Jurnal Kejuruteraan 33(1) 2021: 147-153
https://doi.org/10.17576/jkukm-2020-33(1)-15

Intelligent Street Lighting Energy-Saving System Based on Climate Conditions and Vehicle's Movements

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Received 30 September 2019, Received in revised form 01 June 2020
Accepted 05 July 2020, Available online 28 February 2021

ABSTRACT

The huge amount of electric power and cost associated with street lighting has raised the need to investigate both cost issues and environmental concerns. Cities worldwide are increasingly investing in energy-efficient street lighting systems. Modern street lighting technology can lower energy consumption as well as operation and maintenance costs significantly. In addition, bright street lighting can reduce accidents and crime rate in the area. Street lighting is an essential public service that provides a significant factor contributing to the quality of life and productivity of people workforces. This paper proposes an intelligent and energy-efficient traffic sensing system based on the widely distributed street lights. It is intended to observe vehicle's movement on the road and turn ON a block of street lights ahead of vehicle whenever needed. As the vehicle passes by, the system turns OFF the trailing lights. The brightness (intensity of light) of the street light is adjusted based on the surrounding using LDR sensor. Hence, the street lights will be switched ON in the evening around sunset when a vehicle passes by, and switched OFF in the morning after sunrise when there is sufficient light on the streets. In addition, the proposed system will control the intensity level of the street light using the LDR sensor. The Proteus Software Simulation of the proposed system was performed and tested. Then a hardware prototype was designed and implemented to evaluate the performance of the proposed system. This technology can save significant costs and energy.

Keywords: Light Dependent Resistor (LDR); light emitting diode; street light; PIC microcontroller; IR sensor

INTRODUCTION

Cities worldwide are increasingly investing in energy-efficient street lighting systems. Modern street lighting technology can lower energy consumption as well as operation and maintenance costs significantly. In addition, bright street lighting contributes in reducing accidents and crime rate in the area (Gouthami et al. 2016). Street lighting is an essential public service that provides a significant factor contributing to the quality of life and productivity of people workforces. This makes it a key consideration for any government from several perspectives. These include environmental, safety, and economical issues (Al-Smadi et al. 2019). Lighting can account for 10-38% of the total electricity consumption in typical cities worldwide (Devi & Kumar 2012; Saad 2013). Cho and Dhingra (2008) stated that about 30% of the total electricity consumption of any country is consumed in lighting the streets and roads. Nowadays, all the lights on the roads stay switched ON all night long on a lot of streets, while energy problem is a social focus these days. This in turn consumes a huge amount of electrical power in lighting these streets and roads. In addition, for some roads, vehicles pass with small rate during the night. Never the less, these streets still consume electricity. If there is no traffic on the street at night, street lights will be not necessary. Street lighting control systems play an important role in the reduction of electrical power consumption. Power electricity related emissions count for about 80% of air emissions and serious environmental hazards and climate change (Rajput et al. 2013).

Hence, street lighting control systems become a necessary solution for energy saving and environmental issues. There are many proposals in the literature to electrical power consumption and reduce pollution in lighting the streets (Wu et al. 2009; Li et al. 2009). Wu et al. (2009) and Li et al. (2009) proposed a street lighting intelligent system based on wireless network control that can implement real-time monitoring for road lighting without manual intervention.

