Smart Campus Illumination: Arduino-Based Automated Street Lighting for Energy Optimization

Vaishnavi M. Sutar
Department of Electrical Engineering
JSPM'S Rajarshi Shahu College of Engineering Pune, India

Prachi B. Gaikwad
Department of Electrical Engineering
JSPM'S Rajarshi Shahu College of Engineering Pune, India

Shivkanya A. Ghanwate
Department of Electrical Engineering
JSPM'S Rajarshi Shahu College of Engineering Pune, India

Mrs. Manjusha A.Kanawade
Department of Electrical Engineering
JSPM'S Rajarshi Shahu College of Engineering, Pune, India

Mrs. Sujata S. More
Department of Electrical Engineering
JSPM'S Rajarshi Shahu College of Engineering, Pune, India

Abstract - **This paper presents the implementation and design of smart, automated street lighting system tailored for institutional campuses, aiming to optimize energy usage and operational efficiency. Utilizing the Arduino Nano microcontroller as the core processing unit, the system intelligently controls street lighting based on real-time ambient light and motion detection inputs. A relay module governs the switching mechanism, while an LCD interface provides user feedback. The designed system automates street lighting operations, thereby minimizing human intervention and significantly conserving energy by activating lights solely based on real-time requirements. Compared to traditional street lighting setups, this automated solution offers a cost effective, scalable, and eco-friendly alternative suitable for smart campus infrastructures. The prototype developed demonstrates reliable performance under test conditions, showcasing its potential for broader implementation in academic or residential environments. Future enhancements may incorporate IoT connectivity and wireless data monitoring to further improve system responsiveness and analytics.**

Keywords—Smart Campus, Automated Street Light, Arduino Nano, Energy Efficiency, Relay Control, LCD Display.

I. INTRODUCTION

As urban and educational campuses continue to grow, the demand for sustainable and intelligent energy solutions has become increasingly vital. Street lighting constitutes a significant share of a campus's overall energy usage, and conventional systems often left active regardless of necessity lead to considerable energy wastage and increased maintenance requirements. With the rise of automation and embedded systems, it is now feasible to implement smarter alternatives to traditional lighting methods. This research focuses on developing a compact, automated street lighting system using a low-cost microcontroller (Arduino Nano), supported by a suite of sensors and output modules. The objective is to minimize power consumption by ensuring street lights function only under low-light conditions and when motion is identified within the surrounding area. Beyond saving energy, this solution also reduces human dependency and operational costs. The project integrates a relay module for power switching, an LDR (Light Dependent Resistor) for ambient light sensing, and an ultrasonic sensor to detect motion. An LCD interface provides real-time feedback of system status. The prototype is implemented and tested on a breadboard-style PCB setup and demonstrates stable, responsive behaviour in controlled environments. By integrating such a system into institutional campuses, it is possible to build a smarter and more energy-conscious infrastructure. This paper outlines the system architecture, component specifications, implementation strategy, and testing outcomes. The results indicate that automation in campus lighting can deliver substantial energy savings and improved management without the need for expensive infrastructure changes.

II. LITERATURE REVIEW

The automation of public lighting systems has emerged as a focal point in recent advancements, especially concerning smart city applications and energy conservation [1]. Several studies have focused on the use of microcontroller-based systems and sensor integration to manage lighting in a more intelligent and efficient manner [2][3]. In the authors proposed an IoT-based lighting system using real-time data to dynamically control street lights via wireless modules [4]. Similarly, explored the application of Arduino and NI LabVIEW for timer-based automation, demonstrating improved efficiency in scheduled lighting [5]. Another study utilized motion detection and ambient light sensing for adaptive control, reducing unnecessary energy usage. Modern implementations are increasingly shifting from manual or purely time-based lighting to adaptive systems using real-time inputs [6][7]. Projects like those in and show the effectiveness of integrating microcontrollers with RTC modules and relay drivers to create cost-effective and user-configurable street lighting frameworks [8]. While these works provide a strong foundation, many of them either focus on large-scale implementations or rely heavily on external infrastructure [9]. Our work distinguishes itself by tailoring the system for a college campus setup with minimal hardware, aiming for low-cost, solar-compatible deployment. This makes it ideal for semi-urban institutions where resources and maintenance capacity are limited [10].

