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Movement-Controlled Street Lighting System with Minimal Power Consumption

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ABSTRACT

Energy consumption in the public lighting system represents the largest part of the energy usage of a community, while the maintenance and operation of the system are a considerable expense for every city. This paper focuses on products and innovative components for street lighting, proposing a consumption-reducing solution based on an intelligent system for remote measurements and control with dimming technologies for high-intensity discharge (HID) lamps. The results indicate that considerable energy savings are achieved and the service life of the lamps is extended. A movement-controlled street light system is controlled according to the specific mode. The modes are controlled by two sensors, which are the light-dependent resistor (LDR) and the infrared (IR) sensor. This system can automatically turn on and off the lights according to traffic flow. It operates at night, and the focus is only on the one-way road at a junction. The street light will be on when there is at least one road user; otherwise, it will turn off. This design can save a great deal of energy compared to conventional street lights that keep a light throughout the night. Moreover, the maintenance cost can be reduced, and the lifespan of the system will increase. As a result, the system has been successfully designed and implemented as a model system.

Keywords: Infrared sensor, Light dependent resistor, Light emitting diode, Street-light, Energy saving, Microcontroller, and Circuit design.

INTRODUCTION

The rapid urbanization and continuous development of technology has made intelligent street lights an important part for building the smart cities (Xu, X., Zhan, A., & and Li X., 2019). Traditional street lighting systems consume a lot of energy as they run from evening to early morning and require a large installation cost. This is a major drawback in running our day-to-day activities (Mary, et al., 2018). The paper aims to regulate the energy demand of street light with respect to demand. The rapid development of embedded systems has paved the way for the design and development of microcontrollers based on an automated control system. If a village or town has the technology or means to design smart street light system like this, it would save energy occasionally. (Mary, et al., 2018).

The conventional manual operated street lighting systems consume a large amount of power, need manual operators and heavy cost on installation which has been a great disadvantage and an area of major concern. The cost of energy can be reduced immediately to 35% through intelligent on/off mechanism and targeted progressive dimming and organized way of power consumption. We can reduce the overall consumption costs up to 42% by proper maintenance (Mary, et al., 2018). However, the traditional lighting systems are not reliable because of its design based on the old lighting standards and inefficient instruments and devices. Thus, it results in energy losses, frequent replacement of devices, lack of pervasive and effective communications, monitoring, automation, and fault diagnostics problems (Zeeshan kaleem, 2014). The system is more economical. Two points are at the core of this work, first Light emitting diode (LED) technology and second brightness adjustment control. The chosen LED panels have less power consumption and their lifetime is very large as compared to other illumination technologies.

RELATED WORK

In the work of (Mohring, K., Mayers., T.S., & I.M., 2018) The paper investigates low-cost and scalable technologies to provide economically important data for civil defense and traffic management using a streetlight-mounted sensor platform that consists of three sensor technologies for pedestrian and vehicle detection and shows that a lidar and an infrared array sensor each counted traffic with over 98% accuracy.

The work by (Kokilavani M., & Malathi A. 2017) focuses on an automatic street lighting control unit using LDR. The system can select bright or dark environment with LDR. When the weather is dark, the system allows the operation of street-lights, while in the bright morning and afternoon, it allows turning off the lights.

The investigation by (Gianfranco, et al., 2020) elaborates on the use of an IoT infrastructures whereby each lighting pole is an element of a network that can increase their amplitude. The system combines various sub-systems and electronic devise, each responsible for a specific operation.

An "Artificial neural networks (ANNs) based power management for smart street lighting systems is studied by (Dr. Smys, Basar, & Wang, 2020). The proposed system uses ANNs due to the malleable reconfiguration of the frame, the capability to acquaint with a variety of inputs, and furthermore for its capability to train the developed neural networks and modify their parameters. Expert systems such as genetic algorithms, artificial neural networks, and fuzzy systems are typical AI methods used in formulating a smart street lighting system.

