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DEVELOPMENT AND IMPLEMENTATION OF AUTOMATIC SOLAR-POWERED STREETLIGHT SYSTEM FOR A UNIVERSITY CAMPUS

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ABSTRACT
Streetlight system is an important feature in modern development to address the problem of night-time insecurity. The existing streetlight system, which uses incandescent bulbs to address this problem, has resulted in energy wastage. This work developed and implemented a solar-powered automatic street light system at Landmark University Omu-Aran campus, intending to optimize energy consumption, while providing enough illumination. The system incorporates; a light sensor, Arduino microcontroller, motion detection and Light Emitting Diode (LED) units for intelligent operation and optimal energy utilization. The system's electric circuitry was designed using PROTEUS software. Arduino IDE was used to develop a code to help the Arduino microcontroller module interact with the system by controlling the motion and ambient light sensors. Motion sensors were employed with Passive Infrared (PIR) sensors to detect human presence, enabling the system to adjust lighting levels dynamically based on real-time traffic and pedestrian movements, enhancing safety and security. The system utilizes solar photovoltaic panels to harvest renewable energy from the sun, making it environmentally sustainable and cost-effective. Also, Light Detecting Resistor (LDR) light sensors were used to facilitate automatically adjusting illumination levels according to environmental conditions, ensuring optimal visibility while conserving energy during nighttime. However, the developed streetlight prototype was implemented and tested in the Landmark University Omu-Aran campus to determine its optimal energy efficiency over High-Pressure Sodium (HPS) and LED-based streetlight systems. The result shows that the developed solar-powered automatic street light reduced power usage by providing an optimal energy-saving option.

Keywords: Ambient light sensors, Arduino microcontroller, Energy management, Motion sensors, Streetlight

INTRODUCTION

Streetlights play an important role in urban development, influencing everything from street safety to visual appeal. Streetlight design has evolved over time and with technological advancements (Agramelal et al. 2023a; Bachanek et al. 2021). The historical history of street lighting, from simple oil lamps to the High-Pressure Sodium (HPS) and, more recently, the efficiency of Light Emitting Diode (LED)-based systems, demonstrates the transformational potential of innovation. Streetlights have their background from a Russian Electrical Engineer Pavel Yablochkov who developed the Yablochkov candle in 1875 (Baldwin 2023). This was the first picket that put aflame the route for future advancements in street lighting. This invention paved the way for other inventors like Charles F. Brush who had perfected the concept of dynamo arc light which became the first ever electrically powered streetlight (Bevis 2021; Gross 2024). In the 20th Century, the advancement of technology has brought awareness of energy consumption and its environmental impact (Asif et al. 2025; Deshmukh et al. 2023; Kong et al. 2024; Omogoroye et al. 2023). The evolution of traditional streetlight systems such as incandescent streetlights to LED technology has been witnessed, marking a significant milestone in human development. However, traditional streetlight systems often lack adaptability, resulting in unnecessary energy consumption during periods of sufficient sunlight within the environment or in cases of low pedestrian activity (Jabbar et al. 2025; Kouah et al. 2024; Wang et al. 2025). Traditional streetlights rely on a conventional fluctuating grid supply system for energy, unlike alternative independent power sources that can provide stand-alone energy for the street. This challenge harms the power industry due to the unnecessary wastage of power; it can also affect the efficiency of the streetlight system due to its operational fluctuations (Khemakhem and Krichen 2024; Pereira de Morais et al. 2024; Sankhwar 2025).

Therefore, the concept of smart street light system was put up to address these drawbacks; This system consists of a variety of sub-components that perform different functions to help achieve desired results such as integration of sensors, adaptive lighting, solar energy control, and microcontrollers amongst others. The idea of a solar-powered smart streetlight system emanates from the need to conserve energy while maintaining a high level of efficiency in all areas of operation (Abedin 2023; Baharin et al. 2023; Belloni et al. 2024).

