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INTELLIGENT SOLAR STREETLIGHT WITH ENERGY MANAGEMENT AND ENVIRONMENT MONITORING SYSTEM

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ABSTRACT :

At present, there is a great acceleration among countries innovating and developing advanced technologies that produce and use clean and renewable energy for use in our daily lives. This shift is driven by the growing awareness of environmental challenges and the need for sustainable energy solutions. In modern life, an individual spends a lot of time doing work with the use of energy. Examples of these developments include cars. These cars also drive in the streets, and to make these streets visibility during darkness and to look more beautiful, they are illuminated with lamps. These lamps often use electrical energy from unclean energy sources, and our project aims to replace these sources with clean sources to protect the environment and save money. Protecting the environment is our responsibility. Solar energy is free energy that everyone can obtain and exploit to produce energy and charge tools as well. As cities grow, there is a rising need for energy efficient and ecofriendly infrastructure. Traditional streetlights use a lot of energy and are expensive to maintain. Smart street lighting solves this problem by using technologies like sensors, timers, and LED lights. These systems adjust brightness based on movement, time, or light levels, and can be controlled remotely to save energy and reduce costs. Furthermore, many smart lighting setups offer remote management capabilities, allowing for real-time monitoring, control, and early detection of technical issues.

KEYWORDS : *Predictive Maintenance, Cloud Computing, Real-time Monitoring, Smart Streetlight System, Internet of Things (IoT), Energy Optimization, Sensor Network, Infrastructure Monitoring.*

1. INTRODUCTION

Smart streetlighting these days has become a necessity, to facilitate movement and transportation with energy saving and monitoring various parameters and for the aesthetics of the place. As we know, these lightings require energy to operate, and electrical energy is often used by conventional energy sources with renewable energy such as solar energy and adding tools that help and

facilitate control through programming. With the advancements in smart technologies, it is possible to save energy by utilizing it effectively and with proper control remotely. Intelligent streetlighting is able to control the lighting and monitor environmental parameters such as humidity and temperature.
Renewable energy is important because it helps reduce the use of fossil fuels for power plants that use fossil fuels and helps reduce the emissions of toxic gases that affect the ozone layer. An example of the use of this energy is the ability to achieve its ambitious goals in the field of clean energy. Tax breaks, provided by the governments, to further emphasize the importance of solar energy, making it a financially viable and environmentally friendly option for most homeowners. Through these measures, the transition to a greener energy future, reducing environmental impact and promoting energy independence. With the rapid growth of urban populations and the continual expansion of cities, there is an increasing need for public infrastructure that is not only energy-efficient and cost-effective but also environmentally sustainable. One area where modern innovation can drive meaningful change is in street lighting. Conventional street lighting systems, although vital for ensuring safety and enhancing the look of urban environments, tend to consume large amounts of energy, are costly to maintain, and often operate inefficiently by staying lit regardless of actual necessity.

To address these issues, smart street lighting has emerged as a promising alternative. This modern approach incorporates advanced technologies such as motion sensors, timers, wireless communication, and energy-saving LED lights into streetlamp systems. Sunlight, a renewable energy source, is highly reliable and cost-effective, unlike fossil fuels. Solar panels and electric systems have decreased in cost, but initial investment is a one-time event. Conventional electricity is costly, and investing in solar energy saves more money over time.

1.1 Background of the project.

Devices that use less energy capture the most attention in today's world and are perhaps the most important feature of the modern world as we know it. Most of these features have been implemented in various devices and appliances, with the most elementary example being the increasingly popular LED bulbs.

Smart lights can interact with their surroundings, users, and other smart devices, unlike traditional bulbs that need manual control. They support remote or voice operation. Smart streetlights use sensors and cameras to detect motion, enabling adaptive lighting and communication between nearby units brightening when movement is sensed and dimming afterward. Advanced systems may include image, seismic, sound, weather, and water sensors, along with wireless transmitters. Provide software for managing these systems and analyzing collected data to optimize functions like dimming schedules.