The work by (Andrzej & Grela, 2016) describes a control system based on the ISO/IEC EN 14908 BACS standard (Lon-Works) with a power line communication (PLC) on the field level, to control each of a lamp. The experiment is carried out on the installation consisting of eight modern road lighting luminaires with the high-pressure sodium lamps (HPS 70W). In each of the luminaires, there are three additional modules: Lon- works node module, an electronically adjustable smart ballast and an interface filter module. The applied electronically controlled smart ballast is a source of power for HPS lamps. It ensures optimal lamp use parameters throughout the period of its operation, extending the life of the lamp and reducing energy consumption compared to conventional ballasts.

In work of (Khattak, et al., 2022) a compute vision methodology has been employed for traffic characterization under heterogeneous traffic conditions and unlike both intrusive and non-intrusive sensors, the proposed solution can detect pedestrians, two/three wheelers and animal/human driven carts.

METHODOLOGY

Working Principle

The working principle of the system is that when in the evening light intensity becomes less than a critical predetermined value, lights are switched on, and after midnight, they are automatically switched off based on the real clock value. After midnight, it works on vehicle and human movement sensed by sensors installed at each pole of light. Lights will be on in the region through which the vehicle is moving. These lighted poles will move with the vehicles, meaning that pole lights above the vehicle will remain on, previous ones will be off, and the next poles will be on. LDR sensors and IR sensors are the two main conditions for working the circuit. If the two conditions have been satisfied, the circuit will do the desired work according to a specific program. Each sensor controls turning on or off the lighting column. With commands from the controller, the lights will be on in the places of the movement when it is dark. These cycles continue with the vehicle. This also helps in the reduction of power usage.

The system development process starts with the design architecture of the proposed system. The components for this work have been classified based on the component group consisting of input, output, and controller. LDR and IR sensors are used to control the desired system parameters. Next, the information gathered by the sensors is transferred to the controller, which runs the program in order to analyze the system. The programmable interface controller (PIC) microcontroller ATmega328P is used as the brain to control the street light system. Meanwhile, the purpose of the microcontroller is to process the data from the street light and transfer it as the output of the system.

Design Algorithms:

Below are steps used to design an algorithm

STEP 1: Start

STEP 2: Microcontroller initiates IR and LDR sensor

STEP 3: LDR checks light intensity to verify night time

STEP 4: IR checks motion and activate the respective lamp

STEP 5: Go to STEP 2 (continuous) or

STEP 6: Stop.

Flowchart

The flowchart, which indicates the entire operation of the system and in which the control on two modes, is shown in Figure 1. These modes are controlled by two sensors, which are the LDR and IR sensors. The focus of this project is only a one-way road at the junction, and it will detect any movement, whether vehicle or pedestrian. Firstly, Mode 1 will be selected when LDR detects day or night. If it senses night, automatically the street lights at the junction of the road (L1, L2) and all IR sensors will be switched on. Next, Mode 2 will take over when each IR sensor at any point senses the motion or any movement of the vehicle within 5 meters. The PIC microcontroller will switch on the street lights at the edge of the road. The street lights will turn on until the IR sensor does not sense any movement within 20 seconds; therefore, the street lights will have turned off. When the LDR sensor senses the intensity of light from the sun, the system will turn off both the street lights and the IR sensor. Lastly, the system will loop back to the initial state.

