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Effi Street: IoT-Driven Urban Illumination by Enhancing Energy Efficiency in Street Lighting

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Abstract:

In urban areas, street lighting is essential for ensuring safety and visibility, but it often leads to significant energy wastage and high electricity costs. Traditional manual streetlight systems remain powered throughout the night, regardless of natural light availability, resulting in unnecessary consumption. To address these challenges, this project introduces an IoT-Based Smart Street Light Management System. This system leverages IoT technology to conserve energy, reduce electricity wastage, and minimize manual intervention. Key components include energy-efficient LED lights with adjustable brightness, a DHT11 Temperature-Humidity sensor for real-time environmental data, and a programmed Arduino board for intelligent light intensity regulation. By optimizing streetlight operation, this IoT-enabled solution offers enhanced energy efficiency and performance compared to traditional systems, benefiting both the environment and the economy.

Keywords: *IoT-Based Smart Street Lighting, Energy Efficiency, LED Lights, Environmental Monitoring, Street Light Management, Internet of Things (IoT), Energy Conservation, Automated Control, Sustainability, Arduino Controller*

1. INTRODUCTION

In today's rapidly urbanizing world, where cities are constantly expanding This paper introduces a streetlamp control system that relies on the Bolt IoT platform. As published paper The primary objective of this project is to conserve energy, reduce electricity wastage, and minimize the need for human intervention [1]. Where in this paper says that the street lights are governed by an embedded brightness sensor, which activates them in low-light conditions and deactivates them when the surroundings become sufficiently bright[2] .This specified that it includes findings from practical tests involving dynamic street lights implemented in urban environments. The suggested dynamic lighting control solution allows for approximately 56% energy savings when compared to the conventional static, time-based street lighting control[3]. This paper have published his paper and in this paper he mentioned that The core objective of this project centers on crafting a street light control system geared towards diminishing power consumption. The prototype is fashioned using components such as a Light Dependent Resistor (LDR), an Infrared sensor (IR), a battery, and LED lights. The orchestration of these elements is overseen by the Arduino UNO microcontroller. The project primarily focuses on regulating the brightness of the lamps to curtail power usage [4].This paper in year 2020 This article tackles the growing demand for decision support tools aimed at effectively managing energy in urban street lighting systems [5]. According to this paper It employs wireless devices based on ZigBee technology, facilitating enhanced management of street lamp systems through a sophisticated interface and control architecture, leading to improved efficiency [6].

Furthermore, the paper published highlights the increasing energy consumption in India due to the growing number of street lights [7] .The project aims to provide automatic control and fault detection for street lamps, focusing on energy efficiency and affordability for street lighting. It employs IoT technology for remote control and monitoring of street lights [8].

The research paper addresses the energy consumption and manual monitoring challenges of street lights worldwide. It proposes an IoT-based system that monitors and controls street lights, optimizing their operation from 6 pm to 6 am to conserve energy [9]. .IOT-based Street Lighting Control System. As he said in his paper the primary goals are to conserve energy, reduce electricity wastage, and minimize the need for manual intervention. Streetlights play a crucial role in ensuring safety and visibility in urban areas, but they also consume a significant amount of electricity [10]. This published paper utilizes LDR sensors, an MSP430 microcontroller, and relay switches to control LED street lights based on natural light levels. Integrated IP65 CCTV cameras and panic buttons enhance safety by recording street activities and triggering emergency alerts when needed [11] .This paper shows that the intelligent street lighting system presents an effective solution to the substantial energy expenses associated with city street lighting, potentially reducing costs by 50% - 70%. Employing technology like IR sensors, LDRs, PIC16F877A microcontrollers, relays, UART, and Wi-Fi modules, it automates light control based on traffic and ambient light conditions [12]. It combines renewable energy sources, such as solar panels and Vertical Axis Wind Turbines (VAWT), to provide a sustainable and eco-friendly solution for public lighting installations [13] .In this paper the system's architecture includes an Arduino Mega 2560 microcontroller, infrared and voltage sensors, a relay module, and a Wi-Fi module (ESP-01) for network connectivity. This smart controller system aims to enhance energy conservation by dynamically adjusting street light usage based on real-time conditions [14]. Furthermore, The primary contribution is the ability to adjust the luminance intensity of smart LED lights based on changing diurnal traffic volume, enabling energy conservation and emissions reduction.[15] .