Numerous recent reviews and research articles are available in the literature. For instance, (Agramelal et al. 2023b) reviewed recent trends in smart street lighting, the authors emphasized the selection of light lamp types, methods for controlling light intensity, and strategies for integrating sensors. The sensors used in the work, allow for remote light control, weather condition monitoring, and remote diagnosis of lamp failures. The authors also compared various intelligent street lighting systems, focusing on their control methods and connectivity options. (Cheng et al. 2020) Jilin1-03B (JL1-3B) satellite a new source of multi-spectral high spatial resolution night-time light imagery to automatically extract street lights' night-time light data was presented. The author(s) implemented a local maximum algorithm to locate the position of street light, and the values of original bands were used to define the types of street lights as HPS lamps or light-emitting diode lamps. Also, a novel approach was simulated by replacing HPS lamps with solar street lights. The study used hourly cloud cover data from SHORTWAVE-C and a digital surface model to evaluate solar energy streetlights at night. The results demonstrated that conversion from HPS to solar street lights extended their lifespan and reduces greenhouse gas emissions. An IoT-based smart street lighting system that measures air quality was investigated (Kazmi, Ulasyar, and Khan 2020; Prasanth and Thuraka 2024). The smart street lighting system essential components in the work include Light Detecting Resistor (LDR) sensors and Infrared (IR) sensors. The sensors can allow the system to adjust streetlight brightness based on traffic patterns and ambient light levels. The study further dissects the system internal workings, including sensor configuration, data collection methods, and the regulations governing streetlight brightness. It also emphasizes how significant savings could result from the use of smart power management strategies and green energy sources. Additionally, (Yusoff et al. 2020) demonstrated an IoT-based smart street lighting system. The writers examined the most recent IoT applications for street lighting. They examine how different parts and sensors such as temperature, proximity-photoelectric, ultrasonic, infrared, Passive Infrared, (PIR) optical, pressure, and humidity sensors work in IoT-enabled street lighting systems. An IoT-based automatic street light control system with fault detection and reporting capabilities was explored in (Sukumar et al. 2025). The growing significance of smart technology in encouraging energy conservation is underscored in the article through automated fault detection systems. Also, (Almaliki et al. 2025) the authors developed an adaptive street lighting system management that uses deep deterministic policy gradient reinforcement learning algorithm. The algorithm helps in optimizing the lighting time automatically based on real-time information. The authors employed modern sensing technology namely; inductive loops and cameras to dynamically correct phase signal and check load conditions. This invention resulted in more economical and effective urban lighting solutions.

The authors (Shaheen et al. 2023) presented an adaptive predictive scheduling method. This method achieved a notable energy reduction in infrastructure of street lighting, by emphasizing on traffic-responsive lighting solutions and a predictive approach. At Thammasat University in Thailand automated light-adjusting system was developed and implemented in (Deepaisarn et al. 2023). The goal of the project is to increase energy efficiency in order to provide adequate lighting for the campus. The two components of the development are the device control and the prediction model. The user interface was utilized to make the smart street light systems functional, and the application programming interface was used to send commands for changing the lights. Then, using the existing conditions, suggest a dimming value. Predictions based on data analysis with the help of an artificial intelligence platform, forecasts are fed into the models every nine months. Four machine learning techniques were tested on environmental datasets. The real brightness levels and the anticipated light levels using the test dataset are found to have a linear relationship. This suggests that the window size of three days is the optimal setting for the XGBoost model. It enables automatic adjustments to the smart street lighting system and real-time feedback for features specifically created for data analysis.

(Zakaria, Amr, and Ragheb 2025) pointed to a number of practical scenarios and functions that illustrate how linked devices enhance expenditure reduction, conservation of energy, safety for citizens, and metropolitan data management. In this regard, Barcelona has set up an advanced intelligent street lighting system featuring sensors to adjust streetlight brightness to reflect pedestrian and vehicle activity, resulting in a 30% reduction in energy use. In an attempt to aid improve congestion control and city planning, San Diego installed more than 3,000 intelligent lamps featuring sensors that monitor environmental conditions and traffic. Additionally, Los Angeles has installed an innovative street lighting system that integrates IoT sensors and connections with LED lights. Streetlights may be remotely monitored and controlled with this setup, reducing energy use by 60% and helps save countless dollars annually.