The present technologies are directed towards making a device more intelligent by incorporating features that allow it to use less energy compared to its predecessor. In trying to make the device intelligent, the project considers streetlight. The key question is to discuss what is intelligent, and how can we make it intelligent. This project is aimed at building a light management system in which a motion sensor triggers the LED light for adjustable periods set with PWM dimming. The Light can also be toggled ON and OFF from a web application. Artificial intelligence programs are developed using high-level programming language. The device also reports when the battery powered voltage goes below a certain point. The aim is to create a data logger that will periodically record readings of humidity, temperature and every ten minutes to a connected device. Between the times the sensors are read, the circuit board goes into deep sleep to minimize battery usage. The ESP32 Microcontroller which is incorporated into this project can execute programs while having Wi-Fi and Bluetooth capabilities. It further connects too other mobile devices or PC through Wi-Fi, to showcase the environment and energy variable. It is also feasible to control the light remotely and turn it ON and OFF.

It is linked to wireless internet. The light turns on if it senses motion and someone present, if not, it turns off. The LDR job is to determine whether there is sunlight.

Project Objectives

The purposes of the project:

- Intelligent system for monitoring the streetlights.
- Energy conservation through intelligent systems.
- Reduce pollution by minimal usage of energy.
- Effective use of Renewable source.
- Provide Cleanest energy sources.

Functions of Major Components.

Microcontroller ESP32

This ESP32 is a less cost, and it is a low power system on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. It can be used to make environmental sensors, smart home appliances, and more. ESP32 based devices are a very popular choice for automation projects in the home as they can be used to control lights, thermostats, and other appliances through Bluetooth or Wi-Fi connections.

ADC to read light intensity from LDR sensor.

The light-sensitive characteristics of LDRs are made possible by the semiconductor materials used in their construction. Although a variety of materials are employed, CADMIUM SULPHIDE (CdS) is a common one. These LDRs or PHOTO REISTORS work on the idea of "Photo Conductivity". This concept states that anytime light strikes the LDR's surface, in this case, the LDR itself the element's conductance rises, or, to put it another way, the resistance of the LDR falls. Because it is a feature of the semiconductor material utilized on the surface, the LDR's resistance lowering is achieved. Most often, LDRs are employed to measure or detect the presence of light.

Current sensor: Many electrical and electronic systems depend on modern sensors to ensure the equipment and devices operate safely and effectively. To examine modern sensors in this post, including their types, considerations for choosing one, performance comparisons, and uses. A current sensor measures and detects the electric current passing through a conductor. It transforms the current into an output that can be measured, such as a voltage, current, or digital signal, which can be utilized in a variety of ways for monitoring, control, or protection.

The main components of this system are

- The Solar smart streetlight that sends status messages to the cloud and receives command for operation
- A ready cloud server
- Remote monitoring device, usually a PC or a Phone

In this project we will be using a ready cloud server and PC with web browser. All configurations to monitor the various parameters are done in the cloud graphical interface. The data received from smart streetlight will be displayed to the monitoring device in a graphical way.

3. Design and Working

With the advancement of technology, information and control has become the center for control and maintenance of public deployed assets. Here in this project, we will take the case of the streetlight system and its control and maintenance. The streetlight will be a solar streetlight model which will be connected to a cloud service. The powerful cloud features bring a method to show the centralized control and maintenance of streetlight.

For a demo battery voltage, current, Light brightness and ambient temperature are monitored. With the representation of these parameters in cloud we will be demonstrating how helpful it will be to monitor online status of a public infrastructure and take preventive maintenance for a failsafe system.

The Cloud – Arduino cloud

Arduino IoT Cloud is an online platform that allows users to create, manage, and monitor Internet of Things (IoT) projects:

- Create projects: Users can quickly create projects using the Arduino Cloud.
- Connect devices: Users can connect Arduino-based devices to the internet using the Arduino Cloud.
- Control devices: Users can control devices remotely using dashboards.
- Visualize data: Users can visualize and control sensor data from anywhere.
- Share projects: Users can share projects with anyone.
- Collect data: Users can collect data from their projects.
- Interact with objects: Users can interact with connected objects.

The Arduino IoT Cloud offers a variety of features, including:

- An Integrated Development Environment (IDE) for programming boards
- A cloud backend service for synchronizing data
- A graphical tool (dashboard) for controlling and monitoring boards
- A mobile app

The Arduino IoT Cloud is built on the Arduino ecosystem, which is known for its ease of use in electronics prototyping.