2. LITERATURE REVIEW

This paper [1] presents a streetlamp control system based on the Bolt IoT platform, aimed at conserving energy and reducing manpower in street lighting. It uses energy-efficient LED lights and light intensity control through LDR sensors. IR sensors detect vehicle density and movement to activate LEDs for specific road sections, improving efficiency. The system offers better performance than existing systems and leverages IoT for remote monitoring and control. It addresses issues with manual streetlamp systems and offers power-saving components like LEDs and LDRs. The Bolt IoT platform provides wireless connectivity and cloud access for efficient remote management. This paper [2] discusses the concept of smart street lighting to address the issue of energy wastage in traditional street lighting systems. It focuses on designing a system that reduces power consumption using components like Light Dependent Resistors (LDR), Infrared sensors (IR), batteries, and LEDs controlled by an Arduino UNO microcontroller. It also highlights the importance of smart city concepts and the need to improve existing street lighting systems for environmental and cost-effectiveness reasons. The proposed smart street light system aims to reduce power consumption and enhance energy efficiency. Street lighting systems for environmental and cost-effectiveness reasons. The proposed smart street light system aims to reduce power consumption and enhance energy efficiency.

This paper [3] introduces a dynamic street light control and management solution based on an open and flexible Internet of Things (IoT) architecture. The system's innovative aspect lies in using model-driven communication agents to expedite the integration of sensors and actuators into IoT platforms. Real-world tests have demonstrated that this dynamic light control solution can save approximately 56% of energy compared to traditional static, time-based street light control methods. The paper addresses the economic and ecological challenges associated with street lighting and highlights the potential benefits of dynamic street lighting in terms of energy efficiency and cost reduction. This paper [4] introduces a smart street lighting system based on IoT technology, which efficiently controls street lights by using sensors to adjust brightness as needed. The system aims to reduce accidents on roads, save power, enhance safety, and provide well-lit environments for pedestrians during nighttime. It addresses the issue of excessive energy consumption by traditional street lights and highlights the benefits of using efficient LED lights and sensor-driven control to conserve electricity. Overall, the paper emphasizes the economic and environmental advantages of implementing this technology in street lighting.

This paper [5] presents a decision-making procedure for optimizing the energy retrofit plan of a public street lighting system in urban areas. The proposed model aims to maximize energy consumption reduction while efficiently allocating retrofit actions and budget. It formulates the optimization problem as a quadratic knapsack problem and employs a decentralized control algorithm. The approach is computationally efficient and scalable. The article includes a real-world case study from the city of Bari, Italy, demonstrating the effectiveness of the proposed strategy in managing large-scale street lighting systems for optimal energy efficiency and environmental sustainability. This paper [6] introduces a remote-control system for optimizing the management and efficiency of street lighting systems. It utilizes ZigBee-based wireless devices to enable more efficient control and monitoring of street lamps. The system employs sensors to control and maintain desired parameters, transferring data point by point through ZigBee transmitters and receivers. A control terminal is used to monitor lamp status and take corrective actions in case of failures. This integrated system combines LED technology, remote control, and renewable energy sources for more cost-effective and environmentally friendly street lighting management.

This paper [7] Street lighting is essential for urban and rural infrastructure but consumes a significant amount of electricity, posing both energy wastage and high costs. The paper highlights the increasing energy consumption in India due to the growing number of street lights. The research introduces a Street Light Monitoring System that leverages IoT technology and GSM modules for wireless communication. Each street light is monitored by a server-based system, enabling data transmission through a wireless network. The system employs PHP, JAVA, AJAX, and web-based applications for monitoring and controlling street lights. Users can access a web-based interface to check street light status and make remote adjustments. Users can remotely control street lights through the web-based interface. Data from each street light is collected, transmitted, and processed for efficient operation. The IoT-based Street Light Monitoring System offers an efficient and cost-effective solution for managing street lighting, aiming to reduce energy consumption, minimize light pollution, and provide flexibility to adapt to user needs. This paper [8] presents an automatic street light system with sensors and wireless technology The project aims to provide automatic control and fault detection for street lamps, focusing on energy efficiency and affordability for street lighting. It employs IoT technology for remote control and monitoring of street lights. Automatic Operation: Light levels are sensed using an LDR sensor, ensuring lights are on in the dark and off in well-lit areas. An SMS is sent to ward members and service personnel through a GSM module for immediate action. Sensor data is stored in a cloud server, allowing access to street light system information anywhere and anytime. Light-dependent resistors (LDRs) are used to sense the light environment The system incorporates wireless modules for data transmission, allowing remote access to street light status through a Wi-Fi module and cloud-based monitoring.

