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Solar Powered LED Street Lighting Based on Vehicle Motion Detection for Sustainable Energy Utilization

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Abstract

A large amount of energy can be saved by developing a smart street lighting system which essentially assuage the problem of power consumption and reduction of carbon footprint. The conventional process involves higher energy consumption because of longer and unnecessary operating hours of the street lights based on night hours. However, by controlling the intensity of the street lights based on the movement of traffic in the street saves a great deal of energy. In this research, a smart system for operating the street lights is developed for controlling brightness of the light bulb based on the motion of the movement of the vehicle. In this research, a prototype for smart street light system is developed based on the solar PV panel, battery, light dependent resistor (LDR), passive infrared sensors (PIR) and battery charge controller. Moreover, the control system is designed based on Arduino UNO as the microcontroller which provide the necessary pulse width modulated signal to control the light intensity. The research has been conducted based on four different simulation scenarios where the operating time and traffic condition is varied. In this study, the developed smart street lighting system is able to save up to 50% of energy than the conventional system per day during light traffic condition.

Keywords: Solar Powered LED, Energy Utilization, Vehicle Motion Detection, Street Lighting, Prototype.

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1 Introduction

The street lighting system is an indispensable component of the modern civilization which provides necessary road safety, crime prevention and comfort [1]. Moreover, it has a great impact of lowering the crime rate, increasing the range of visibility and reducing traffic accident. However, unplanned and inefficient use of lighting has become a major concern in the energy industry About 19% of the global electrical energy is used for the purpose of lighting around the world.[2]. Hence, it has a profound effect on the environment because of increasing the emission of carbon dioxide. However, study show that, by implementing advanced lighting system can save energy consumption around 40% rather than the conventional system [3].

The conventional process of operating the street lighting system involves processes such as manual switching and timer-based switching system, which is used to activate the street lights during night time and street lights are turned off after sunrise. Usually, the operating hours for the conventional street lights are from around 7PM to 7AM. Hence, this longer operating hours of the conventional system generally contributes to a large amount of energy wastage, which is also undesirable and costly. In this way the, street light being turned on uninterruptedly when it is absolutely unnecessary. Hence, energy saving street lighting control system based on automation have been developed for turning the lights on and off based on the traffic condition in the streets [4], [5]. Automation based smart systems are widely popular in the industries for a long time in order to increase the efficiency and accuracy[6].

In the recent times, numerous researches have been conducted in the field of smart street lighting system for improving the efficiency and reducing the power consumption [7]–[9] Solar PV module-based battery powered street lighting system has been proposed in literature for lowering dependency on the conventional power source. Striving for being more energy efficient several cities have switched to light emitting diode based (LED) based light bulbs [10]–[12] In advanced lighting control system the variation in illuminance based on time and traffic condition on the street is considered [3], [13], [14],[15]. This luminance control process is particularly suitable for tuning the level of light based on the weather condition and traffic condition for lowering energy consumption. lowering energy consumption. The advanced lighting control strategy is implemented by tuning the light intensity level and switching the lights based on level of daylight, unoccupied hours and variation in the available illuminance [3].

In this research, a low-cost automatic street light system has been developed by utilizing sensors and PWM to manage the light intensity in order to progress existing street lighting and to recompense the increasing energy insist by using solar energy resources. In particular, a solar PV source based automated street lighting system has been developed based on solar PV module, battery, integrated sensors and a economical charge regulator. This research is mainly concerned with the energy efficiency for an LED based Solar Street Light.

2 Solar Powered Based Street Lighting System

The design of energy efficient street lighting schemes relies mainly on the use of sensor-based technologies. The job can be split into two groups in order to detect the demand by detecting movement of the motor vehicle and regulating the strength of street lighting based on presence of vehicle. Therefore, sensor-based systems have been developed to assess street light intensity based on sensor data. The basic structure of the solar power-based LED lighting system comprises PV source, a battery and DC to DC buck converter as shown in the Figure 1 below [16].