Shahzad et al. (2016) proposed an approach to traffic-flow-based smart light emitting diode (LED) street lighting for energy optimization. Their proposed system uses low power ZigBee mesh network give maximum power efficiency in response to adaptive traffic on the street. Lobao et al. (2015) proposed a novel software application and experimental validation to select the most appropriate system of street light installations. Their proposal takes into account the reduction in the electric power consumption of the used lamps and losses in the electrical conductors. Husin et al. (2012) proposed an automatic energy efficient street lighting system based on the number of traffic. The system has five different levels of street light brightness for lighting up the streets is proportional to the number of traffic. Their system was programmed to operate automatically according to climate conditions; that is, the system would turn OFF during the daylight and turns ON during night hours and bad weather. Escolar et al. (2015) proposed a study to improve the energy consumption of street lighting in Spain. The study analyzed different devices including lamps and lamp globes which influence electric power consumption. Their study showed some aspects that should be incorporated into the Spanish Standards to improve quality of street lighting and optimize electric power consumption. Escolar et al. (2014) proposed an intelligent street light control system using adaptive behavioral rule. The system enables multiphase light sources to adapt their intensity to the environment conditions. Their approach was evaluated using a simulator which combines wireless sensor networks and belief-desire-intention (BDI) agents to get an accurate simulation of both the city infrastructure and the adaptive behavior that it implements. Alzubaidi and Soori (2012) presented a case study on electric power efficiency for the streets in Qatar using DIALux4.9 software. They used different types of lamps highlights to investigate the efficiency of the street lights. Their study concluded that their proposed system can achieve 40% reduction in the electrical power consumption. Elejoste et al. (2013) found that street and road lighting has the greatest impact on electric power consumption in most Spanish municipalities, and may use up to 80% of the electric power consumed by municipalities.

In this paper, an intelligent and energy-efficient street lighting system which will eliminate the manual operations is proposed. It is intended to observe vehicle's movement on the road and turn ON a block of street lights ahead of vehicle whenever needed. As the vehicle passes by, the system turns OFF the trailing lights. The brightness (intensity of light) of the street light is adjusted based on the surrounding using Light Dependent Resistor (LDR) sensor. Hence, the street lights will be switched ON in the evening around sunset when a vehicle passes by, and switched OFF in the morning after sunrise when there is sufficient light on the streets. This technology can save significant costs and energy.

PROPOSED SYSTEM

In modern societies, the interest in street lighting control systems is growing rabidly with rapid growth in industry. This paper proposes an intelligent and energy-efficient street lighting system automatically according to the amount light intensity upon the lamp post. The proposed system is intended to observe vehicle's movement on the street and turn ON a block of street lights ahead of vehicle whenever needed. As the vehicle passes by, the system turns OFF the trailing lights. The system will control the intensity of the lamp post light. That is, the street lights are switched ON based on the intensity of the Sun light upon the LDR sensor. The brightness (intensity of light) of the street light is adjusted based on the surrounding using Light Dependent Resistor (LDR) sensor. Hence, the street lights will be switched ON in the evening around sunset when a vehicle passes by, and switched OFF in the morning after sunrise when there is sufficient light on the streets. The aim of this paper is to reduce energy consumption and operation cost of street lighting system while ensuring the safety of peoples and vehicles (Ożadowicz and Grela 2017). The system consists of PIC Microcontroller (16F877A), Light Dependent Resistor (LDR), Infrared (IR) sensor, Light Emitting Diode (LED). The Block Diagram of the proposed system is shown in Figure 1.

PIC MICROCONTROLLER (16F877A)

The PIC microcontroller was originally developed by General Instruments Microelectronics Division in 1975. The name PIC initially referred to Peripheral Interface Controller. The General Instruments used the acronyms Programmable Interface Controller and Programmable Intelligent Computer for PICs (Prasad 2014). It is a compact Microcomputer designed to control the operation of embedded systems in robotics, office machines, medical devices, mobile radios, motor vehicles, home appliances, and many other devices.

