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# IOT Based Smart Street Light System From Legacy to Intelligent: A Retrofit Approach

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*Abstract*—**This paper presents a novel approach for transforming existing street lights into an intelligent network using a compact, easily install-able hardware module. This retrofit solution eliminates the need for complete infrastructure replacement, offering a cost-effective and scalable path towards smart city development. The integrated IoT devices within the module gather real-time data on environmental conditions and occupancy. A custom-developed software application processes this data, enabling features like dynamic light adjustment, automated on/off control based on time and weather, and real-time maintenance management for faults like blown fuses or damaged bulbs. Additionally, the project incorporates an administrator application facilitating complaint lodging, emergency SOS alerts, and comprehensive lamp post health monitoring. This innovative system empowers municipalities to seamlessly upgrade their street lighting infrastructure, enhancing efficiency, safety, and citizen engagement within their smart city initiatives.**

## I. INTRODUCTION

Traditional street lighting infrastructure, while functional, faces limitations in efficiency, responsiveness, and data collection. Upgrading entire systems can be costly and disruptive, posing a significant hurdle for the success of smart city initiatives. In India, the Smart Cities Mission launched in 2015 by the Government of India highlights this challenge. A total investment of Rs.2,01,981 crore has been proposed by the 99 participating cities, with a significant portion earmarked for revamping identified areas (Area Based Projects) and implementing smart city initiatives across entire cities (Pan City Initiatives). However, despite this substantial investment, only a few cities like Pune, Jaipur, and Odisha are currently focusing on Smart Street Light Systems due to major challenges like high upfront costs, existing infrastructure limitations, and integration complexities.

An IoT-based smart street light system designed for easy retrofitting into existing infrastructure. Our approach leverages a compact hardware module packed with various IoT devices. This module seamlessly integrates with existing street light fixtures, transforming them into intelligent nodes within a connected network. The benefits are twofold:

a) Cost-Effectiveness: It eliminates the need for complete infrastructure replacement, offering a significantly more affordable path towards smart city development compared to traditional, full-scale upgrades.

b) Scalability: Additional modules can be easily added as needed, allowing cities to implement the system incrementally and adapt to budgetary constraints.

This paper delves into the functionalities of the proposed system, which extend beyond basic illumination. The integrated IoT devices gather real-time data on environmental conditions and occupancy. A custom-developed software application analyzes this data, enabling features like:

*a)* Energy-saving dynamic light adjustment: Optimizes energy consumption by increasing light intensity only when the system detects movement of an object, and reducing it during periods of low activity. Studies have shown that such dynamic light adjustment can achieve energy savings of up to 70% compared to traditional street lighting systems that operate at full capacity throughout the night. Furthermore, depending on the severity of the situation, the system can switch the light completely off for damage protection. For instance, during a power surge or extreme weather events, the system can temporarily disable the light to prevent electrical damage.

*b)* Automated on/off control: Leverages current weather reports and daylight hours for automatic light activation and deactivation.

*c)* Real-time maintenance management: Identifies and reports issues like blown fuses or damaged bulbs, facilitating prompt repairs.

*d)* Admin-focused Complaint Reporting: The system incorporates a comprehensive administrator application designed for city officials. This application empowers them with real-time monitoring capabilities and allows them to report and manage various aspects of the street lights, including:

*e)* Damage/Complaints Reporting: City officials can use the application to report damage observed or raise complaints during maintenance checks or upon receiving complaints from citizens.

*f)* SOS features for emergencies: While citizens cannot directly trigger SOS alerts, officials can utilize the application to dispatch emergency services if needed based on incoming reports or observations during patrols.

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*g)* Fuse/bulb/lamp post maintenance and management: The application facilitates real-time monitoring and management of lamp post health, allowing for proactive maintenance and repairs.

By seamlessly integrating into existing infrastructure and offering a suite of valuable functionalities at a reduced cost, this IoT-based smart street light system empowers municipalities to overcome major hurdles hindering smart city development. It promotes energy efficiency, citizen engagement, and contributes to a more sustainable and responsive smart city environment, aligning perfectly with the goals of the Smart Cities Mission.

## II. EXISTING TECHNOLOGIES

*1)* EB-Controlled Street Lights (Likely Electronic Ballast Controlled): While these offer some efficiency improvements over older magnetic ballasts, they often lack dynamic control. Lights typically operate at full brightness throughout the night, wasting energy when there's no movement.

*2)* LDR Automatic Streetlights (Light-Dependent Resistor): These basic systems rely on light-dependent resistors (LDRs) for on/off control. LDRs are easily fooled by moonlight or cloudy weather, leading to unnecessary light activation or deactivation. Additionally, they offer no control over brightness levels.

