IOT-BASED SMART STREET LIGHT SYSTEM USING ESP32

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Abstract: To designed Internet of Things (IoT)-developed on a Adaptive street light infrastructure using ESP32, combining the benefits and advantages of solar energy power, the LDR-based automation, and current sensing fault detection using the techniques to bring forth efficient and reliable lighting solutions. The system used an LDR sensor for automatic turning ON of the lights during low light condition and automatic turning OFF of the lights during daylight hours, thus reducing energy loss and the need for human intervention. For sustainable power availability during nighttime hours, a solar panel charges a battery during daytime hours. To further ensure reliability, the system uses a current sensor that monitors the load current constantly. As a result, the solution provides automatic fault detection for conditions such as burning out of the lights, open-circuit conditions, and disconnection, which can be detected automatically once the current level goes below a predetermined threshold. The ESP32 microcontroller sends real-time current values and fault information data to the ThingSpeak cloud server for remote monitoring purposes. In this manner, a reliable and sustainable energy solution can be provided for the lighting system that has the added advantage of smartness by means of the Internet of Things (IoT).

Keywords: IoT, ESP32 microcontroller, Digital street lighting, Solar energy utilization, LDR sensor automation, Current-based fault detection, ThingSpeak cloud monitoring, Energy.

1. INTRODUCTION

Street lighting plays a vital role as a critical application within the provision related to safety to the community, but it represents a key areas of power usage of energy in the municipality. Notably, the increasing focus is being placed on smart city development, prompting the need to adopt smart, efficient, and optimized street lighting by reducing wastage of energy [1]. Conventional streetlighting solution includes manual processing of the system, which may result in a solution of an wastage of energy, delayed identification of faults, and incurring higher maintenance costs. In a bid to solve the problem associated with the traditional the IoT-based street lighting solution using ESP32 utilises automation, solar energy, and real-time processing [2]. The system incorporates the use of an LDR sensor, which ensures night-and-day automatic switching, a solar panel, which is environmentally sustainable as it uses solar energy, and a current sensor, which ensures fault identification, all of which are processed by the ESP32 microcontroller [7]. This enables the real-time transfer of data to the Think Speak cloud data, which ensures remote monitoring of the system, hence rapid identification of faults. Dislike the traditional system, this proposal incorporates solar energy, automation, and IoT-based fault identification [3].

Street lighting is one of the crucial infrastructure systems in urban and rural areas, providing safety, security, and facilitation during the night hours [8]. However, the traditional street lighting infrastructures are known to consume a huge and very large amount of electricity and are dependent on non-renewable energy sources, thereby incurring massive costs and challenges related to climate change. But owing to the increasing popularity of smart city initiatives in the global scenario, the need to execute intelligent, eco-friendly, and automated lighting systems that possess the ability to reduce usage while avoiding affecting the same levels as well as stages of functionality has witnessed an escalation [9]. Implementation of IoT in renewable energy systems seems to be an innovative solution to the successful achievement of the same [4]. The traditional street lighting infrastructure is linked to various limitations in relation to its efficiency and sustainability. Most of the traditional street lighting infrastructure involves lighting in accordance with a routine or switching pattern, thereby incurring massive energy wastage due to the activation of lights even when sufficient ambient lighting is present in the surroundings [10]. Apart from that, the procedure of detection of faults in conventional wheel balancing machines is slow with low sensitivity, hence requiring manual analysis, thus incurring extra costs with regard to the same [5]. Overcoming the challenges of energy management and fault detection, the proposed system can serve to support the development of sustainable intelligent street lighting. It can be seen from the proposal that the combination of technologies of the Internet of Things with Renewable Energies can ensure cost-effective, environmentally friendly, and sustainable infrastructure development[6]. The applicability and robustness of the proposal assure its efficiency and viability across different areas, from high-population cities to resource-poor areas. At last, this proposal helps to support achieving the vision of smart cities, which focuses on efficient resource consumption, environmental sustainability, and public security through reliable street lighting [11].
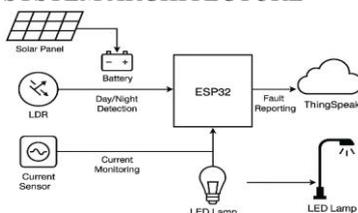
2. SYSTEM ARCHITECTURE