Therefore, this study developed a solar-powered automatic street light system designed to save energy and reduce operational costs. The system integrates four key components: LDR and Passive Infrared (PIR) sensors, an Arduino microcontroller, and LED lights. The primary goal is to evaluate the energy savings achievable by replacing traditional street lighting with Solar powered LED technology while ensuring the proper functioning of the smart public street lighting infrastructure by integrating sensors and the microcontroller unit. The main contributions of this study are summarized as follows:

i. Design of the electrical circuitry of solar-power automatic streetlight system using PROTEUS software;
ii. Develop a programming code that enables the Arduino Uno R3 to interact with the motion and ambiance sensors using the Arduino IDE software;
iii. Test the various components;
iv. Construct a prototype of the solar-power automatic streetlight system;
v. Testing the efficiency of constructed solar-power automatic streetlight system.

The paper is structured as follows: Section II presents the material and methods used in the development of a solar-power automatic streetlight system. Section III presented the microcontroller programming code. The construction and implementation of solar-power automatic streetlights is described in section VI. Section IV presents the performance testing of constructed solar-power automatic streetlight. Section V concludes the paper.

MATERIALS AND METHODS

System Method

The session focuses on the development of a solar-power automatic street light system, as illustrated in Figure 1. Prior to constructing the system, the circuit was designed using Proteus software. This design is divided into five main units: the power supply unit, light sensor unit, microcontroller unit, motion detection unit, and LED units. During the design phase, the microcontroller was programmed utilizing Arduino IDE software. The subsequent development involved building all units on a breadboard. After construction, thorough testing was conducted to evaluate the system's performance. The goal is to establish a fully automated smart streetlight system that operates based on environmental conditions and is powered by solar energy, which determines the ON/OFF status of the streetlights. The LDR monitors sunlight intensity from the solar panel and activates the streetlight when the light intensity is low. Additionally, the ON/OFF status of the streetlight is influenced by the motion detection unit, which uses a PIR sensor for infrared motion detection. When motion is detected and the LDR confirms low sunlight intensity, the streetlight illuminates at full brightness. In the absence of motion, the streetlight remains on for a brief period before dimming until it detects movement again. This cycle continues until sunrise when the LDR detects adequate lighting and the streetlight turns off.

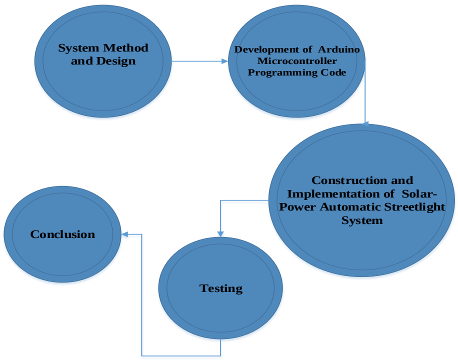

Figure 1: Method of Developing a Solar-Powered Automatic Street Light System

System Design
The design of solar-power Automatic Street light was carried out on Proteus software. The design is divided into five main units as illustrated in Figure 2 and Figure 3 shows the circuit design of the system.