PIC (16F877A) is a 40-pin PIC Microcontroller. It is one of the most commonly used microcontrollers in the industry because of its operational flexibility and availability. The

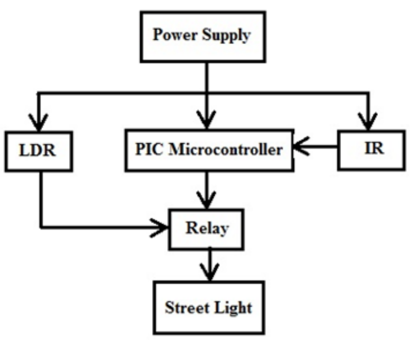

FIGURE 1. The block diagram of the proposed intelligent street light system

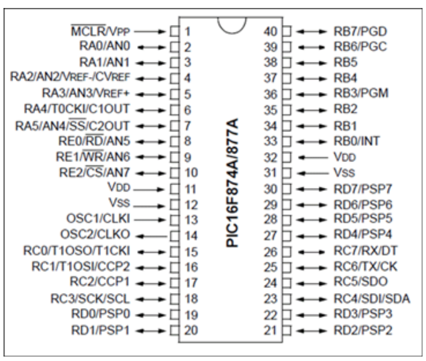

FIGURE 2. Pin diagram for PIC (16F877A) Microcontroller (Al-Smadi et al. 2019)

PIC (16f877A) Microcontroller finds its applications in a huge number of devices. For example, it is used in remote sensors, home automation, security and safety devices, and in many industrial instruments. It has a total number of 40 pins and a CMOS FLASH-based 8-bit. The Pin diagram for the PIC (16f877A) is shown in Figure 2.

LIGHT EMITTING DIODE (LED)

A light-emitting diode (LED) is a semiconductor light emits light when current flows through it. Early LEDs were often used as indicator lamps, replacing small incandescent bulb. LEDs have many advantages over incandescent light sources, including lower energy consumption, smaller size, faster switching, and longer lifetime. LEDs are manufactured in different sizes, colors, and shapes (Boylestad & Nashelsky 2009).

Nowadays, lightening-up of highways is done through high intensity discharge (HID) lamps which are a type of electrical gas-discharge lamps which is based on gas discharge (Singh 2014). However, the energy consumption of these lights is high as well as there is no particular mechanism to turn ON/OFF the lights from sunrise to sunset. Therefore, the light intensity of the HID cannot be controlled by voltage reduction. In addition, HID lamps consume more energy. The proposed system uses LEDs lamps rather than the used HID. LEDs lamps are energy saving because of its high luminous efficiency. LEDs are coupled with relay to be switched ON or OFF.

INFRARED (IR) SENSOR

An infrared sensor is an electronic device used to sense certain characteristics of its surroundings. It does this by either emitting or detecting infrared radiation (Tambare 2016). The IR sensor consists of IR transmitter and IR receiver. The transmitter emits infrared radiations. This infrared signal is bounces (reflected back) from the surface of an object and the signal is received at the infrared receiver. Figure 3 shows the function of the IR sensor.

LIGHT DEPENDENT RESISTOR (LDR)

A photoresistor or LDR is a light controlled variable resistor. It measures the amount of light; that is, the resistance of the LDR sensor depends on the light intensity. The resistance of an LDR decreases with increasing incident light intensity (intensity of the Sun light). If the light intensity is low, then the value of resistance of the LDR will be high. This value increases as the night gets darker. The resistance value of the LDR reaches its maximum at midnight. As the dawn starts, the resistance of the LDR decreases and the light intensity on the LDR increases. Figure 4 shows a typical LDR resistance versus light intensity.

RELAY MODULE

Relay is an electromagnetic device which is used to isolate two circuits electrically and connect them magnetically. It works as a switch that opens and closes circuits electromechanically or electronically. Relays are useful devices and allow one circuit to switch another while they are completely separated. They are often used to interface an electronic circuit (working at a low voltage) to an electrical circuit which works at very high voltage. Relays control one electrical circuit by opening and closing contacts in another circuit. Relays are used where it is necessary to control a circuit where several circuits must be controlled by one signal (Gurevich, 2006). In a basic relay there are three contactors: Normally Open (NO), Normally Closed (NC), and Common (COM). At no input state, the COM is connected to NC. When the operating voltage is applied the relay coil gets energized and the COM changes contact to NO **(**Tambare 2016**)**.