*3)* Timer-Based Systems: These offer some improvement over LDRs, but they lack real-time responsiveness. Lights turn on and off based on pre-programmed schedules, regardless of actual activity or weather conditions.

*4)* Astronomical Timers: These advanced timers use sunrise and sunset data for more precise scheduling, but they still don't adapt to real-time needs. They can't adjust light levels based on actual usage patterns.

## III. PROPOSED TECHNOLOGY

A cost-effective and scalable IoT-based smart street light system designed for seamless retrofitting into existing infrastructure. Unlike traditional systems with limited control capabilities, our approach leverages a compact hardware module brimming with advanced sensors and a powerful microcontroller unit (MCU) for intelligent data processing and communication. Here's a breakdown of its key responsibilities:

*a)* Sensor Data Acquisition: The MCU continuously gathers data from connected sensors, like light levels, motion detection, and potentially environmental data (optional).

*b)* Data Processing and Decision Making: Based on pre-programmed logic or cloud-based algorithms, the MCU interprets sensor data and makes control decisions for the LED street light. This involve adjusting light intensity based on motion or ambient light levels, or utilizing environmental data for adaptive light control strategies.

*c)* Light Control: The MCU instructs the relay module, which acts as a switch, to turn the LED/traditional street light on/off or adjust its brightness according to the processed data.

*d)* Cloud Communication: The MCU transmits sensor data (including light level, motion detection, and environmental data - if applicable) along with the current light status (on/off/dimmed) to a cloud platform (e.g., Firebase) via Wi-Fi at regular intervals.

*e)* Alert Notification (optional): If the MCU detects potential issues (e.g., voltage fluctuations exceeding pre-defined thresholds - if voltage monitoring is supported), it can trigger an alert notification to the cloud platform for further troubleshooting.

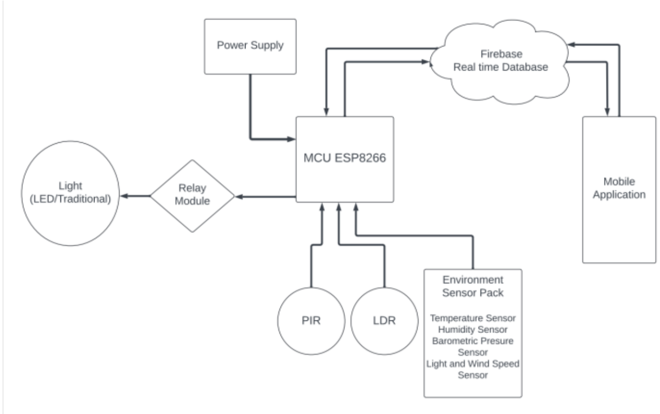


Fig 1. Block Diagram

### A. Data Flow

1) Sensors send data to the MCU.
2) MCU processes sensor data, makes control decisions and publishes data to the Firebase ( Cloud ).
3) Mobile app receives data updates.
4) Mobile app allows admins to set up the instructions about how the lights should react to the sensors and keep updating its current status.
5) Admin commands are sent to Firebase.
6) MCU listens to the commands from the Firebase and adjusts the behaviour of the light accordingly.

## IV. HARDWARE COMPONENTS

### A. Microcontroller Unit ESP8266:

The ESP8266 is a low cost, Wi-Fi enabled microcontroller that can be used either as a standalone unit for various IoT projects. Here are some functionalities:

*1)* Processing Unit: The ESP8266 acts as the brain of the system. It reads data from the connected sensors (LDR, PIR, environmental pack).

*2)* Data Analysis and Control: Based on the sensor readings and pre-programmed logic, the ESP8266 makes control decisions. This could involve:

*a)* Turning the LED street light on/off based on LDR readings (daytime vs. nighttime).

*b)* Adjusting light intensity based on motion detection from the PIR sensor (brighter when motion is detected, dimmed otherwise).

*c)* Processing environmental data from the sensor pack and potentially using it to influence light control strategies (e.g., brighter lights in cold weather or turn on/off depending on the weather condition like typhoon etc).

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*3)* Wi-Fi Communication: A key feature of the ESP8266 is its built-in Wi-Fi capability. This allows the MCU to connect to a Wi-Fi network and communicate with the cloud platform (Firebase) in our project.

*4)* Data Transmission: The ESP8266 transmits the collected sensor data (light level, motion detection, temperature, humidity, pressure) and the current light status (on/off/dimmed) to the Firebase Real-time Database at regular intervals.

*5)* Command Reception: The ESP8266 listens for commands sent from the mobile application (via Firebase). These commands could be to turn the light on/off or adjust its intensity. The ESP8266 receives these commands and adjusts the LED light accordingly through the relay module.