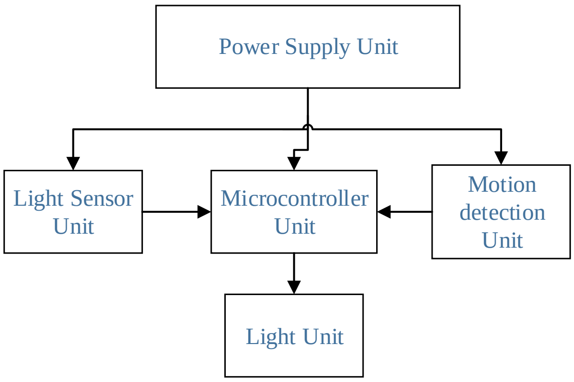

Figure 2: Block Diagram of the Design Units

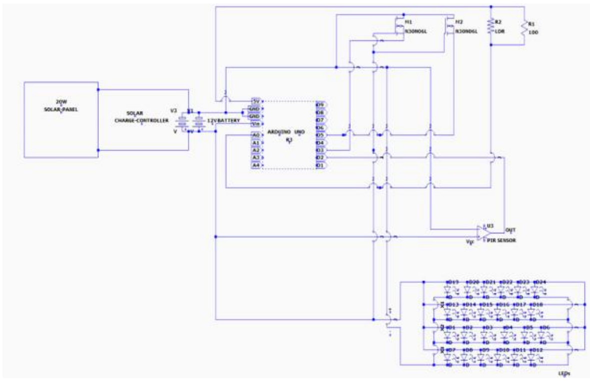

Figure 3: Circuit Design of the Proposed Solar Power Smart Street Light System

Power Supply Unit
A 12V DC power supply was used to power the Microcontroller unit and other components. The Arduino Uno which is the microcontroller used operates at 5V, therefore, a voltage regulator was used to step down the DC voltage from 12V to 5V. The power supply circuit as illustrated in Figure 4 consists of the following components: Solar Panel, charge controller, 12V 5Ah lithium-ion battery, and Voltage Regulator. During the day, the solar panel converts sunlight into electrical energy. This energy is used to charge the 12V 5Ah lithium-ion battery via the charge controller. The charge controller regulates the charging process to prevent overcharging ensuring optimal battery performance and longevity. The electrical energy generated by the solar panel is stored in the battery.

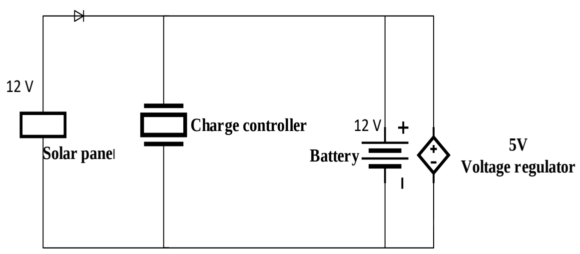

Figure 4: Power Supply Circuit Diagram with Voltage Regulator

Microcontroller Unit
The Arduino UNO R3 microcontroller tracks changes in resistance and interprets the data using the written logic code. Whenever it receives a minimal value for resistance generated by the LDR, it knows there is enough ambient light, therefore, it helps to modify the light and motion sensor outputs and automatically switch on/off the light. Thus, adjusting to changes in the environmental ambient light, the microcontroller allows the solar-powered streetlight system to be controlled responsively and adaptively.

Light Sensor Unit
The light sensor unit uses LDR to detect the absence or presence of sunlight and automatically switch off and on the streetlight. LDR is a resistor with semiconductor material that generates a free flow of electrons when light falls on it increasing the material conductivity while reducing the resistance value.

Motion Detection
The Passive Infrared (PIR) sensor was used to detect the movement of pedestrians and vehicles at night-time based on the principle of infrared radiation. Whenever motion is detected especially at night the PIR sensor transmit electrical signal to the microcontroller unit and the streetlight LED turns on to full capacity. However, when motion is not detected at night the LED is set at 0.5 of full capacity to save energy.

Light Unit
The light unit consist of LEDs a semiconductor that produces light when electric current flows through it. The streetlight LEDs are controlled by the microcontroller based on data receives from LDR and PIR sensors.

RESULTS AND DISCUSSION

Microcontroller Programming Code
A C++ programming language code was written and complied on Arduino Integrated Development Environment (IDE). After completing the code, it was successfully transferred to the Arduino Microcontroller, enabling it to perform specified tasks and functions. Table1 shows the specifications of the Arduino Microcontroller.

Construction and Implementation of the Automatic Solar-Powered Streetlight
This session focuses on the integration of all components that comprise the solar-powered automatic street light system, as depicted in Figure 5 to Figure 10. Before assembling these components on a breadboard, each was thoroughly tested to ensure proper functionality. A 6-meter fabricated pole was also constructed, as illustrated in Figure 11. The Arduino microcontroller, which has been programmed, was integrated into the breadboard. The positive and negative terminals of the 12 V solar battery were connected to a voltage regulator, which converted the power output from 12 V to a 5 V supply. The regulator's output was then linked to the power input pins of the microcontroller. The LDR sensor is connected to the analog input pins. While the motion sensor is connected to the digital input pin, the LED bulb is also connected to the digital output of the Arduino microcontroller through a 3-ohm resistor. Furthermore, the solar panel is connected to the charge controller. and the battery terminal is connected to the output of the charge controller. A diode is included in the circuit to prevent reverse current from the battery back to the solar panel. This configuration ensures that the battery will not be overcharged and over-discharged by the energy produced by the solar panels.
The solar panel was exposed to light to test the integrated circuit, and variations in the surrounding light and motion were noted. Their behavior was also examined to make sure the LEDs worked as planned. After successful testing, the integrated circuit was placed within a waterproof enclosure and mounted on the fabricated pole, showcasing a prototype of a fully integrated solar-powered automatic streetlight system as illustrated in Figure 12.