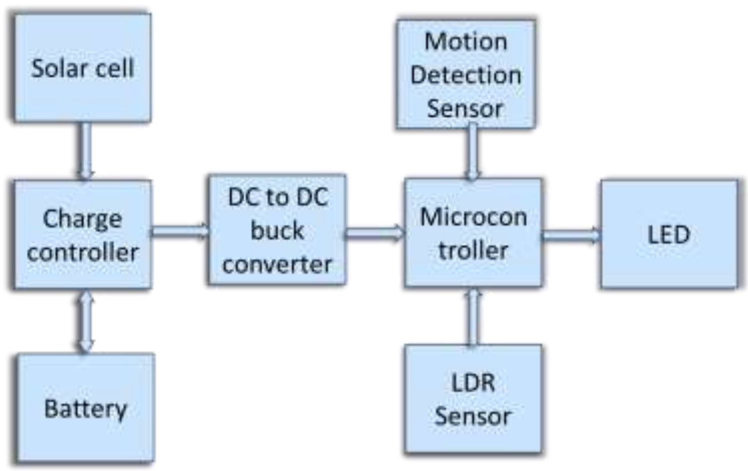

Figure 1 Block diagram of microcontroller based solar powered led street lighting system

The system model is developed on the up on consideration of a stand-alone solar operation PV source where the battery charge controller is used to ensure battery is fully charged to supply the LEDs as required. The energy harvested from the solar photovoltaic source is stored in a battery and then supplied via DC to DC step down converter. The microcontroller generates the PWM signal based on the level on the light intensity obtained from the light sensor. In this way the light measurement sensors provides the signal to the microcontroller in order to turn the LEDs ON or OFF.

The power generated from of the solar module must fulfill the power required by the LED bulbs and the LED driver. The required power from the solar PV cell to supply the battery based solar street lighting system cha can be designed using the subsequent equation [16].

$$P(pv) = \frac{1}{\eta 1 \eta 2} \times \frac{P(LED) \times h(LED)}{h(pv)} \times \quad (2)$$

where, η(1) and η(2) denotes the battery charging efficiency and LED driver efficiency respectively; P(LED) represents the power consumption by
the LED bulbs; h(LED) and h(PV) represents daily hours when light is ON and daily sunshine hours respectively; k denotes the solar panel loss coefficient.

However, the efficiency of solar based battery power street lighting system is largely dependent on selection of battery. In general, the batteries supply necessary power to the LEDs during night and low lighting conditions which is supplied by the solar PV cells during the day light. Hence, selection of battery size is crucial for the batteries in order to keep the seamless operation of the system. Choosing the lower battery size will cause power shortage and led to the failure of the system [16].

$$C = \frac{Q \times (D+1)}{k_1 \times (1-k_2)} \quad (3)$$

where, C is battery capacity, Q is power consumption per day, D power required during the rainy day, K_1 battery discharge depth and K_2 is self-discharge from the battery.

In general, the light dependent resistor (LDR) is a low-cost solution for light measurement which is well known for simpler structure and easier implementation. Basically, LDR is photoresistor with a light sensitive property. The 5V (VCC) of the LDR circuit will vary at the output of the sensor during the changes of the light sensitivity, which can be measured via the following equation [17].

$$V_o = VCC \times \frac{R_2}{R_1 + R_2} \quad (4)$$

where, the R_1 and R_2 are the resistor of the LDR circuit; and R_2 = 500/Lux, which represents the correlation between the light intensity (Lux) and resistance R_2; VCC is the biasing voltage of the LDR circuit.
The output voltage from the LDR is then converter to the light intensity via the following equation [17].

$$Lux = \frac{(2500 * V_o - 500)}{R_1} \quad (5)$$

3 Development of the System

In this research, the solar power-based LED street light system based on detection on vehicle motion is developed based on the measurement of the light intensity of the approaching vehicle. This process is accomplished by turning the street lights ON based on detecting the movement of an approaching vehicle. Consequently, the lights are turned OFF as soon as the vehicle moves forward. In this way, by switching the street lamps according to the need is more likely to save a great deal of energy instead of keeping the lights ON overnight. The design steps of the developed system are provided below. The overall process is shown in the Figure 2 below.