This research paper[9] addresses the energy consumption and manual monitoring challenges of street lights worldwide It proposes an IoT-based system that monitors and controls street lights, optimizing their operation from 6 pm to 6 am to conserve energy. When a fault occurs, the system disconnects the light and notifies the user, enhancing reliability and maintainability. Real-time voltage, current, power consumption, and fault status data can be accessed globally through a Thingspeak IoT portal. Key components include Arduino UNO, NodeMCU, and sensors. This automation not only ensures that energy consumption is optimized but also reduces the manual effort required for street light operation. This project [10] focuses on the development of an automated streetlight management system using IoT technology. The primary goals are to conserve energy, reduce electricity wastage, and minimize the need for manual intervention.

To address this issue, an IoT-based streetlight management system is proposed. Key components of this system include Light Emitting Diodes (LEDs) that are energy-efficient and capable of adjusting their intensity. Unlike traditional High-Intensity Discharge (HID) lamps, LEDs can vary their brightness, optimizing the efficiency of streetlights. The system also incorporates a DHT11 Temperature-Humidity sensor to provide real-time data on temperature and humidity in a specific region. The system is controlled by a programmed Arduino board, which regulates the intensity of the LED lights at different times. This IoT-enabled approach offers better energy efficiency and performance compared to traditional manual systems.

This paper [11] represents proposed smart street lighting system aims to address the significant expense of traditional street lights by reducing energy wastage through automation. It utilizes LDR sensors, an MSP430 microcontroller, and relay switches to control LED street lights based on natural light levels. Integrated IP65 CCTV cameras and panic buttons enhance safety by recording street activities and triggering emergency alerts when needed. Footage is stored in a server and sent to a cloud account, alerting nearby police stations in case of emergencies. This innovative system not only improves safety but also helps optimize energy consumption and municipal spending. This paper [12] states intelligent street lighting system presents an effective solution to the substantial energy expenses associated with city street lighting, potentially reducing costs by 50% - 70%. Employing technology like IR sensors, LDRs, PIC16F877A microcontrollers, relays, UART, and WiFi modules, it automates light control based on traffic and ambient light conditions. This innovative approach eliminates emission manpower requirements and promoting energy-efficient urban environments. the need for manual operation, leading to energy savings, reduced maintenance expenses, lower CO_2 emissions, and less light pollution. Furthermore, the system leverages wireless communication, reducing manpower requirements and promoting energy-efficient urban environments

This paper [13] proposed hybrid lighting system, integrated with IoT technology, addresses the increasing energy demand driven by population growth and industrial expansion. It combines renewable energy sources, such as solar panels and Vertical Axis Wind Turbines (VAWT), to provide a sustainable and eco-friendly solution for public lighting installations. This system efficiently monitors battery parameters, solar panel and wind generator outputs, LED lamp luminance, and more in real-time, facilitating effective control, preventive maintenance, and increased system lifespan. By leveraging abundant non-conventional energy sources, this self-sustaining hybrid system minimizes transmission losses and reduces reliance on limited conventional energy sources, contributing to reduced energy costs and environmental impact. This paper [14] is for lot importance of optimizing electrical energy utilization, particularly in street lighting systems, due to the significant energy consumption involved. It highlights the inefficiency of traditional timer-based street lighting systems and the need for more intelligent solutions. The proposed solution is an IoT-based smart street lighting system that uses sensors to detect movement and Control Street lights accordingly, reducing energy wastage. The system's architecture includes an Arduino Mega 2560 microcontroller, infrared and voltage sensors, a relay module, and a Wi-Fi module (ESP-01) for network connectivity. This smart controller system aims to enhance energy conservation by dynamically adjusting street light usage based on real-time conditions. This paper [15] introduces an advanced level of intelligence in smart street lighting by implementing adaptive traffic control. The primary contribution is the ability to adjust the luminance intensity of smart LED lights based on changing diurnal traffic volume, enabling energy conservation and emissions reduction. This adaptive control system is experimentally implemented and has the potential to align with varying seasonal daylight timings. Furthermore, the paper discusses the integration of smart street lights into a broader smart grid platform with demand response (DR) and advanced metering information (AMI), offering opportunities for future green cities. The paper concludes with insights into energy consumption challenges and the role of communication standards in building smart grid networks, with a focus on ZigBee-based wireless mesh networks and TCP/IP protocols for remote monitoring and demand response.