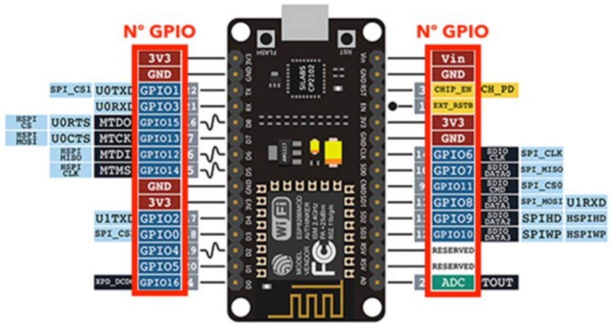


Fig 2. ESP8266 Pin Diagram

## B. LIGHT DEPENDENT RESISTOR

The LDR sensor, or Light Dependent Resistor, is a passive component that plays a key role in light detection for our IoT smart street lighting system. Here's how it works:

*1)* Light Sensitivity: The LDR's key characteristic is its ability to change its electrical resistance based on the intensity of ambient light. As the light level increases (brighter conditions), the LDR's resistance decreases. Conversely, when it's darker, the LDR's resistance increases.

*2)* Light Level Detection: While the LDR doesn't provide absolute light intensity measurements, it can be used as a relative indicator of ambient light conditions. By monitoring the LDR's resistance, the microcontroller unit (MCU) in our system can gain insights into the surrounding light level.

*3)* Potential Applications: Depending on our project goals, the LDR data, combined with other sensors or algorithms, could be used for:

*a)* Dimming Control: The MCU could adjust the brightness of the LED street light based on the LDR readings. This could lead to a more nuanced approach to lighting, with brighter lights during twilight and dimmer settings during darker hours.

*b)* Data Collection and Analysis: The LDR data, along with timestamps, could be collected and stored to analyze lighting patterns and potentially optimize light control strategies over time.

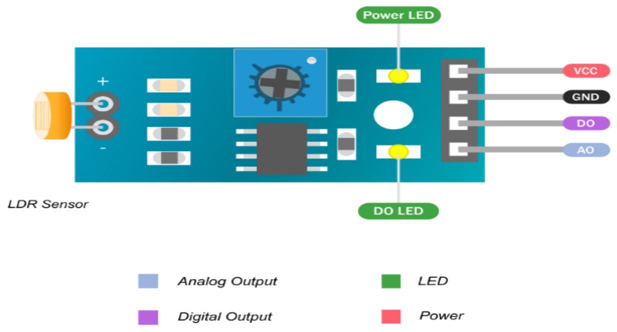


Fig 3. LDR Sensor

## C. PASSIVE INFRARED SENSOR

In our smart street light system, a PIR sensor, which stands for Passive Infrared sensor (not Pyroelectric Infrared Radial Sensor, though the technology uses pyroelectric crystals), plays a key role in motion detection. Here's how it works:

*1)* Infrared Radiation Detection: Unlike light-based sensors like LDRs, PIR sensors are sensitive to infrared (IR) radiation. This invisible type of radiation is emitted by objects with heat, including humans and vehicles.

*2)* Movement Trigger: The PIR sensor continuously detects the level of infrared radiation in its surroundings. When someone (or something) emitting infrared radiation moves within the sensor's range, the pattern of infrared radiation reaching the sensor changes. This change triggers the PIR sensor to send a signal to the microcontroller unit (MCU) in our system.

*3)* Dual Sensor Design: Many PIR sensors have two pyroelectric infrared sensors positioned slightly apart within the housing. This design helps differentiate between actual movement and changes in ambient infrared radiation (like sudden temperature shifts). If one sensor detects a significant change in infrared radiation compared to the other, it's more likely to be caused by movement within the field of view.

*4)* Focusing Lens: A dome-shaped plastic lens is typically placed in front of the PIR sensor elements. This lens acts like a funnel, concentrating the infrared radiation from the environment onto the pyroelectric sensors, improving their detection sensitivity.

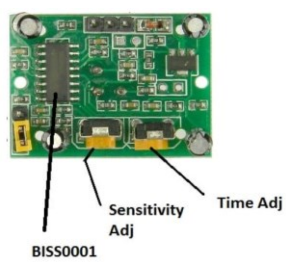


Fig 4. PIR Sensor

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### D. ENVIRONMENT SENSOR PACK

#### *1)* LM35 Temperature Sensor

The LM35 is an integrated circuit specifically designed to measure temperature. It provides a voltage output directly proportional to the Celsius temperature it detects. This makes it a simple and convenient way to monitor the ambient temperature around the street light.

