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IOT – Enabled Smart Street Light Using ESP32

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Abstract: *The proposed project presents a Smart Solar-Based Automatic Street Light and Weather Monitoring System using ESP32 and Blynk IOT platform. The system is designed to provide energy-efficient street lighting along with real-time environmental monitoring using renewable energy sources. The system utilizes a solar panel to generate electrical energy, which is stored in a battery through a charging module. The stored energy powers the ESP32 microcontroller, which acts as the central control unit. Multiple sensors such as LDR (Light Dependent Resistor), IR sensor, DHT11 temperature sensor, and rain sensor are integrated to monitor environmental conditions. Based on the LDR readings, the system automatically distinguishes between day and night conditions. During daytime, the street lights remain OFF to conserve energy. At night, the system operates in energy-saving mode by maintaining LEDs at 50% brightness, and when a vehicle is detected using the IR sensor, the brightness increases to 100%, ensuring safety and visibility. Additionally, the system monitors temperature and rainfall conditions, displaying real-time data on a 16×2 LCD. The collected data is also transmitted to the Blynk IOT platform via Wi-Fi, enabling remote monitoring and control. This system is highly efficient, cost-effective, and eco-friendly, as it reduces power consumption and utilizes renewable energy. It is suitable for smart city applications and helps in improving energy management, automation, and environmental awareness.*

Key Words: *IoT, Smart Street Lighting, ESP32, Blynk IoT Platform, Solar Energy, Energy Efficiency, Automatic Street Light, Vehicle Detection, Weather Monitoring, LDR Sensor, IR Sensor, DHT11 Sensor, Rain Sensor, PWM Control, Smart City Applications.*

I. INTRODUCTION

Street lighting plays a major role in modern urban infrastructure by providing safety, security, and visibility for pedestrians and vehicles during nighttime. Conventional street lighting systems generally operate continuously at full intensity regardless of traffic density, weather conditions, or environmental requirements. This results in excessive energy consumption, increased operational costs, and unnecessary wastage of electrical power.

With the rapid development of smart city technologies and the growing demand for energy conservation, intelligent and automated street lighting systems have become an important area of research. The integration of Internet of Things (IoT) technology with embedded systems enables real-time monitoring, automation, and efficient management of street lighting infrastructure. IoT-based systems provide remote accessibility, data visualization, and adaptive control mechanisms that improve overall system performance.

The proposed project, "IoT-Enabled Smart Street Light Using ESP32," presents an intelligent and energy-efficient street lighting system that automatically controls street light brightness based on environmental and traffic conditions. The system utilizes an ESP32 microcontroller as the central processing unit due to its built-in Wi-Fi capability, low power consumption, and compatibility with multiple sensors. Various sensors such as LDR, IR sensor, rain sensor, and DHT11 temperature and humidity sensor are integrated into the system to monitor ambient light, vehicle movement, rainfall, and atmospheric conditions.

The system operates automatically by switching OFF the street lights during daytime and maintaining dim lighting during normal nighttime conditions. Whenever a vehicle is detected or adverse weather conditions such as rain or fog occur, the brightness of the LED street lights increases to maximum intensity to improve visibility and road safety. In addition, the system is powered using solar energy with rechargeable battery support, making it environmentally friendly and suitable for sustainable smart city applications.

The collected sensor data is displayed on a 16×2 LCD display and simultaneously transmitted to the Blynk IoT cloud platform through Wi-Fi connectivity. This enables real-time remote monitoring and analysis of system performance. The proposed system not only reduces energy consumption but also enhances automation, improves public safety, and supports the development of smart and sustainable urban infrastructure.

II.MATERIAL AND METHODS

Materials

The proposed IoT-enabled smart street light system consists of various hardware and software components that work together to achieve automatic street light control, environmental monitoring, and remote IoT communication.

Hardware Components

1. ESP32Microcontroller

The ESP32 acts as the main controller of the system. It processes sensor data, controls LED brightness, manages Wi-Fi communication, and sends data to the Blynk IoT platform.

2. LDR Sensor (Light Dependent Resistor)

The LDR sensor is used to detect ambient light intensity and determine day and night conditions.

3. IR Sensor

The IR obstacle sensor is used for vehicle detection. When a vehicle is detected, the system increases street light brightness to improve road visibility.

4. DHT11 Sensor

The DHT11 sensor measures temperature and humidity from the surrounding environment for weather monitoring.

5. Rain Sensor Module

The rain sensor detects rainfall or wet road conditions and increases the street light brightness during rain.

6. LED Street Light Prototype

LEDs are used as the street light model. Their brightness is controlled using PWM signals generated by the ESP32.

7. 16×2 I2C LCD Display

The LCD display is used to show real-time sensor readings, operating modes, and system status locally.

8. Solar Panel and Rechargeable Battery

The solar panel generates electrical energy, while the rechargeable battery stores energy for nighttime operation.

9. Battery Charging Module and Booster Converter

These modules regulate voltage and safely charge the battery to ensure stable system operation.

10. Breadboard and Connecting Wires

Used for prototype implementation and hardware interconnections.