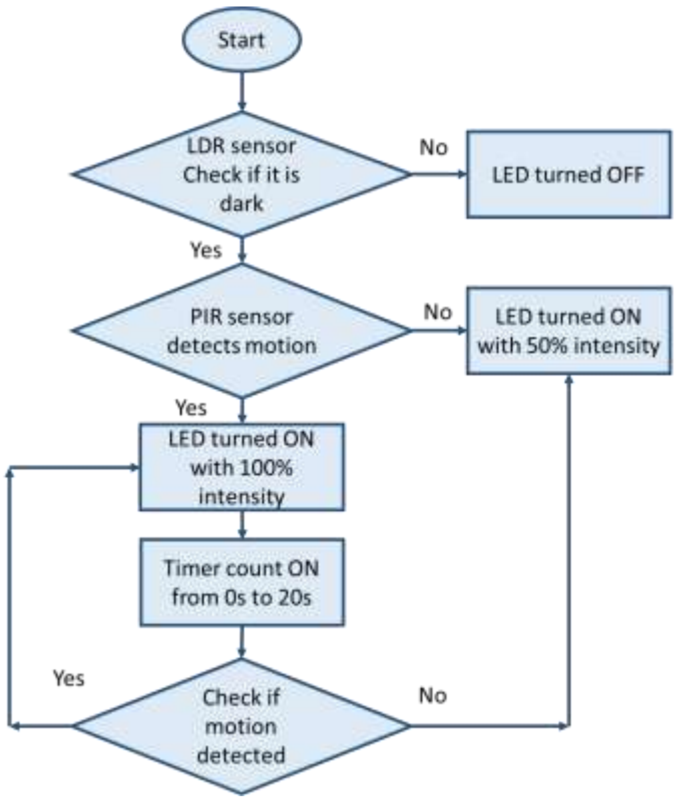

Figure 2 Overall process the developed street lighting based on vehicle motion detection model.

Step 1: In the first step, the energy consumption and entire power is estimated for all the load needed for the solar photovoltaic, PV system. The computation is done based on the amount of power (Wh) per day by must be generated by the solar PV modules in a typical day to support the system. The energy loss is also considered in the computation process. The total computed power for a typical day for the developed system is found around 15Wh. By considering energy loss during functioning the prototype by 1.3 times the total power consumption becomes 1.3 times of the total required power which is around 17Wh per day. Table 1 provides detail about developed system's power consumption per day

Table 1 Developed system's power consumption per day

Component	Unit	Wattage (W)	Usage Duration (h)	Consumption (Wh)
Passive Infrared Sensor	2	0.65	6	3.9

Light Dependent Resistor Sensor	1	0.075	12	0.9
Arduino UNO	1	0.48	12	5.76
Light Emitting Diode	6	0.36	12	4.32

Step 2: In this step the computation process involves sizing the solar PV module (Wp). Peak power (Wp) produced by the solar PV modules depends on its size. Moreover, in the computation process, the sunlight factor is considered, which is measured from the available sun light hours per day. In Malaysia the considered sunlight hour is around 8 hours per day. The total required power (W) is computed by dividing the total required power (17Wh) with the available sunlight hour, which gives the approximate 2 watt per hour.

Power required to produce by the solar panel =17 Wh / 8 h = 2 W.

Based on this calculation the selected PV module for this research is listed in the Table 2 below.

Table 2 PV Module Specification

Component	Unit
Maximum power capacity	5 Wp
Maximum voltage output	18V(dc)
Maximum current output	0.27 A
Open circuit voltage	20.5 V
Short circuit current	0.3 A

Step 3: This step involves sizing of the battery. The battery needs support the energy supply in order to operate the device during the night. In general, the minimum battery capacity is found based on dividing the battery voltage by the total required power by the load (Wp). For the calculation purpose nominal battery capacity is chosen as 12V. Moreover, in order to obtain the ampere hour (Ah) rating of the battery a 15% loss is also considered. The calculation involves following steps.