3. METHEDOLOGY

Introduction:

In this section, we will outline the methodology used to create an energy-efficient outdoor lighting system that serves two primary scenarios: car headlights detection and pedestrian detection. The system leverages Light Dependent Resistors (LDR) and Passive Infrared (PIR) sensors, along with the NodeMCU microcontroller for smart control of outdoor lighting.

a. Hardware Setup:

The hardware components used in this project include:

- LDR sensor for measuring ambient light levels.
- PIR sensor for detecting motion.
- NodeMCU, an ESP8266-based microcontroller, to control and monitor the system.
- LEDs for illumination.

The physical setup involves connecting these components as follows:

- The LDR sensor is connected to one of the NodeMCU's analog pins.
- The PIR sensor is connected to a digital pin on the NodeMCU.
- LEDs are connected to digital pins on the NodeMCU for adjustable illumination.

b. Software and Platform:

To enable data monitoring and control, the project utilizes the following software and platform:

- ThinkSpeak, a cloud-based Internet of Things (IoT) platform, is used for data monitoring and analysis.
- The NodeMCU is programmed to integrate with ThinkSpeak for real-time data transmission.

Scenario 1: Car Headlights Detection:

In this scenario, the system continuously measures ambient light levels using the LDR sensor. When a significant decrease in light is detected, indicating the presence of car headlights, the PIR sensor is triggered, and it locks the last recorded LDR value. The LEDs then adjust their brightness based on this locked LDR value, providing appropriate lighting to complement the external light source from the car's headlights.

Scenario 2: Pedestrian Detection:

For pedestrian detection, the PIR sensor is the primary component. It is programmed to detect motion within its range. When motion is detected, the system sets the LEDs to their maximum brightness. This ensures well-illuminated pathways for pedestrians, enhancing safety.

Scenario 3: Default Minimum Brightness:

In the absence of both the car headlights and pedestrian detection scenarios, the outdoor lights remain at a default minimum brightness level. This ensures that the area is never completely dark, providing a basic level of visibility and safety.

c. Data Monitoring:

Sensor data collected by the LDR and PIR sensors are transmitted to the ThinkSpeak platform for real-time monitoring and analysis. This data can be visualized and analyzed to make informed decisions about lighting adjustments.

d. Testing and Calibration:

To ensure the effectiveness and accuracy of the system, it is crucial to test it under real environmental conditions. The system should be calibrated to respond appropriately to different light levels and motion patterns. This calibration process involves fine-tuning the sensor sensitivity and LED brightness levels to optimize energy efficiency and safety.

- Data Monitoring:
  - Transmit sensor data to ThinkSpeak for monitoring and analysis.
- Testing and Calibration:
  - Test in real conditions and calibrate for accurate detection and lighting adjustments.

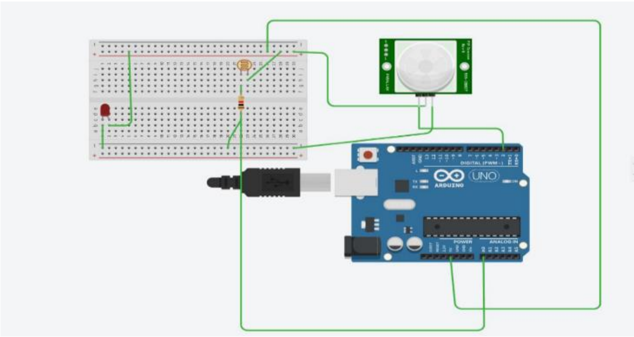

Fig.1 Components connections

4. CIRCUIT DISCRIPTION

Fig.1 shows following components and connectios

Components :

1. ESP8266 (NodeMCU or similar)
2. LDR (Light Dependent Resistor)

3. PIR (Passive Infrared) Motion Sensor
4. LED
5. Resistors
6. Breadboard and jumper wires

Connections :

1.LDR(Light Dependent Resistor) :

One leg of the LDR is conneted to the common Vcc (3.3V) of the ESP8266 and other one is to the resistor.