Software Requirements

The software components used in the project include:

- Arduino IDE
- ESP32 Board Package
- Blynk IoT Platform
- Embedded C/C++ Programming Language

The following libraries are used in the Arduino IDE:

- WiFi.h
- BlynkSimpleEsp32.h
- DHT.h
- LiquidCrystal_I2C.h
- Wire.h

Methodology

The working methodology of the proposed smart street lighting system is based on sensor data acquisition, intelligent decision-making, automatic brightness control, and IoT-based remote monitoring.

Step 1: System Initialization

When the system is powered ON, the ESP32 microcontroller initializes all connected peripherals including:

- Sensors
- LCD display
- PWM control

- Wi-Fi connection
- Blynk cloud communication

The LCD displays the message “System Ready” after successful initialization.

Step 2: Sensor Data Collection

The ESP32 continuously reads data from different sensors:

- LDR sensor for ambient light detection
- IR sensor for vehicle detection
- DHT11 sensor for temperature and humidity
- Rain sensor for rainfall detection

Step 3: Day and Night Detection

The LDR sensor determines whether it is day or night by comparing the light intensity with a predefined threshold value.

- Daytime → Street light OFF
- Nighttime → Street light activated

Step 4: Vehicle Detection and Brightness Control

During nighttime:

- If no vehicle is detected, the LED street light operates at dim brightness (around 40–50%) to conserve energy.
- If a vehicle is detected by the IR sensor, the brightness increases to 100% using PWM control.

Step 5: Weather-Based Lighting Control

The rain sensor and humidity readings help identify rainy or foggy conditions. During such conditions, the system automatically increases brightness to improve road visibility and safety.

Step 6: LCD Display Monitoring

The 16×2 I2C LCD display continuously shows:

- Temperature
- Humidity
- Vehicle detection status
- Day/Night mode
- Light operating condition

Step 7: IoT Data Upload

The ESP32 connects to the internet through Wi-Fi and uploads sensor data to the Blynk cloud platform using virtual pins. The Blynk dashboard allows users to monitor system parameters remotely in real time.

Step 8: Continuous Operation

The system continuously repeats the process of:

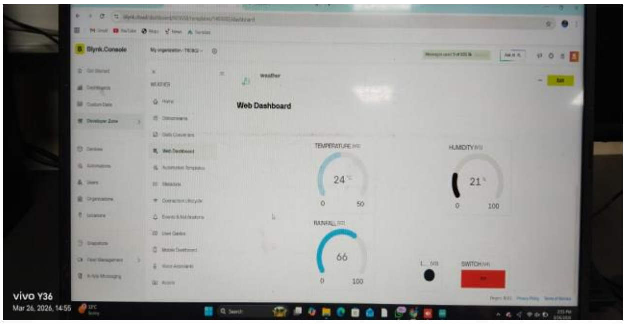
- Reading sensor values
- Processing data
- Adjusting street light brightness
- Updating LCD display
- Uploading IoT data

This methodology enables the smart street lighting system to operate automatically, efficiently, and intelligently while reducing energy consumption and improving road safety.

III.RESULT

A. Blynk IoT Dashboard Output:

- Blynk Dashboard Live Data

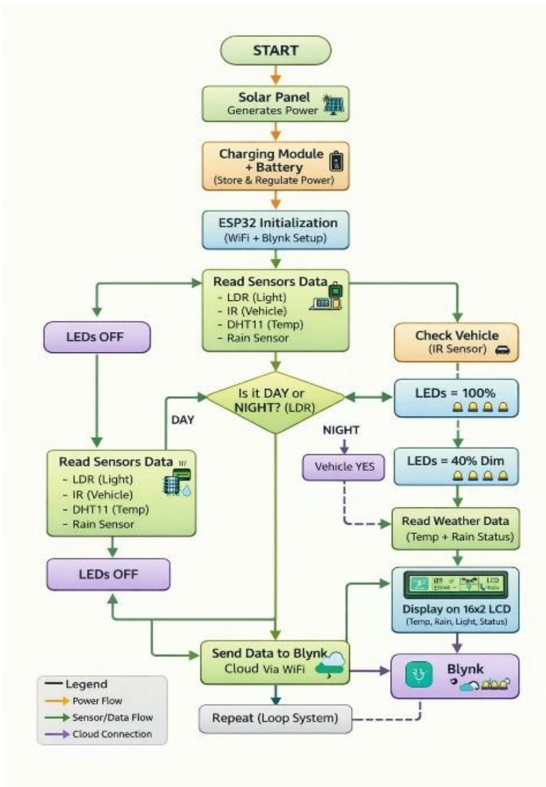


The Blynk IoT dashboard was used for real-time monitoring of environmental and street light parameters. The ESP32 successfully transmitted temperature, humidity, rainfall, and LED status data to the cloud platform through Wi-Ficommunication. The dashboard displayed live sensor values and switch control status. The experimental results confirmed reliable IoT communication between the ESP32 microcontroller and the Blynk cloud server

B. **LCD Display Output**

The 16×2 I2C LCD display successfully displayed real-time system information including temperature, humidity, and lighting status. The LCD dynamically updated sensor readings according to environmental conditions. During daytime, the display indicated “Light OFF” mode, while during vehicle detection or rainfall conditions the lighting status changed automatically. The LCD output verified correct sensor integration and real-time data processing by the ESP32.