III. SYSTEM DESIGN AND METHODOLOGY

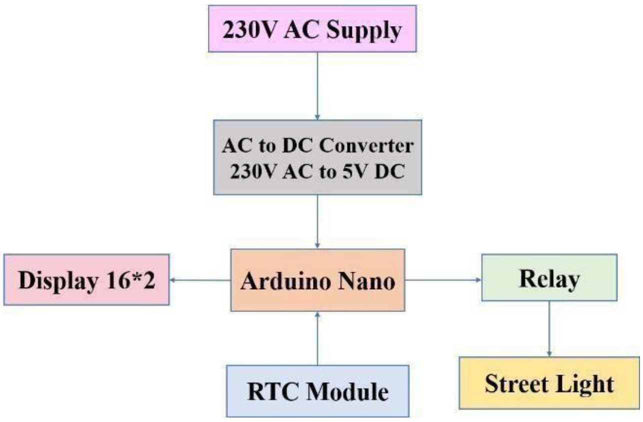

Fig 1. System Architecture

The proposed system autonomously controls street lighting through microcontroller-based logic integrated with a real-time clock (RTC), as illustrated in Fig.1, which depicts the overall architecture and interconnection of the system components. It is structured for reliability, scalability, and ease of maintenance. At the heart of the design is an Arduino Nano, which receives time data from an RTC module (DS3231) and determines the appropriate time to switch lights on or off. The system controls AC street lighting through a 20A relay module, triggered via a BC547 transistor. A 16x2 LCD display provides user feedback by showing time and system status. The input 230V AC supply is stepped down and converted to 5V DC using an AC to DC converter (HLK-2M05). This supplies electrical power to the Arduino, LCD display, RTC, and relay components. The RTC DS3231 is used for accurate real-time control. It communicates with the Arduino via I2C (SCL/SDA). The Arduino compares the current time with pre-set values and sends corresponding control signals. The relay is connected to the Arduino output pin through a BC547 transistor, which acts as a switch. When the relay is energized, it connects the AC line to the street light. A 220Ω resistor protects the transistor from overcurrent, and a 10K potentiometer adjusts LCD brightness.

The Arduino Nano provides a signal to the relay, that either closes or opens the circuit of street light. Street Lights is the load being controlled. The relay controls the connection of the street light to the AC supply, turning it ON or OFF based on the time determined by the RTC module and the Arduino Nano. The flow of operation is as follows, the 230V AC supply is converted to 5V DC to energize the Arduino Nano and other components. The RTC module provides time data to the Arduino. The Arduino controls the relay based on the time, turning the street light on or off.

IV. HARDWARE COMPONENTS

The system architecture is built around a compact and efficient combination of readily available hardware.

Table 1. Hardware Components

Sr No	Components	Working
1	Arduino Nano	Acts as the central controller.
2	RTC Module (DS3231)	Maintains accurate time.
3	Relay Module (20A)	Switches high-voltage AC load.
4	BC547 Transistor	Acts as relay driver.
5	LCD Display (16x2)	Displays time and system status.
6	AC to DC Converter (HLK-2M05)	Converts 230V AC to 5V DC.
7	Potentiometer (10K)	Controls LCD brightness.

V. WORKING PRINCIPLE

The system operates on a time-based automation principle. The complete circuit schematic of the automation system is shown in fig.2. The Arduino Nano reads the current time from the RTC DS3231 module. When the time matches predefined values (e.g, ON at 6:00 PM, OFF at 6:00 AM), the microcontroller outputs a control signal to the BC547 transistor. This transistor acts as a switch, energizing the 20A relay that completes the AC circuit and powers the street light. The LCD 16x2 display continuously updates the system's real-time clock and status (e.g., Light ON/OFF), providing a user-friendly interface. A 10K potentiometer is used to adjust the brightness of the LCD, making it adaptable to different lighting environments. The system avoids false triggers that are common with LDR or motion sensors, as it strictly follows a reliable and preprogrammed schedule. The PCB-mounted components are compact and arranged for low maintenance. Testing showed the system's ability to handle varying voltage conditions without affecting timing accuracy or relay switching behavior.