3.1 Block diagram

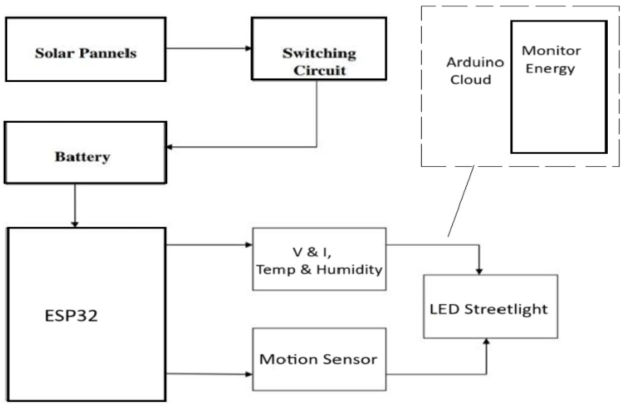
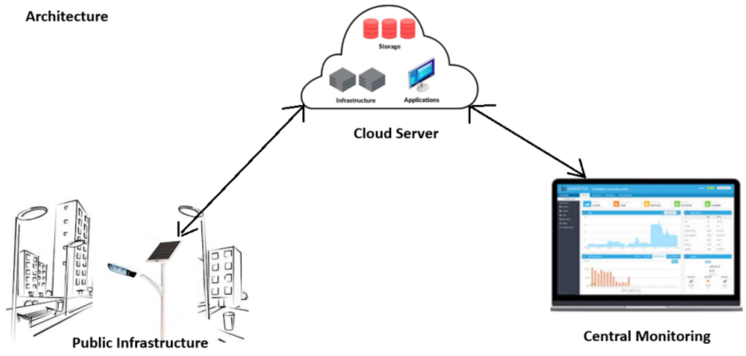


Fig.1: ***Block diagram- Intelligent Solar streetlight with Energy Management and Environment Monitoring system.***

Referring to the ability to track and measure different aspects of the environment, such as temperature and humidity. This helps us to understand how the environment is changing and detect any harmful effects, ensuring better protection and management of natural resources and public health.



3.2 Circuit diagram

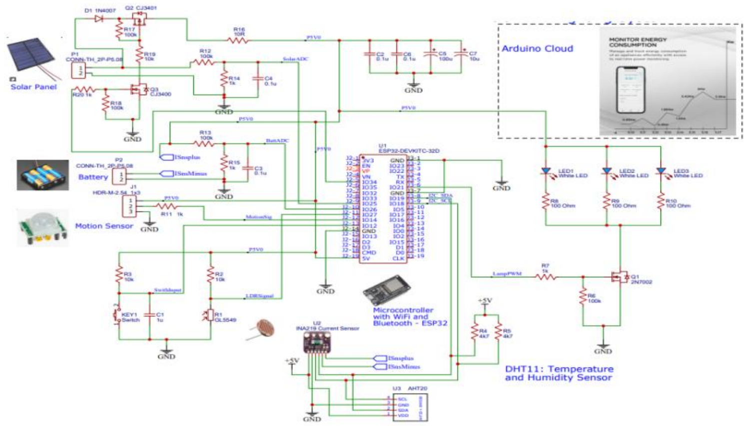


Fig.2: circuit diagram.

Circuit diagram: This circuit diagram shows a smart solar LED lighting system controlled by an ESP32 microcontroller. The system uses solar energy to power LEDs and activates them based on motion detection. This motion sensor-based smart solar LED lighting system uses a solar panel to charge a battery, providing power for nighttime lighting. An ESP32 microcontroller monitors the battery and solar panel voltage, detects ambient light using an LDR, and responds to motion detected by a PIR sensor. During the day, the solar panel charges the battery, while the system remains off. At night, if motion is detected and light levels are low, the ESP32 activates the LEDs, adjusting their brightness using a MOSFET. A manual switch allows users to override automatic control. The system is energy-efficient, cost-effective, and ideal for outdoor lighting applications, relying entirely on solar power and smart automation.