C. **System Flowchart and Operation**



The flowchart represents the overall working procedure of the proposed smart street lighting system. Initially, the ESP32 initializes all sensors and establishes Wi-Fi communication with the Blynk cloud platform. The LDR sensor continuously monitors ambient light conditions to determine day or night operation. During nighttime, the IR sensor detects vehicle movement and adjusts LED brightness accordingly using PWM control. Sensor data is displayed on the LCD and uploaded to the Blynk cloud for remote monitoring. The system continuously repeats this process to achieve intelligent and energy-efficient street lighting.

D. Vehicle Detection Result

The IR sensor successfully detected vehicle movement during testing. When a vehicle or obstacle was detected, the LED brightness increased automatically to 100% intensity to improve road visibility. Simultaneously, the LCD displayed the vehicle detection status, and the corresponding data was updated on the Blynk dashboard. The test results confirmed proper operation of the vehicle detection mechanism.

E. Rain Detection Result

The rain sensor successfully detected rainfall conditions when water droplets were applied to the sensor surface. During rain conditions, the LED brightness automatically increased to maximum intensity to improve visibility and road safety. The rainfall data was transmitted to the Blynk platform for remote monitoring. The results confirmed that the system effectively responds to changing weather conditions.

F. Overall System Performance

The rain sensor successfully detected rainfall conditions when water droplets were applied to the sensor surface. During rain conditions, the LED brightness automatically increased to maximum intensity to improve visibility and road safety. The rainfall data was transmitted to the Blynk platform for remote monitoring. The results confirmed that the system effectively responds to changing weather conditions.

IV.DISCUSSION

The proposed IoT-enabled smart street lighting system was successfully implemented using the ESP32 microcontroller, multiple environmental sensors, and the Blynk cloud platform. The system demonstrated efficient automatic street light control based on real-time environmental and traffic conditions.

The LDR sensor accurately detected day and night conditions, enabling the system to automatically switch OFF the street lights during daytime and activate them during nighttime. This automation significantly reduced unnecessary energy consumption. During nighttime conditions, the LED street lights operated at dim brightness to conserve power. Whenever a vehicle was detected using the IR sensor, the LED brightness automatically increased to maximum intensity, improving road visibility and enhancing public safety.

The rain sensor and DHT11 temperature-humidity sensor successfully monitored environmental conditions. During rainfall or high humidity conditions, the system increased the LED brightness to improve visibility on wet or foggy roads. These features demonstrate the intelligent and adaptive behavior of the proposed system under changing environmental conditions.

The integration of the ESP32 with the Blynk IoT platform enabled successful wireless communication and real-time cloud monitoring. Sensor readings such as temperature, humidity, rainfall status, and lighting conditions were continuously uploaded to the Blynk dashboard through Wi-Fi communication. The dashboard displayed real-time updates, confirming reliable IoT connectivity and remote accessibility of system data.

The 16×2 I2C LCD display also provided effective local monitoring by displaying system parameters such as temperature, humidity, vehicle detection status, and operating mode. The LCD output changed dynamically according to sensor inputs, confirming proper sensor integration and real-time processing capability of the ESP32 microcontroller.

The use of solar power, rechargeable batteries, and adaptive brightness control improved the overall energy efficiency of the system. Compared to conventional street lighting systems that operate continuously at full intensity, the proposed system minimized power consumption while maintaining proper illumination and road safety.

Overall, the experimental results confirmed that the proposed smart street lighting system is reliable, energy-efficient, cost-effective, and suitable for smart city and intelligent transportation applications.

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V.CONCLUSION

The proposed IoT-enabled Smart Street Light System using ESP32 was successfully designed and implemented to provide an intelligent, automated, and energy-efficient street lighting solution. The system effectively controlled street light brightness based on environmental conditions such as day/night detection, vehicle movement, and rainfall conditions.

The LDR sensor automatically switched OFF the street lights during daytime and activated them during nighttime, reducing unnecessary power consumption. The IR sensor successfully detected vehicle movement and increased LED brightness to improve road visibility and safety. The rain sensor and DHT11 sensor monitored environmental conditions and enabled adaptive lighting control during adverse weather conditions.

The ESP32 microcontroller efficiently processed sensor data and established wireless communication with the Blynk IoT platform through Wi-Fi connectivity. Real-time monitoring of temperature, humidity, rainfall status, and lighting conditions was successfully achieved using the Blynk dashboard. The 16×2 I2C LCD display also provided local monitoring of system parameters and operating status.

The integration of solar power, rechargeable battery support, and adaptive brightness control significantly improved the energy efficiency of the system compared to conventional street lighting methods. The experimental results confirmed reliable system performance, automatic operation, reduced energy consumption, and effective IoT-based monitoring.

Therefore, the proposed smart street lighting system provides a cost-effective, environmentally friendly, and scalable solution suitable for smart city and intelligent transportation applications.

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