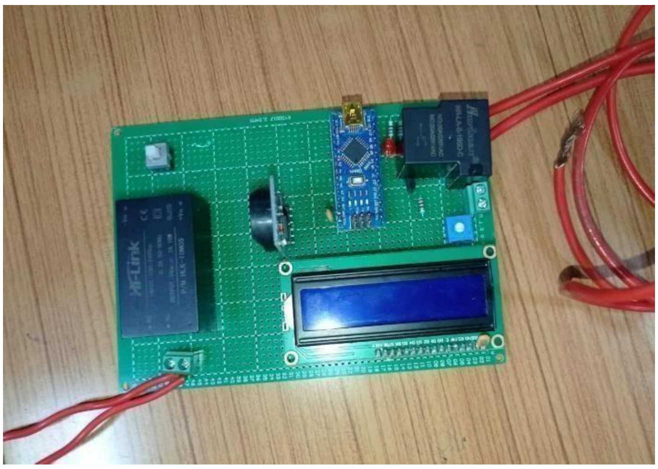

Fig.2 Automation Hardware Circuit

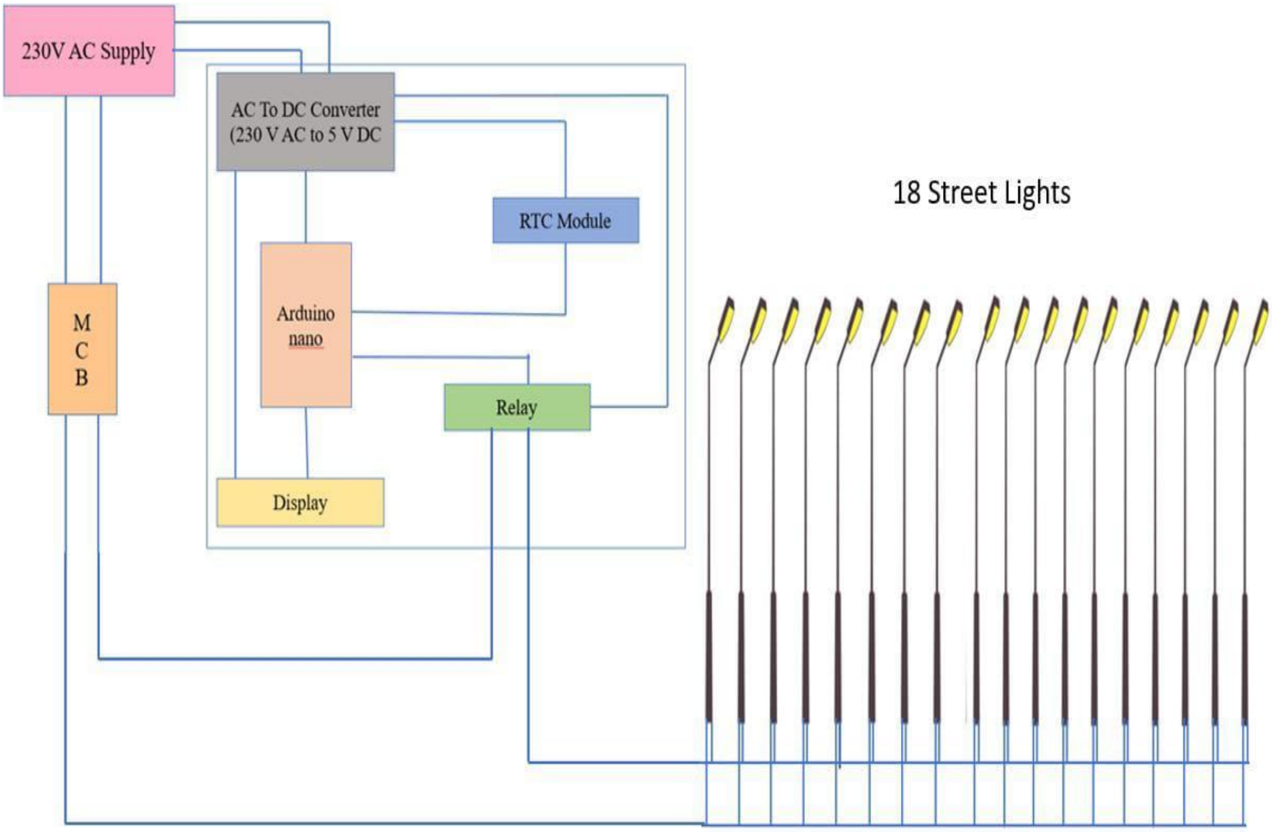

Fig.3 *Automation of Street Lights at Institute Campus*

Fig.3 shows the installed automation system operating within the institute campus. Including Solar-Powered Street Lighting, to increase the sustainability of the automated street lighting system, a solar-powered street light has been added to the project. Fig.4 represents the automated lamp integrated with a solar charging module, demonstrating how the integration of automation with renewable energy sources enhances energy efficiency and minimizes both environmental degradation and power usage. This gadget features a photovoltaic (PV) panel, a rechargeable battery, a charge controller, and an energy-efficient LED light. Throughout the day, the solar panel collects sunlight, converting it into electrical energy, that is stored in the battery. The LED bulb is powered by the stored energy to provide night time illumination without relying on grid electricity. The solar-powered streetlight and the timer-based automation system cooperate to maintain the synchronization of the other grid-powered lights. The Arduino Nano and RTC module also control the solar device's on/off timing. It serves as a model for future smart campus initiatives that focus on renewable energy and effective control.

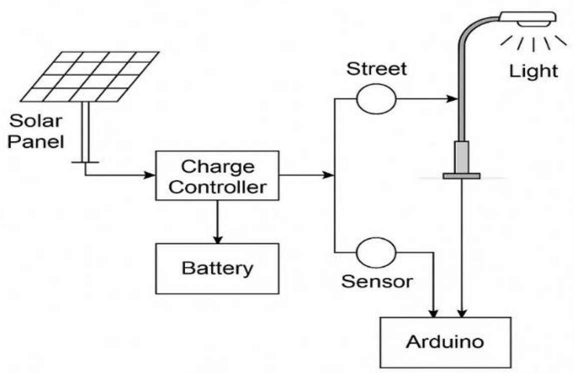

Fig.4 Street lamp with solar energy charging

VI. RESULT AND ANALYSIS

The circuit was successfully tested in a simulated campus environment. The system responded correctly to the RTC-triggered time intervals, consistently switching lights ON and OFF as per the programmed schedule. Fig.5 and fig.6 shows the circuit in its initial, inactive state (lights OFF) the circuit in operation with the (lights ON) activated based on the timer. Extensive testing was performed to evaluate the effectiveness of the automated streetlight system. The tests were conducted over a period of three days in a simulated campus environment, where the circuit was exposed to real-time variations in voltage, timing, and load conditions.

Table.2 shows the system responded accurately to the predefined ON and OFF schedule, without any failure. The relay switching was smooth, and the LCD displayed the correct system time and lighting status throughout the cycle. The AC to DC converter output was consistent at 5V with negligible ripple, ensuring reliable operation of all components.

Table.2 System Performance Summary

Sr.no	Parameters	Observed	Status
1	ON Time	6:00 PM	Accurate
2	OFF Time	6:00 AM	Accurate
3	LCD Update	Real-Time	Stable
4	Relay Switching	Instantaneous	Smooth and Reliable
5	Power Supply output	5V DC	Stable
6	Overall uptime	72 Hours	No Failure

Fig.5 Circuit before operation

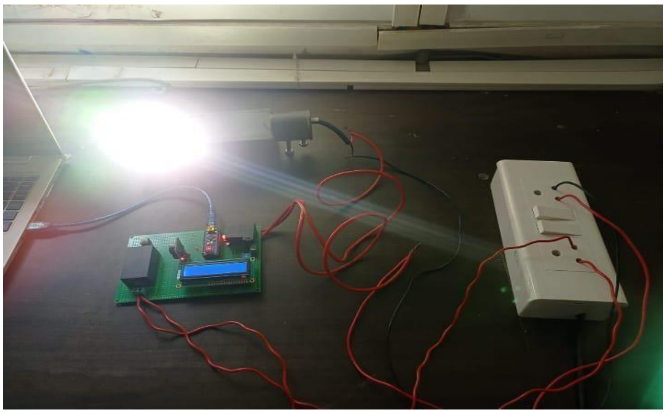

Fig.6 Circuit during operation

VII. CONCLUSION

The implemented system demonstrates the feasibility and effectiveness of automating street lights in a controlled campus environment using Arduino Nano and RTC-based logic. The project meets its objective of reducing energy consumption, eliminating manual effort, and offering a low-maintenance alternative to traditional lighting control systems.

Its modular design allows for future customization, while its simplicity ensures it can be implemented by institutions with minimal resources. The use of open-source hardware keeps costs low while maintaining high reliability.

VIII. REFERENCES

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