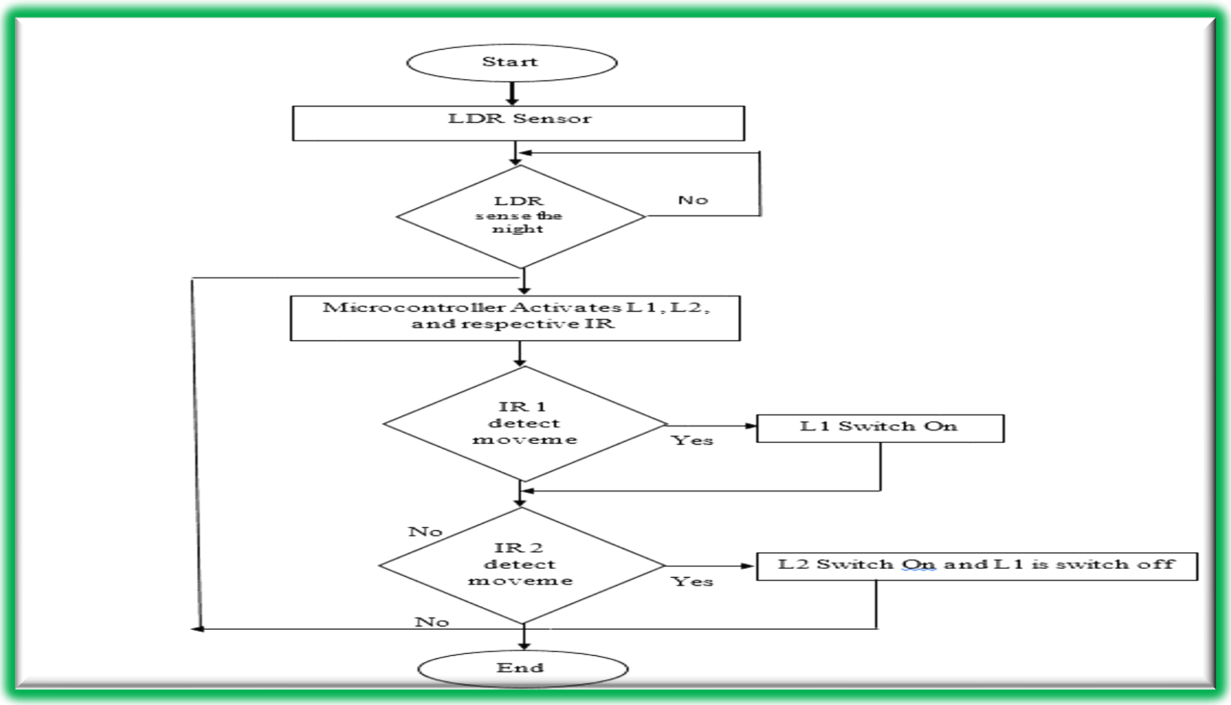

Figure 1: Flow chart of the system

3.4 Circuit Design

Simulation was done using ProteusTM circuit simulation software and the circuit of figure 2 was tested on breadboard before it was then transferred to the Vero board.