3.3 Working model

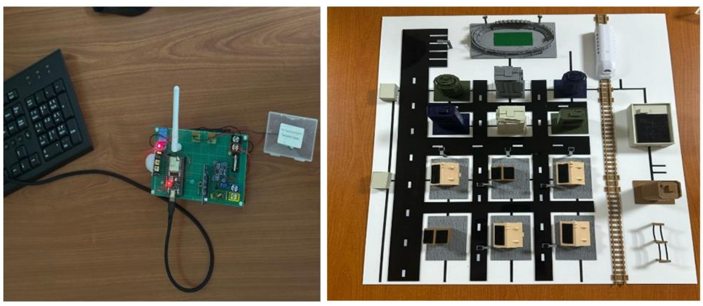


Fig.3: Testing of circuit.

The figure above illustrates the complete hardware setup of the Intelligent Solar streetlight with Energy Management and Environment Monitoring system.

During the day, the battery is charged by the solar panel. If solar power is unavailable, the power source is switched to battery. The circuit also contains several sensors, including a motion sensor, which helps determine when the lamp is on. If someone passes by, the lamps turn on, but if no one passes by, they turn off to conserve energy. There are also sensors for measuring voltage and current to determine the amount of energy consumed and, therefore, the amount of money wasted in the circuit. To facilitate the data measurement processes current and voltage data are recorded throughout the day, making it easy to calculate costs.

Methodology:

Circuit using Proteus 8 Professional and replaced the ESP32 with another microcontroller to act as the control center for the circuit. We also replaced the motion sensor with a PIR SENSOR. The purpose of this simulation is to understand the complex system and also to test the circuit before connecting it and to determine the amount of power needed to operate this circuit.

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Test Results.

The remote monitoring and control of street lighting systems, particularly in general infrastructure deployments, facilitates proactive service and maintenance. By incorporating motion sensors and key system components, the solution enhances energy efficiency in street lighting. Additionally, the system monitors both electrical and environmental parameters, transmitting this information to end users. This enables users to stay informed about system performance and schedule maintenance activities in advance, reducing the likelihood of unexpected failures.

Over time, data collected can be leveraged in models to forecast potential system failures based on various influencing factors.

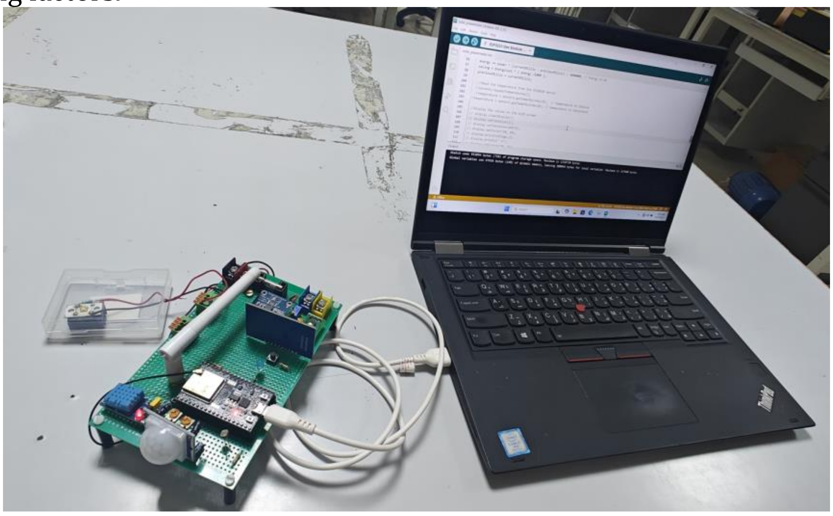

Fig.4: Testing with PC

To ensure the system functioned effectively and efficiently, a comprehensive testing phase was conducted:

- Functional Testing: Each component was evaluated independently and then as part of the complete system to verify smooth interaction and reliable performance. Emphasis was placed on ensuring the system responded promptly and accurately to sensor inputs.
- Temperature Monitoring: The temperature and humidity sensor was assessed for its capability to track environmental conditions. Adjustments were made to calibrate the system's responses to various temperature and humidity levels for optimal operation.

Lighting Validation: The lighting feature, activated by motion sensors, was tested in diverse scenarios. The system's ability to detect movement and adjust lighting intensity accordingly was confirmed, ensuring dependable and energy-efficient functionality

Energy Consumption Reduction:

Through the use of motion and light sensors, streetlights can be dimmed or switched off when not in use.