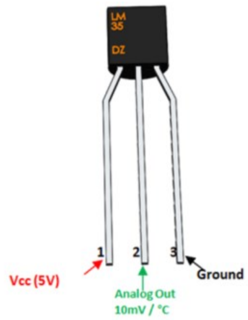


Fig 5. LM35 Sensor

#### *2)* DTH11 Sensor

The DHT11 utilizes a capacitive humidity sensor. This sensor element changes its capacitance (ability to store electrical charge) based on the amount of moisture present in the surrounding air. As the humidity increases, the capacitance also increases.

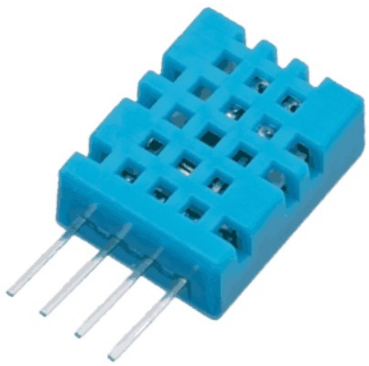

Fig 6. DTH11 Sensor

#### *3) BMP180 Sensor*

BMP180 focuses on measuring barometric pressure. This is the pressure exerted by the atmosphere on the Earth's surface, and it fluctuates based on weather conditions. By monitoring barometric pressure changes, the BMP180 can offer valuable insights into weather patterns. Fluctuations in barometric pressure can often indicate upcoming weather changes. For example, a rapid drop in pressure might suggest an approaching storm. The MCU in our system can use the pressure data from the BMP180 to trigger adjustments in the smart street light system based on the predicted weather. If a sudden pressure drop suggests a storm with heavy rain or fog, the MCU could automatically adjust the LED light intensity to be brighter, ensuring better visibility for pedestrians and drivers.

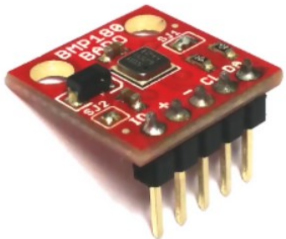

Fig 7. BMP180 Sensor

#### *4)* RELAY MODULE

A relay module acts as an intermediary between these two circuits. It receives a control signal from the MCU (low voltage) and uses it to control a high-power switch within the module. This switch can then turn on/off the LED street light in the high-power circuit.

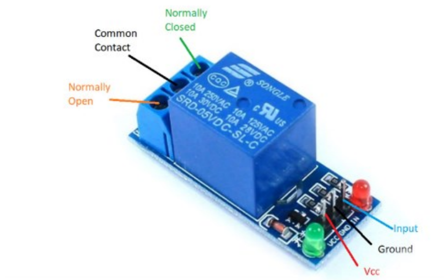


Fig 8. Relay Module

## V. SOFTWARE COMPONENTS

### A. MCU Firmware

*1)* Reads sensor data (LDR, PIR, Environmental Pack - if used).
*2)* Based on LDR readings and pre-defined thresholds, controls the relay module for on/off based on daylight.
*3)* If using PIR, adjusts light intensity based on motion detection.
*4)* If using environmental sensor pack, processes data for weather monitoring and potentially influencing light control strategies (optional).
*5)* Connects to Firebase Real-time Database using an MQTT library or cloud service specific protocol.
*6)* Publishes sensor data (light level, motion detection, temperature, humidity, pressure - if applicable) and light status (on/off/dimmed) to Firebase at regular intervals.
*7)* Initialized customisable timer for auto day and night on/off feature.

### B. Firebase Realtime Database

Cloud storage platform to store and manage sensor data and light control commands.

### *C.* Mobile Application ( Flutter *)*

*1)* Subscribes to relevant topics in the Firebase Realtime Database to receive sensor data and light status updates.
*2)* Admin Login/Sign-up with employee IDs.

3) Displays the received data on the app interface (light level, motion detection, temperature, humidity, pressure, light status).
4) Allows users to send commands (on/off/dim) to Firebase Database, which the MCU firmware listens to and adjusts the light accordingly.
5) Enable live location of each lamp post with its health status report for post prevention of any damage as well as manual control over each lamp through a single app.

## VI. CONCLUSION

Our innovative, IoT-based smart street light system tackles limitations of traditional lighting by offering a cost-effective retrofit solution. The compact hardware module seamlessly integrates with existing fixtures, transforming them into intelligent nodes within a connected network. This eliminates expensive infrastructure upgrades while enabling features like occupancy-based light control for potential energy savings, automated on/off based on weather and daylight, and real-time maintenance management. City officials gain a comprehensive management application for damage reporting, potential emergency response based on reports, and proactive lamp post maintenance. This future-proof approach empowers municipalities to create smarter, more sustainable cities with improved efficiency and citizen engagement, paving the way for a brighter future in urban illumination.

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