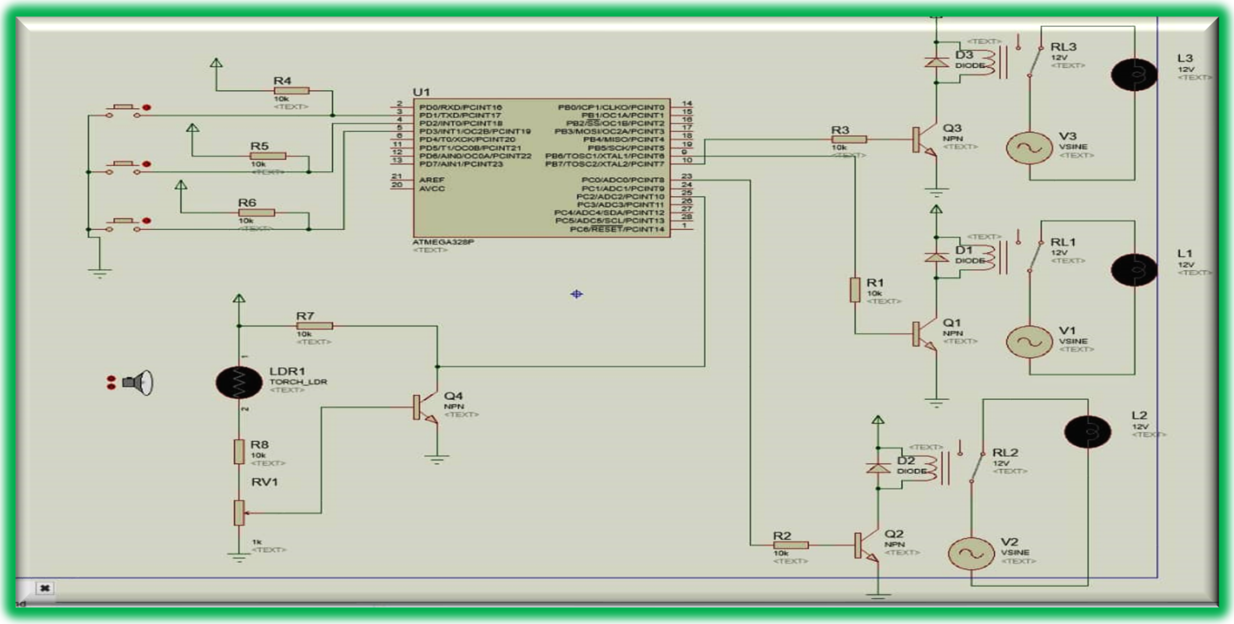

Figure 2: System circuit design

RESULT AND DISCUSSION

Testing is crucial to determining the product's quality and functionality, and this project has already undergone a number of tests to guarantee correct operation. In addition, make sure the user and the components are safe.

Hardware Testing

A prototype of the street lighting automation system is developed, and the whole prototype design is shown in Figure 3 and 4. The design of the whole project was done with three bulbs, three IR sensors, and one LDR sensor. All the wiring and connections are connected to the PIC on the Vero board. Component calibration was carried out, which starts with the LDR sensor, then the IR sensor, and lastly the bulb as the light module. During the day, all bulbs and the IR sensor are turned off. Meanwhile, during the night, when the LDR sensor detects light intensity, all bulbs and IR sensors are active. This condition is on Mode 1 of the flowchart. Figure 4 shows the condition of bulbs that are active (on) during the night.

For Mode 2, IR sensor will detect any movement of vehicles or pedestrians, then, Bulbs will turn on. When IR sensor 1 detects movement, Bulb 1 is turned ON.

