communication with all input and output devices. At this stage, the sensor pins, LED or relay output pins, and necessary threshold values are defined within the program. These threshold values help the controller distinguish between day and night conditions and also determine whether motion is present in the monitored area. Once the initialization is complete, the Arduino enters a continuous monitoring mode through its loop function. In this stage, the controller repeatedly reads the analog value from the LDR sensor using the analogRead() function, which indicates the intensity of surrounding light. Simultaneously, it keeps checking the status of the motion detection sensor to identify any movement of pedestrians or vehicles. This real-time monitoring ensures that the system is always aware of environmental conditions and can respond immediately whenever a change occurs [8][14].

IX. Working Principle of the Project Work

The smart street light with Arduino works by using sensors (like LDR for light or PIR/IR for motion) to detect environmental changes, sending data to the Arduino board, which processes it and controls lights (LEDs/bulbs) via a relay or transistor, turning them on in the dark or for passing vehicles and off when not needed, thus saving energy. The core principle is sensor input -> Arduino processing -> actuator output, automating lighting based on light levels or presence. The Fig. 2 shows the breadboard circuit diagram [9][13].

X. Proposed Block Diagram and Circuit Diagram

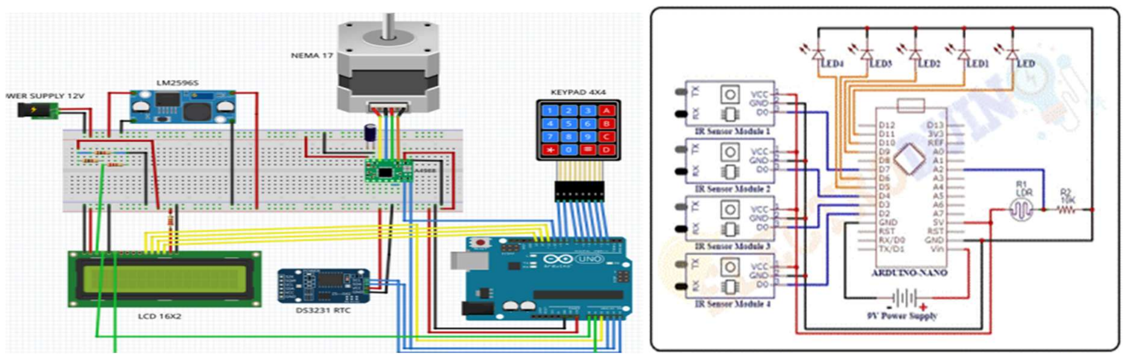

Figure 2. Breadboard circuit diagram

XI. Overall Working of the Project

- Daytime: LDR detects high light, Arduino reads high values, keeps LEDs OFF to conserve energy.
- Dusk/Nightfall: LDR detects low light, resistance increases; Arduino reads lower values, turns all lights ON (or dims them).
- Motion Detection:
- When a vehicle or person is detected by an IR/PIR sensor, it sends a signal (e.g., LOW) to the Arduino.
- Arduino interprets this as a need for more light and uses PWM to increase the brightness of nearby LEDs (e.g., two LEDs controlled by one sensor).
- No Motion: After a set time without motion, the lights dim back to a lower level or turn off (depending on code), optimizing energy use.
- Power: Can be solar-powered for autonomy, with systems sometimes adding IoT for remote monitoring.

XII. Simulation and Experimental Results

Smart street lighting system using Arduino typically employs LDR (Light Dependent Resistor) sensors to detect ambient light levels and PIR (Passive Infrared) or IR (Infrared) motion sensors to detect movement. The system is designed to turn lights on/off automatically or adjust their brightness to save energy and manpower. In a typical simulation environment such as Tinkercad or Proteus, or even in a real-time hardware prototype, the system demonstrates intelligent and adaptive lighting behavior based on environmental conditions and motion detection. During daytime conditions, the LDR sensor detects high ambient light intensity and sends an appropriate signal to the Arduino controller. Based on this input, the Arduino program ensures that the output pins connected to the LEDs remain in a LOW state, keeping the street lights switched off and thereby avoiding unnecessary energy consumption. As the environment transitions to nighttime, the ambient light intensity decreases, causing the resistance of the LDR to increase. The Fig. 3 shows the pictorial view of the sensors used [10][12].

XIII. Photographs / Snapshots

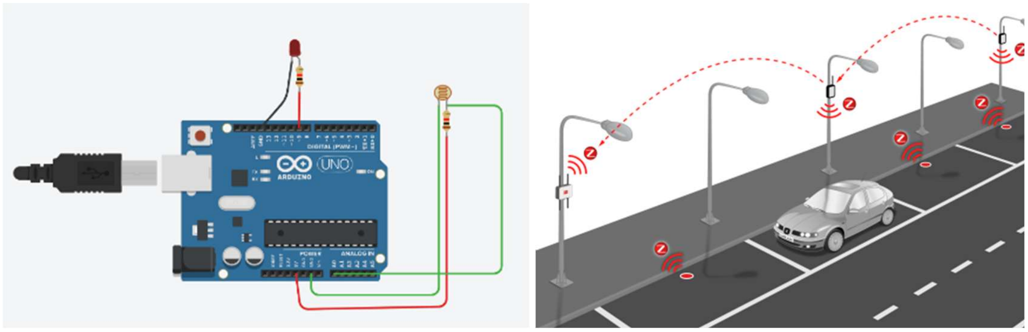

Figure 3. Pictorial view of the sensors used

XIV. Applications and Advantages

The system is designed to achieve effective energy saving by automatically dimming or switching off lights when no human or vehicular presence is detected, thereby significantly reducing unnecessary power consumption. At the same time, it enhances safety by ensuring that lights brighten instantly as people or vehicles approach, improving visibility and acting as a deterrent to potential security threats. Its capability for smart city integration makes it even more valuable, as it can be extended with Wi-Fi or GSM modules to enable remote monitoring, fault detection, and automated alerts. Additionally, the system can be easily integrated with solar power, allowing the development of self-sustaining lighting solutions that operate independently of the conventional grid. Another notable feature is its ability to provide customizable lighting, where brightness levels can be dynamically adjusted based on ambient light conditions using LDR sensors or according to traffic flow patterns. From an implementation perspective, the system is highly cost-effective since Arduino boards and associated components are affordable and widely available, making it suitable for large-scale deployment in communities. Its flexibility and modular design allow easy customization & implementation [10][11].

XV. Conclusions

Arduino-based smart street lights effectively cut energy waste by using LDRs and IR sensors to adjust brightness or turn lights off when not needed, creating sustainable, automated urban lighting that reduces power consumption and human effort, paving the way for smarter, greener cities with potential for IoT integration and future AI enhancements. The core conclusion is significant energy savings (potentially 65%) and improved efficiency over traditional systems, proving technology's role in future smart city infrastructure. The proposed system offers significant energy efficiency by ensuring that lighting is activated only when it is truly required, such as during conditions of darkness combined with the presence of motion. This intelligent operation leads to substantial energy savings compared to conventional lighting systems that remain switched on throughout the night regardless of necessity. In addition, the system enables full automation, thereby eliminating the need for manual switching and reducing both human effort and operational costs. From a safety perspective, it enhances visibility by providing illumination precisely when people or vehicles are present, which improves security in public and private spaces. The system also supports sustainability by lowering overall electricity consumption and minimizing carbon emissions, while simultaneously reducing light pollution. Furthermore, its scalability makes it highly adaptable for larger deployments, as the Arduino-based platform is cost-effective and flexible, allowing easy integration with IoT for real-time monitoring and future enhancements such as AI-based intelligent control for smart city applications.

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