Each LDR is connected directly to the LED bulb through the relay. The system controls the light intensity of the LED bulb based on the light upon the LDR sensor. To represent the switches in real mode, IR sensors were used. The IR sensor module output port was directly connected to the PIC Microcontroller. IR sensor is used to monitor the lights of the streets. It checks the traffic. If it detects a coming vehicle (or any obstacle) in front of the signal, the IR will inform the PIC Microcontroller. The PIC Microcontroller will send a high level output to change the relay state from being normally open to close and turn the LEDs ON. That is, the PIC Microcontroller gives order to turn ON a block of street lights ahead of vehicle. The lights are switched ON for a period of time and (if the IR detects no other vehicles present on road) switched OFF automatically. This period of time is set by the user using the PIC Microcontroller.

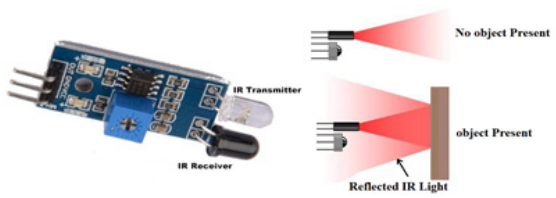

FIGURE 3. Function of the IR sensor

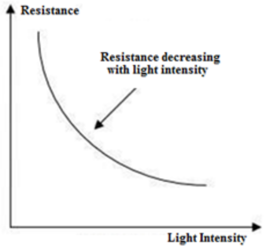

FIGURE 4. Typical LDR resistance versus light intensity

PROTEUS SIMULATION MODEL

The Proteus Software Simulation Circuit is electronic circuit design software which includes a schematic, simulation and Printed Circuit Board (PCB) Layout modules. Proteus is ahead in simulating the circuits containing the Microcontrollers where the circuit can be simulated by uploading the Hex code to the Microcontroller. The Proteus Software Simulation of the proposed system has been done as shown in Figure 5 for each working part of the system. All the components are selected from the component library included in the software itself. The simulation was tested and feasibility is checked before its hardware implementation and real time deployment.

Each LDR is connected directly to an LED bulb through a relay as shown in the proteus circuit. This part of the circuit is shown in Figure 6. The LDR sensor controls the light intensity of the LED bulb based on the Sun light on it. That is, the street lights are switched on based on the intensity of the Sun light upon the LDR sensor. The resistance of the LDR decreases with increasing incident light intensity (intensity of the Sun light). The resistance of the LDR has the following resistances:

$$\text{Daylight}= 50\ \Omega \qquad \text{Dark}= 1\text{M}\ \Omega \tag{1}$$

The voltage across the LRD is represented by V^* on the Proteus Simulation Circuit as shown in Figure 6.

Using Voltage Divider at V^*:

$$V^* = \frac{R_{LDR}}{R_{LDR}+100}(Vcc) \tag{2}$$

At Night:

$$V^* = \frac{R_{LDR}}{R_{LDR}+100}(Vcc) = \frac{1M}{1M+100}(5V) = 4.999\text{V} \tag{3}$$

At Daylight:

$$V^* = \frac{R_{LDR}}{R_{LDR}+100}(Vcc) = \frac{50}{50+100}(5V) = 1.67\text{V} \tag{4}$$

The change in the voltage, V^*, will control the intensity of the LED bulbs. V* is connected to the relay module. The other pin of the relay connected to the LED Bulbs. The relay used is normally open. When the PIC Microcontroller sends 1, the relay closed and LED turns ON with a certain intensity depending on the value of V*. The resistance value of the LDR reaches its maximum at midnight (V* will be