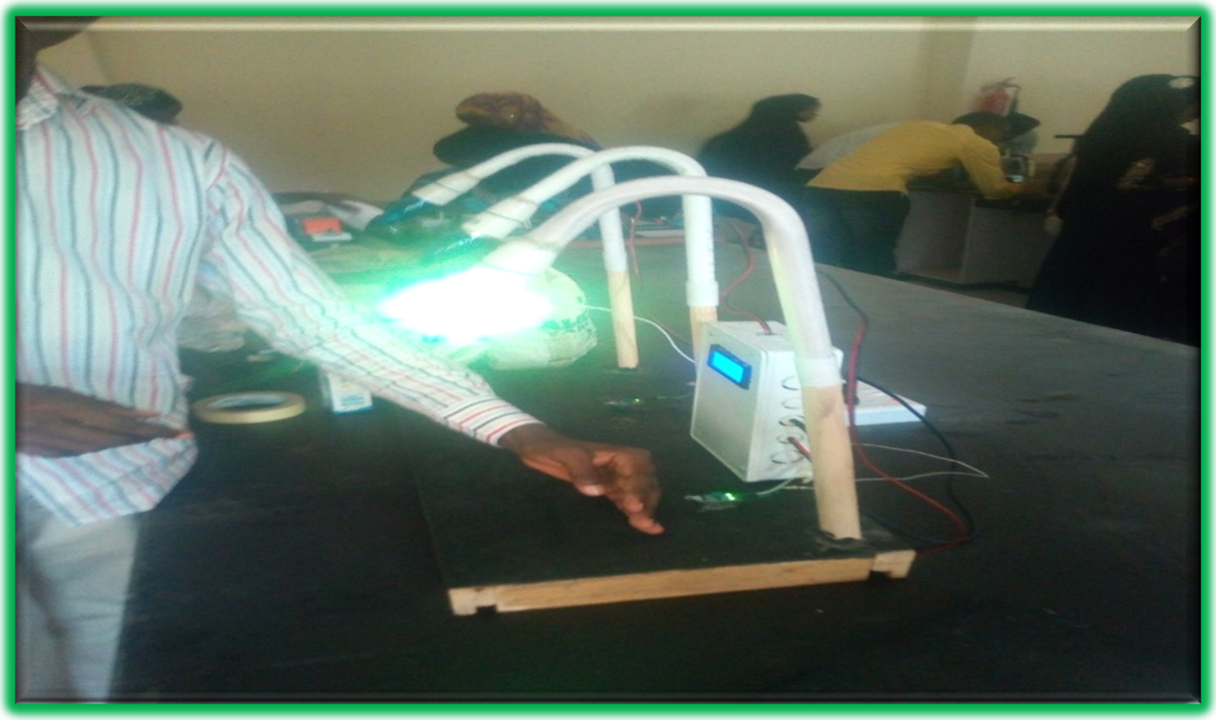

Figure 3: When IR 1 sensor detects movement

Also, Bulb 2 turned ON when IR sensor 2 detects movement. However, Bulb 3 turned ON when IR sensor 3 detects movement. The system then will loop to the initial condition.