Table 1: Arduino Microcontroller Specifications

Operating Voltage	**5 V**
Max Current per I/O Pin	40 mA
Total Max Current on all I/O Pins	200 mA
Input Voltage of PIR Sensor	5 V
Current Consumption	50 µA (at idle state)
Power rating of LED	2 Watts
Output Voltage due to Arduino Uno R3 VO	5 Volts
Output Current, IO	2.5 Amps
Power Dissipation: (Input Voltage - Output Voltage) * Output Current	17.5 Watts


Figure 6: Solar Panel

Figure 7: Charge Controller

Figure 8: 12 V Rechargeable Battery

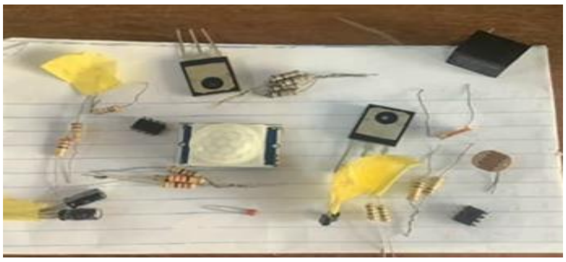
Figure 9: Electrical Components

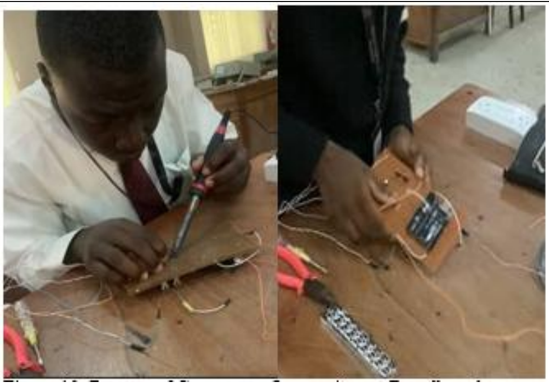
Figure 10: Process of Component Integration on Breadboard


Figure 11: Automatic Solar Powered Streetlight Fabricated Pole


Figure 12: Prototype of the Automatic Solar Power Streetlight System

Performance Testing
To test the efficiency of the solar-power automatic street light system with respect to energy conservation, the performance of a HPS streetlight and an LED streetlight was compared with the constructed automatic streetlight system as illustrated in Table 2. The HPS streetlight is situated at the road connecting the student halls of residency, while the LED streetlight system is located at a bypass connecting the main road to the University campus.

Table 2: Efficiency Comparison of HPS, LED and Automatic Streetlights

Conditions	HPS streetlight	LED streetlight	Automatic streetlight
Power Consumption(per-day)	3600Watts	300Watts	21.13Watts
Motion Sensing Adaptation	Nil	Nil	15Ft range of Passive motion detection
Daytime/Nighttime Adaptation	Nil	Present	Present
Inactivity Period	Nil	12 hours	12 hours

Activity Period	Always	12 hours	12 hours
LED environment Adaptation	Nil	Nil	Present
Number of LEDs	Nil	120	14
Independent Power Source	Nil	Present (Solar)	Present (Solar)
Total Charge Time	Nil	6 hours	5.3 hours
Total Discharge Time	Nil	12 hours	25 hours

CONCLUSION

Solar-powered Automatic Street light are sustainable options to traditional street lights in places that require less luminous. They are required in areas such as a University campus, where the safety of pedestrians and vehicles is important. This work developed and implemented a solar-powered automatic street light system at Landmark University Omu-Aran campus. This technology was able to reduce power usage by providing an energy-saving option. The basic parts, such as the Arduino microcontroller and LED modules resulted in greater cost savings. Additionally, the lifespan, improved lighting, and low power consumption of LED are the additional advantages of using this technology. Also, the performance of the system was tested and compared with HPS and LED streetlight systems in terms of power consumption, motion sensing adaptation, night and day time adaptation.

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