- ***Consider:*** In a setup with 1 LED streetlight, rated at 5W, traditional systems run at full power for 12 hours each night:
  - Traditional Usage: 5 x 12 = 0.06 kWh per night
  - 0.06 x 30 = 1.8 kWh per month
  - Smart Usage (average 40% OFF period):
    - Estimated savings = 0.024 kWh per night
    - 0.024 x 30 = 0.72 kWh per month
    - Annual Savings: 0.024 kWh × 365 = 8.76 kWh

Cost Savings:

With an electricity rate of 0.014 OMR per kWh,

- Annual Savings for say 1000 LEDs: 8.76 kWh × 0.014 x 1000 = 122.64 OMR

Reduced Maintenance Costs:

The smart system supports remote diagnostics and predictive maintenance, reducing the need for on-site visits.

- *Example:* A 20% reduction in maintenance visits could save per year in labor and transportation.

Extended Lifespan of Lights:

Dimming and reduced runtime help to reduce wear on LEDs, extending their operational life.

- *Example:* The LED lifespan is extended by 20%, postponing replacement costs and minimizing waste.

4.1 Discussions.

Our project relies on the ESP32 as the brain of the electrical circuit, controlling the lighting intensity and the sensors in the electrical circuit, such as the motion sensor, temperature, humidity, and finally the current and voltage. This project can be used in modern cities such as the Sultan Haitham City, which is currently under construction.

The developed IoT enabled smart streetlight system, powered by the ESP32 microcontroller, effectively addresses the growing demand for automated and remote-controlled solutions in modern urban environments. This setup enables users to manage lighting operations remotely, promoting both safety and energy efficiency.

At the heart of the system is the ESP32, which coordinates communication among sensors, devices, and mobile applications. Once the ESP32 is programmed, it is linked with an app through which users can configure settings. The relay modules connected to the ESP32 control the power supply to different devices, such as lights.

Testing demonstrated that users could successfully operate appliances like lighting systems through the mobile interface. When a command is sent via the app, the ESP32 transmits a signal to the corresponding relay, which activates the appliance. This ensures real-time interaction and control, allowing users to operate home systems from any location.

Sensor integration plays a crucial role in enabling automation. For example, a motion sensor connected to the ESP32 detects movement and automatically switches on the streetlight. The system also includes an adjustable delay mechanism that controls how long the light remains active, reducing unnecessary power usage.

Additionally, ambient light sensors improve energy efficiency by automatically turning on lights when natural light levels are low. This enhances user convenience and further conserves electricity. When no movement is detected within a defined area, the lighting system turns off, making it especially suitable for public environments where energy conservation is vital.

5. Conclusions.

In conclusion, our project will help control lighting via the ESP32 and make it smarter using the sensors in the circuit. It will also save money by conserving electrical energy. Our project aims to provide solutions to various problems, including energy waste. We use the Arduino IDE to program the ESP32, and then a relay controls the operation of the lighting. To achieve our project goals, we carefully utilized available resources to reduce costs.

In addition, the ESP32 supports a broad array of sensors and actuators, which makes it highly adaptable for various use cases, including environmental sensing and the automation of electrical devices. Its flexibility empowers users to customize their smart home setups based on individual requirements. Furthermore, the ESP32's seamless integration with widely used IoT platforms enhances its functionality, offering easy access to advanced capabilities such as data analysis and predictive maintenance within larger connected systems.

5.1 Future enhancements

Newly built cities can benefit from this system, saving energy and money. They can also be made smarter with sensors provided by the ministry, enhancing energy efficiency, improving lighting conditions, and enhancing the overall user experience. The app will also help track temperature, humidity, voltage, and current, improving the quality of these lamps for consumers and making them more efficient. The consumer can also set the lighting level to suit the intended purpose and determine the time for it to operate after passing through the motion sensor. This increases the efficiency of our project and provides the consumer with many benefits.

The ESP32 offers excellent scalability, allowing easy integration of new devices and features without major infrastructure changes. Security remains vital, requiring encrypted Wi-Fi connections to prevent unauthorized access. Overall, the ESP32 is a reliable foundation for IoT-based smart homes, combining connectivity, flexibility, and user-focused design to enhance convenience and quality of life.

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