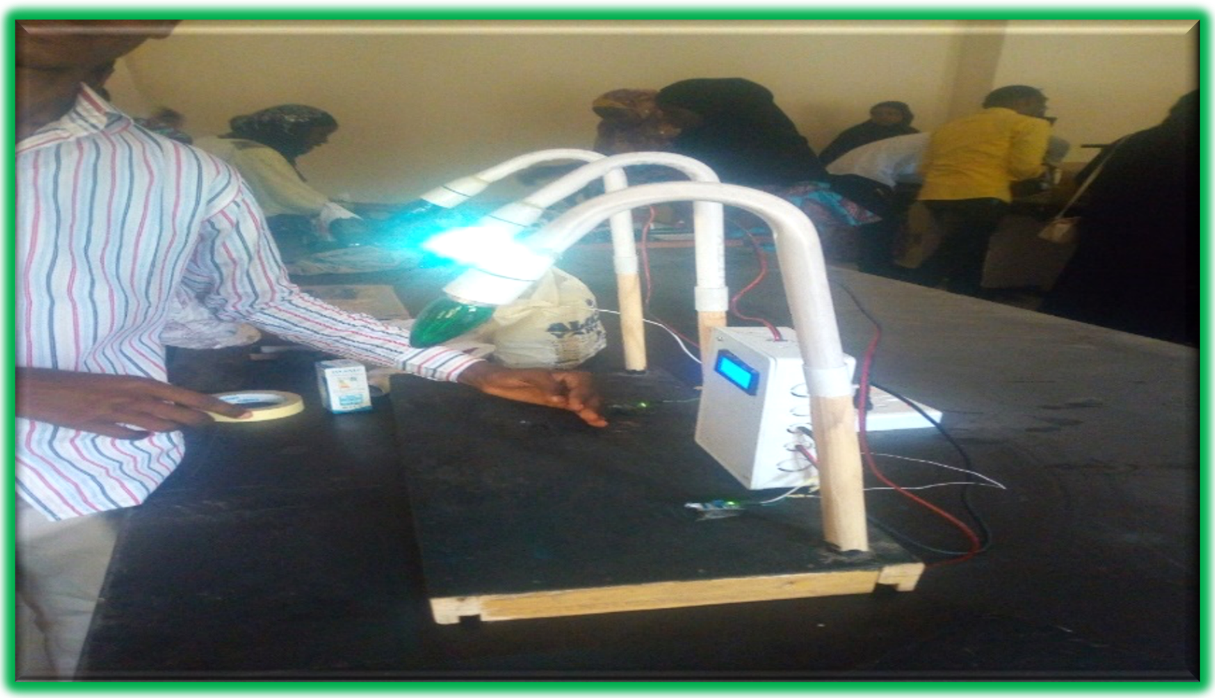

Figure 4: When IR 2 sensor detects movement

Sensitivity Test

Sensitivity test result for IR sensor

Because there is a semiconductor/chip inside the sensor, it must be powered with 3-5V to function. When the microcontroller receives IR signal, it will pull the output low, turning on the LED (Bulb) of the streetlight. The object is placed in front of the right IR detector, about 1-5m. So, if the IR output is stuck at 1 or 0, it usually indicates a wiring problem.

Testing for LDR sensor

A photo resistor, or LDR, is a resistor whose resistance decreases with incident light intensity; in other words, it exhibits photoconductivity. Photoelectric or light-sensing devices are used in almost any branch of industry for control, safety, amusement, sound reproduction, inspection, and measurement.

When the light level decreases, the resistance of the LDR increases. As this resistance increases in relation to the other resistor, which has a fixed resistance, it causes the voltage dropped across the LDR to also increase. When this voltage is large enough (0.7V for a typical NPN transistor), it will cause the transistor to turn on. The value of the fixed resistor will depend on the LDR used, the transistor used, and the supply voltage. Table 1 shows the distance of the lamp from the LDR (m) versus the resistance (k). The results of the test were obtained by using a lamp on the LDR.

The value of the fixed resistor will depend on the LDR used, the transistor used and the supply voltage. Table 1 shows the distance of lamp from LDR (m) versus Resistance (kΩ). The results of the test were obtained by using Lamp on the LDR.

Table1: Test on LDR

Distance of Lamp from LDR (m)	Resistance (kΩ)
0.50	0.300
1.00	1.810
1.50	3.56
2.50	3.76

Energy Utilization

For this street lighting automation system, the usage of energy or power can be less than the normal power consumption that has been analyzed in existing street lighting since this system is using smart street lighting that only lights up if there is a vehicle or pedestrian nearby. Regardless, it is during a peak hour on the night, such as from 7 p.m. until 12 a.m. at midnight. Plus, this system uses a bulb (i.e., LED) as the light module, which is better at saving energy compared to the existing lamps (Ramli, Yamin, Ghani, Saad, & S.A.Md, 2015). Assuming the street lighting functions completely for 12 hours between 7 p.m. and 7 a.m., Assuming 12 nodes are used to work, the power consumed is given below:

Using High Pressure Sodium (HPS):

Total power consumed by 1 HPS = 400W (1)
Number of nodes = 12 (2)
Number of working hours per day = 12 (3)
Power consumed per day = 12 x 12 x 400 (4)
= 57.6 kWh
= 57.6 units
57.6 x 30 = 1728 units per month = 1728 kWh/month

Using LED:

Total power consumed by 1 LED bulb = 10w (5)
Number of nodes = 12 (6)
Number of working hours per day =12 (7)
Power consumed per day = 12 x 12 x 10 (8)
= 1.44 kWh
= 1.44 units
1.44 x 30 = 43.2 units per month = 43.2 kWh/month

Using LED (for street lighting automation system):

For the automation system, three nodes will be fully lit for 12 hours (7 p.m. to 7 a.m.), while the other nodes will be on sensor.