Figure 1: System architecture of IoT-based smart street light system using ESP32

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The above Figure 1 represents an IoT-enabled intelligent street lighting framework using ESP32, aiming to incorporate renewable power sources, automation through sensors, and cloud monitoring for faults into an integrated system. The core controller of the system is the ESP32 microcontroller responsible for managing the input data from multiple sensors and communication with the cloud data. The solar panel charges a battery during daylight hours, which acts as a perpetual power source for the LED lamp during the night. The Light Detecting Resistance sensor examines the surrounding ambient light and helps the system automatically turn the lamp ON during the night and OFF during the day, thereby obviating the need for control through human intervention and preventing wastage of energy. Concomitantly, current sensing from the power detector examines the power stream values of the lamp. If the current drops below a set threshold while the lamp is still ON, the system looks for probable faults or disconnections related to the lamp. These probable faults, along with current values, are transmitted through Wi-Fi to the ThingSpeak cloud platform. The software components involve the Arduino IDE compiler for coding the microcontroller, while ThingSpeak is utilized for data visualization and reporting probable faults. Other protocols, such as MQTT or Blynk.

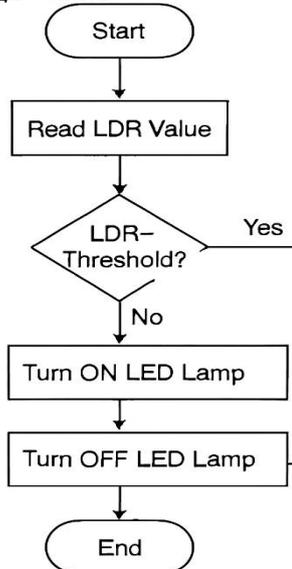## 3. METHODOLOGY
3.1 Day or Night controls

Figure 2: Algorithmic flowchart for day and night controls

The above Figure 2 represents a Day/Night Control mechanism in the smart street light system, based on the IoT, which is one of the most basic but highly effective mechanisms to ensure energy efficiency and automate the systems. At the core of this mechanism is the Light variable resistor sensor that is highly responsive relative to the intensity of the ambient light. This sensor is continuously analyzing the environment, taking real-time input data from the environment, which is then processed by the ESP32 microcontroller. As a result, when it detects a decrease in the ambient light intensity, which is below a predefined level, such as in the evening or low-light conditions, the ESP32 immediately trigger the LED lamp to turn ON, thus providing street illumination without an external push. On the contrary, when it notices the intensity of the ambient is greater than the pre-defined level, as in the daytime environments, the lamp automatically goes OFF to avoid any wastage of energy. The benefit of this mechanism is to be independent of the human factors, reduce the running costs, and increase the efficiency of the street illumination system by functionally switching it OFF when it is not required. This mechanism, based on sensor-controlled logic, dynamically responds to environmental conditions.
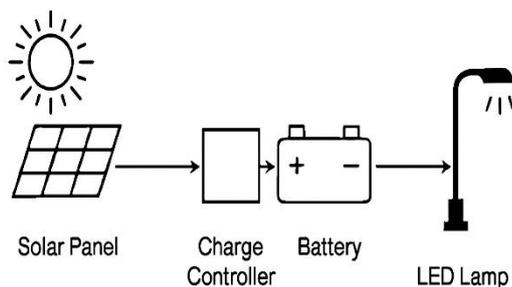
3.2 Solar Charging

Figure 3: Solar charging process in an IoT-enabled intelligent street lighting framework   Above Figure 3 denotes the solar charging system of the intelligent street light, allow to sustainable self-regulation of energy. The sunlight is received by the solar panel and converted into electrical energy, which is then regulated by the charge controller for proper charging of the battery. At night, the electrical energy from the battery allowed the LED light to work independently without the need for connection to the electric power grid. The use of solar energy allowed the system to cut down on energy expenditure while providing uninterrupted lighting even in rural areas. This perfectly synchronizes with the aim of the green energy initiative.
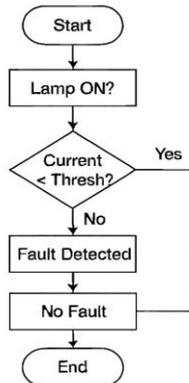
3.3 Fault detection