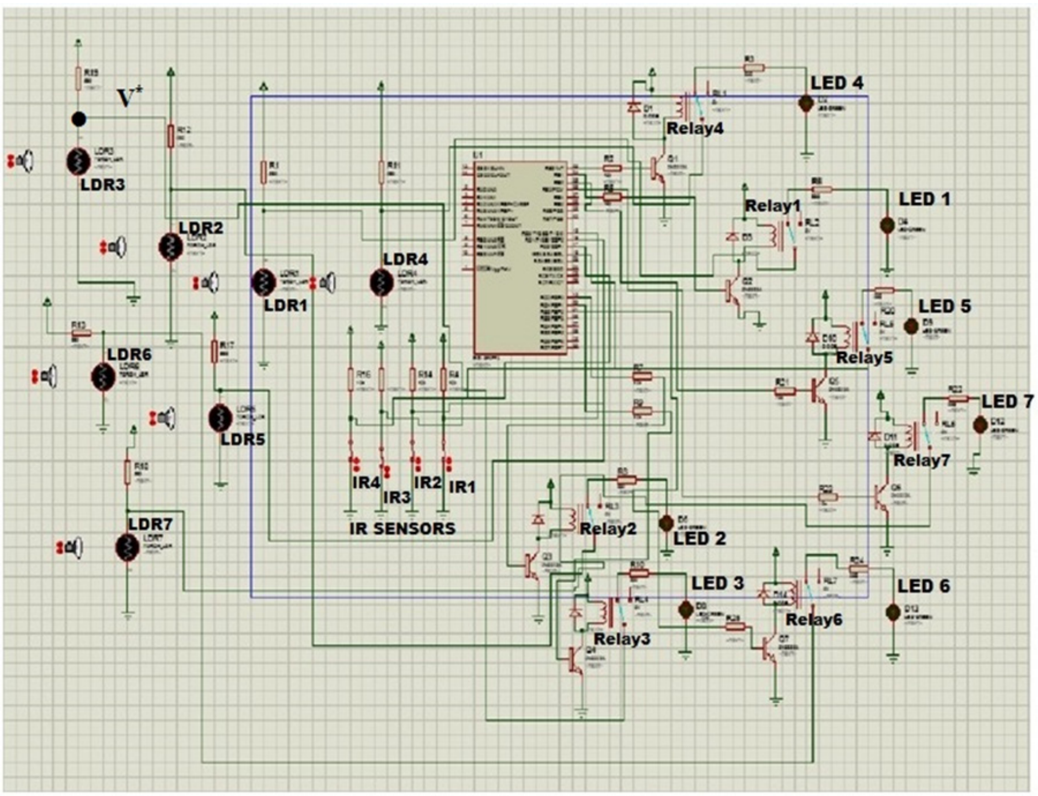

FIGURE 5. Proteus Simulation Circuit for the proposed intelligent street light system

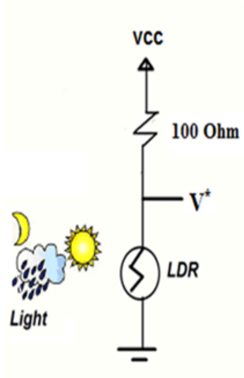

FIGURE 6. The LDR circuit connection

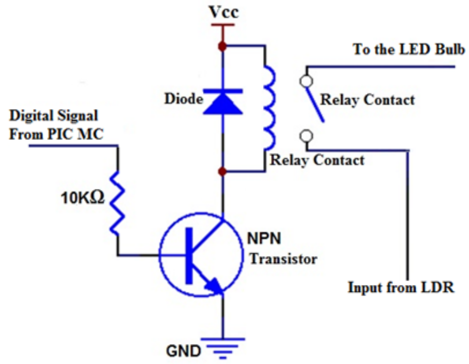

FIGURE 7. Circuit diagram of the relay module

TABLE 1. The connections between the IR sensors and the LEDs through the PIC Microcontroller

Input to the PIC IR Sensor	Output of the PIC LED (Pole)
1	1 & 4
2	5 & 7
3	2 & 3
4	6