The junction point between the LDR and the resistor is connected to the A0 (analog input) pin of the ESP8266 and other leg of the resistor is connected to the common ground

2.PIR (Passive Infrared) Motion Sensor:

Power pin of the PIR is connected to the common Vcc (3.3V) and ground pin to the common ground

OUT or digital pin of the PIR is connected to ESP8266's D2 pin

3.LED :

LED's anode is connected to the ESP8266's D3 pin and the cathode to the common ground

Given:

ldrValue: The input value from the LDR sensor.

brightness: The output brightness value for controlling an LED.

Mathematical Equation:

brightness = m * (ldrValue - ldrMin) + outputMin

ldrMin is the minimum value of `ldrValue`, which is 800

outputMin is the minimum brightness value, which is 0

outputMax is the maximum brightness value, which is 255

m is the slope of the linear equation, which can be calculated as:

$$m = (outputMax - outputMin) / (ldrMax - ldrMin)$$

ldrMin = 800

outputMin = 0

outputMax = 255

ldrMax = 1023

Calculating m:

$$m = (outputMax - outputMin) / (ldrMax - ldrMin)`$$

m = (255 - 0) / (1023 - 800)`

m = 255 / 223`

So, the numeric mathematical equation is:

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brightness = (255 / 223) * (ldrValue - 800)

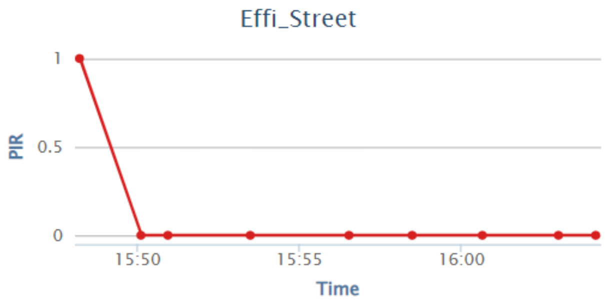

Fig.2 PIR vs Time Graph

According to Fig.2 the value is plotted on the graph as soon as the car or pedestrian is almost in front of the PIR sensor.

Its value ranges from 0 to 1. PIR values are shown on the Y-axis, and time is displayed on the X-axis. The value will be 1 if a movement is detected, else it will be 0, and the graph will display this information.

LDR

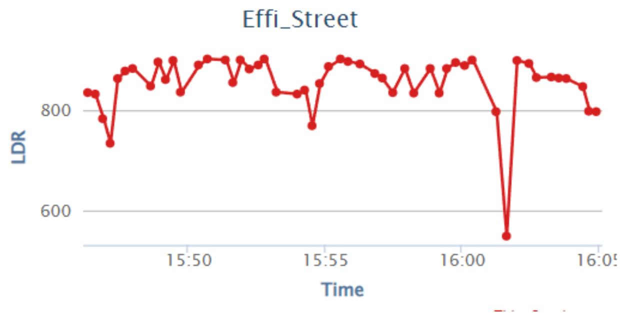

Fig.3 LDR vs Time Graph

In Fig.3 as based on data gathered by the LDR sensor from the car's headlight, this graph was created.

LDR values are shown on the Y-axis, and time is shown on the X-axis. This graph displays the change in brightness of the car over time as recorded by the sensor.

5. CONCLUSION

In conclusion, Contemporary storage architecture is characterized by its emphasis on scalability, which enables it to accommodate the ever-increasing volume of data generated by organizations. It is designed to handle a diverse range of data types, from structured to unstructured, and supports various applications and use cases. Redundancy and data availability are of utmost importance, with techniques such as data replication and failover mechanisms ensuring uninterrupted access to critical information. Data security is a top priority, with encryption, access controls, and authentication measures in place to safeguard sensitive data.

Data lifecycle management is a critical aspect, involving the movement of data between different storage tiers based on relevance, performance needs, and cost considerations. Integration with cloud storage solutions is commonplace, enabling organizations to leverage cloud benefits such as scalability, accessibility, and cost-effectiveness.

High-performance storage options, such as solid-state drives (SSDs) and in-memory storage, are integrated to cater to data-intensive applications and real-time processing requirements. Optimization for data retrieval is crucial, employing indexing, caching, and query optimization to minimize latency and enhance data access speeds. Cost optimization strategies include tiered storage, data deduplication, and compression. Automation and elastic scaling reduce management overhead, and modern storage architecture supports data analytics and AI applications, providing the infrastructure necessary for processing and analyzing large datasets. Additionally, integration with Database Management Systems (DBMS) ensures efficient structured data storage and retrieval, while disaster recovery capabilities offer protection against unforeseen data loss.

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