Figure 4: Fault detection algorithmic structure

Figure 4 denotes that fault detection ensure developed reliability in its operation and to avoid delays in performing the necessary maintenance. The main part of the process, which functions as a cental element in this system, is the current sensor. This sensor keeps track of the loading and the current flowing through the LED bulb. When the bulb is turned ON, which happens through the LDR sensor in low light conditions, the ESP32 microcontroller checks the status of the current sensor to ensure the LED bulb is working correctly. If the values of the current flowing through the bulb go below a certain threshold while the bulb should be ON, the system identifies it as a faulty situation. This situation can be a failure of the bulb, an open circuit condition, or a physical disconnect of the lighting module. If a situation of this nature arises, the ESP32 immediately indicates the problem and sends the status of the faulty situation along with the value of the current to the ThingSpeak cloud server through Wi-Fi connectivity.
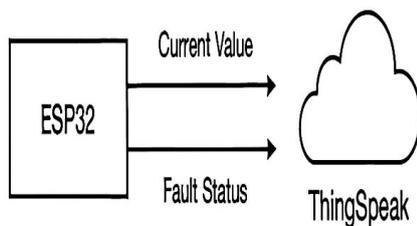
3.4 IoT communication

Figure 5: IoT communication architecture   Above Figure 5 represents the communication infrastructure of IoT in the smart street lighting system, which is very important for remote monitoring and immediate fault management. The heart of this interface lies in the ESP32 microcontroller, which has an integrated Wi-Fi system enabled easy data transfer to cloud services. During system functioning, the microcontroller reads data from sensors continuously, which includes current measurement from the load and faulty statuses calculated by the current sensor logic. The data obtained from the sensor is processed and transmitted to the ThingSpeak cloud system for storage, interpretation, and display. ThingSpeak offers a friendly interface for monitoring live data, creating alerts, and examining current trends, which makes it a preferred choice for smart system applications. By implementing IoT, it becomes feasible for all parties concerned to monitoring the performance and conditions of each street lighting system from a remote locations sending immediate alerts are also provided regarding faults, which helps to support the advanced scheduling of maintenance tasks and goals. This makes the system require minimal physical observation, and system reliability and flexibility are also greatly enhanced. The integration of communication infrastructure from ESP32 and cloud analysis from ThingSpeak helps create a smart, intelligent, and adaptive illumination system that meets current urbanization needs.
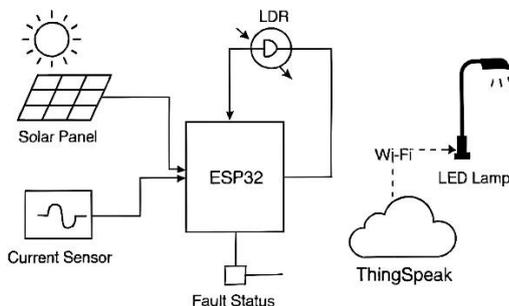
4. EXPERIMENTAL SETUP

Figure 6: Circuit connections for IoT based smart street light system

Above Figure 6 represents the designs of IoT-based smart street lighting system, which was developed in a laboratory setting to accurately test its operation in a real-world outdoor setting. The IoT system prototype consisted of an ESP32 microcontroller, an LDR sensor, a current sensor, a solar panel, a rechargeable battery, and an LED light. These components were all connected via a breadboard and wired. The solar panels were placed near a natural light source so that they can be effectively charged during the daytime. However, this process was also managed by a charge controller to avoid damage to the rechargeable battery. The ESP32 microcontroller was also designed to interface with the Arduino IDE and transmit data to aThingSpeak cloud platform through a Wi-Fi network. Light conditions were varied through artificial shading and natural sunlight to test the logic of the LDR sensor's switch function. The system also detected the load current of the LED while

in operation to verify the authenticity of its fault-detection function. The solar panel's rechargeability was also tested through a series of cycles to ensure its stable recharge and discharge function.