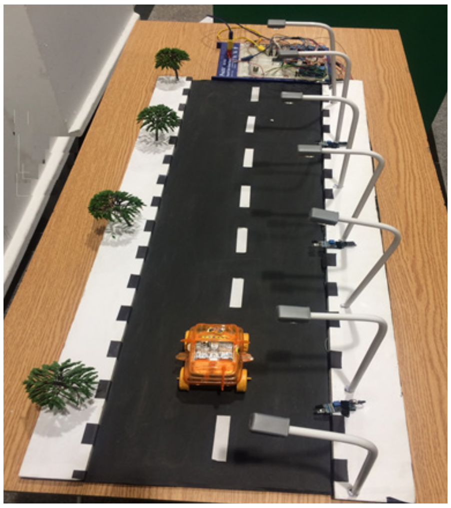

FIGURE 8. A prototype of the proposed intelligent street light system

maximum), street lights will switch ON at full intensity when a vehicle comes by. As the dawn starts, the light intensity upon the LDR increases. Then, the resistance of the LDR decreases. Hence, the intensity of the street lights gradually decreases until it is switched OFF (V* will be minimum).

To represent the switches in real mode, IR sensors were used. The model has 4 IR sensors. Each sensor controls the light of two poles (LED Bulbs). The IR sensor module output port was directly connected to the PIC Microcontroller. IR sensor checks the traffic. If it detects a coming vehicle (or any obstacle) in front of the signal, high level output will be sent by the PIC Microcontroller to change the relay state from being normally open to close and turn the LEDs ON. That is, the PIC Microcontroller gives order to turn ON a block of street lights ahead of vehicle. The lights are switched ON for a period of time and (if the IR detects no other vehicles present on road) switched OFF automatically. This period of time is set by the user using the PIC Microcontroller. Table 1 shows the connections between the IR sensors and the LEDs through the PIC Microcontroller as shown in Figure 5.

In this paper, the PIC Microcontroller is used to analyze vehicle existence on the road and to generate signal that controls an NPN transistor which is part of the relay. The transistor used in the relay module is a 2N2222 NPN bipolar junction transistor. It is used here for switching applications. When transistor is ON, power flows through the coil as shown in Figure 7 (this circuit is part of the proteus circuit in Figure 5). This will generate a magnetic field that attracts a contact and activates the next circuit. When the power is switched OFF, a spring pulls the contact back to its original position, switching the second circuit OFF again. This in turn energizes the relay to turn street light ON or OFF. In relay module, NPN transistor is used as a switch, while the resistor at the base of transistor is used as current limiting resistor. Diode is used to avoid back emf voltage which may produce sparking across relay. The proposed system uses 7 relays modules, each relay controls one light.

A prototype of the proposed system has been implemented and tested. It works as expected and will prove to be very useful. Figure 8 shows the complete working prototype of the system with obstacle detection (vehicle) on the street through IR sensor.

CONCLUSION

In this paper, an intelligent and energy-efficient street lighting system was proposed. The system will eliminate the manual operations. It is intended to observe vehicle's movement on the road and turn ON a block of street lights ahead of vehicle whenever needed. As the vehicle passes by, the system turns OFF the trailing lights. The brightness (intensity of light) of the street light is adjusted based on the surrounding using LDR sensor. Hence, the street lights will be switched ON in the evening around sunset when a vehicle passes by, and switched OFF in the morning after sunrise when there is sufficient light on the streets. In addition, the proposed system will control the intensity level of the street light using LDR sensors. The Proteus Software Simulation of the proposed system was performed and tested. Then a hardware prototype was designed and implemented to evaluate the performance of the proposed system.

Some advantages of this system are as follows. A huge amount of electrical power may be saved without affecting the safety of the vehicles. The system will minimize carbon emission. The system will increase the lifetime of the lamps. In addition, it will reduce the maintenance since the lamps will take more time to be replaced.

DECLARATION OF COMPETING INTEREST

None.

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