Total power consumed by 1 LED = 10w (9)

Number of nodes = 3 (fully light on for 12 hours) (10)

= 9 (light on when sensor detect movement)

Number of working hours per day (for sensor):

Assume:

7.00 p.m. – 1.00 a.m. (heavy traffic) = 6 hours (11)

1.00 a.m. – 7.00 a.m. = 3 hours (within 30 minutes' vehicles pass through)

Total: 9 hours

Power consumed per day = [(9 x 9) + (3 x 12)] x 10

= 1.17 kWh

= 1.17 units

1.17 x 30 = 35.1 units per month = 35.1 kWh/month

Energy saved between LED for automation system with HPS for public street lighting:

1728-35.1 = 1692.9 (12)

$$\frac{1692.9}{1728} \, x \, 100\% = 97.97\ \% \quad (13)$$

Energy saved between LED for automation system with LED for public street lighting:

$$43.2-35.1 = 8.1 \tag{14}$$

$$\frac{8.1}{43.2}\ x\ 100\% = 18.75\% \tag{15}$$

The calculations for energy savings have been done using high-pressure sodium (HPS) lamps and light-emitting diodes (LED) (C.A., SWATHI, S.H. KUMAR, & ANNAPPA, 2014). Table 2 shows the estimated power savings after making the comparison between the usage of HPS lamps and LEDs. From this calculation, the comparison in terms of energy efficiency is obtained between High Pressure Sodium (HPS), a type of lamp that is commonly used in public street lighting, and Light Emitting Diode (LED) for automation systems that operate according to traffic flow by sensing the movement within a certain time. Additionally, the comparison with another LED is also made, which was used for Public Street lighting that operated within 12 hours from 7 p.m. until 7 a.m.

Table 2: Comparison of energy saving between LED and HPS

Type of lamps used	Percentage of energy saving
LED for street light automation system VS HPS for public street lighting	97.97%
LED for street light automation system VS LED for public street lighting	18.75%

Meanwhile, for the street lighting automation system, the assumption is made that from 7 p.m. until 1 a.m., which is heavy traffic during the night, the system will be on for 6 hours. During midnight, at 1.00 a.m. until 7.00 a.m., it was assumed that every 30 minutes, vehicles used the road within each hour since fewer people used the road during midnight.

From this calculation, a comparison of the energy saved between HPS lamps and LED lamps is obtained. About 18.75 percent of energy can be saved when comparing LED for street light automation systems with LED used for public street lighting. However, 97.97% of the energy used by HPS for public street lighting can be saved when compared with LED street lighting automation systems. The difference value between the usages of HPS lamps is quite high compared to the usages of HPS lamps and quite high compared to the usage of LED. Consequently, the use of LEDs results in greater energy savings than that of high-pressure sodium (HPS) lamps.

CONCLUSION

It is possible to draw the conclusion that this project's hardware and software development both achieve the design goal by considering all the findings. A successful street lighting automation system prototype was constructed. Since LEDs only turn on when there is movement from cars, using an IR module sensor as the input allows the system to save energy. As a result, the power used by LEDs is reduced. When comparing LED utilized for public street lighting with LED used for street lighting automation systems, about 18.75% more energy can be saved. However, when comparing LED for street lighting automation systems with HPS utilized for public street lighting, energy can be reduced by 97.97%.

The risk of vandalism and theft is the major weakness of this system. Also, if there are issues with the sensors, it might light or it might remain lit for a long time, thus wasting energy.

This method is not just restricted to streetlights; it can also be applied to many modern technologies, including headlights, park lighting, industrial lights, and many more. Without a doubt, the adoption of this system will alter the world as we know it.
For future development, this system can be upgraded for two ways road especially in highways, traffic routes and urban areas.

RECOMMENDATION

This project can be enhanced to include further stages such as solar panel installation and control system installation. This all-encompassing system will lead us to independent street lighting systems that will be more economical and more efficient, and a self-fault detection system will help with maintenance.

This system can also be improved if it could adopt wireless power transmission, which would further reduce the maintenance costs and power thefts of the system, as cable breaking is one of the problems faced today. In addition to this, we can use a supervisory control and data acquisition (SCADA) system, but its initial cost is high and it is an expensive system.

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