5. RESULT AND DISCUSSION

Figure 7: ThingSpeak UI with data panels

The above Figure 7 represents the cloud dashboard provided by the ThingSpeak cloud data is the main monitoring and alerting platform for real-time monitoring and fault notification in the IoT smart street lighting control systems. The cloud dashboard shows the current readings from the sensors that are transmitted by the ESP32 microcontroller. The cloud dashboard is usually composed of two parts indicates one section, a graphical representation of the current readings over time, which helps to analyze the consumption trends, while the other section is used to identify fault readings by using the prominent red colour FAULT signal. Thus, using the cloud dashboard, remote monitoring is possible, which helps the user to analyze the performance of the entire system, as well as immediately identify any faults.
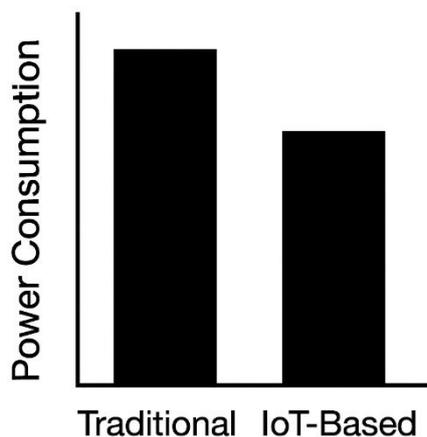

Figure 8: Energy savings

The above Figure 8 indicates that the Energy Savings determines the graphical presentation. The Energy Savings illustrates a great difference in power usage between conventional and IoT-enabled smart street lighting. The vertical bar chart indicates two very different graphed bars, with the Traditional system graphed bar considerably taller, representing higher power usage, and the IoT-Based system graphed bar shorter, representing lower power usage. Such a graphical representation highlights the efficacy of the smart system, where it switches on the lighting only when actually required, depending upon the light conditions, whereas the traditional system remains on continuously or at predetermined timings.
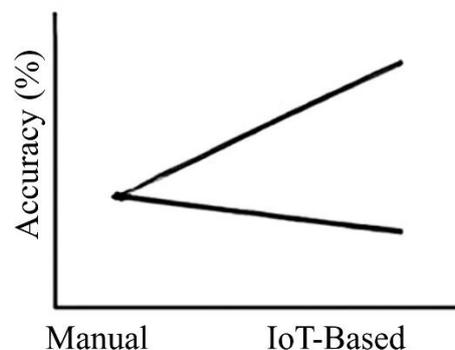

Figure 9: Fault detection accuracy comparision

The above Figure 9, The Fault Detection Accuracy graph findings and identifies the efficiency of both conventional and IoT-based fault detection methods in the intelligent street lighting system. The graph aptly identifies the rising position from conventional to IoT-based fault detection, indicating an improvement in the level of accuracy. Conventional fault detection methods including the checks or user feedback,

which may be postponed or overlooked. The IoT-based method includes immediate current sensing through sensors and automatic analysis for fault detection, which includes lighting or disconnection. The graph aptly identifies the need to integrate the benefits of IoT technology for accurate and immediate fault recognition to enhance the performance of intelligent core.

6. CONCLUSION

The Internet of Things (IoT)-enabled intelligent perfectly integrates the concepts of automation, power efficiency, and fault detection with a streamlined and intelligent approach. The system development and performance with the use of sensors and ESP32 microcontrollers is able to perform the automation of street lighting based on the surroundings, requiring extremely low power consumption. The real-time mechanism of fault detection allows for efficient maintenance work with the highest reliability. The usage of sunlight and cloud computing further increase the environmentally supporting nature of the system with the perfectly fulfilled aim of sustainable development in this regard. The system's high adaptability with cloud access further qualifies it with the most relevant solution for the street lighting problem scenario surrounding the concept of a smart citys.

7. REFERENCE

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