- Required Battery capacity $= \frac{Required\ power\ by\ the\ load(Wp)}{Battery\ voltage\ (V)} = \frac{17Wh}{12V} =$ 1.42 Ah.
- Considering the loss of 15%, battery capacity = $\frac{1.42Ah}{0.85} = 1.7$Ah
- For better battery life 60% depth of discharge is considered, hence the required battery capacity= $\frac{1.7Ah}{0.6} = 2.83$Ah≈ 3Ah.

Step 4: In this step the sizing of charge controller is done. The charge controller is selected in order to match the voltage of the solar PV module and the battery storage. The charge controller must have sufficient capacity to handle the current output from PV source. Moreover, the conventional process sizing the charge controller involves the consideration of the short circuit current of the PV module. For the sizing calculation purpose the short circuit current output is multiplied with 1.2. The computation process comprises following steps.

- Current rating = Power output / voltage= 2/12= 0.17A
- With 20% margin consideration the current rating = 1.7×1.2= 0.2A.

4 Simulation Model and Experimental Setup

The supply for the Arduino Uno is from the lead acid battery through Buck DC-DC Step down converter, which is charged by the simple charge controller from the solar panel, the PIR sensor and the LDR sensor get 5V power supply from Arduino. The entire device, which senses motion and regulates light intensity, is split into two parts. The Arduino UNO is the key control board for motion detection and intensity control.

The Arduino UNO utilizes Arduino IDE to execute the code. Arduino IDE serves as the code compiler and editor that can also convert or dump the whole code into the Arduino UNO. The Arduino UNO is attached to a Passive infrared sensor and a resistor that relies on light. A passive infrared sensor (PIR) is a sensor that is used to communicate with the Arduino UNO by receiving light-dependent resistor instruction.

The Light dependent resistor is attached to the Arduino analog input, which simultaneously instructs the LED to switch ON to half brightness when ambient brightness is low, and instructs the passive infrared sensor to detect is there is any activity. The serial display is used to send data to the Arduino UNO through a serial link and to log incoming data from the board. Proteus Professional 8.6 is modeled on the machine model as seen in Figure 3 below.

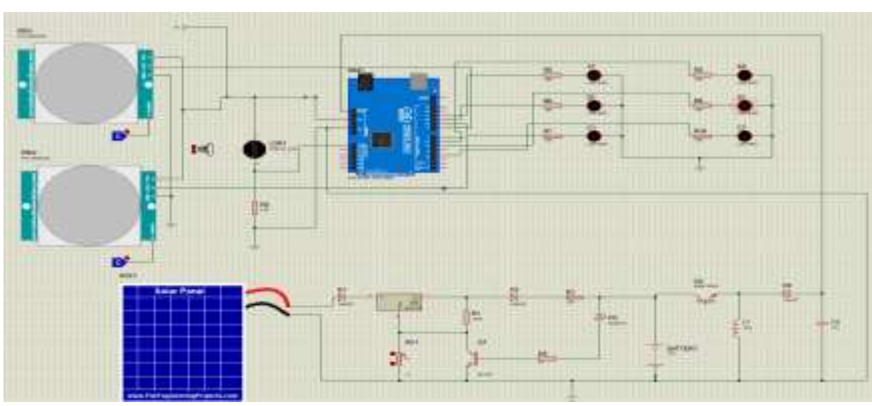

Figure 3 Schematic of overall project in PROTUES

At the control strength end, the Arduino UNO is interconnected to the passive infrared sensor. The light can be ON or OFF with the aid of LDR. In other words, LDR performs as switch. The PWM signal frequency on most pins is roughly 490 Hz.

5 Results and Discussions

As aforementioned, the main objective of this paper is investigating the impact of using smart street lighting systems on the amount of energy saving. In this section, measured data are shown and analyzed for the purpose of quantifying this impact. The developed prototype is tested in real time condition in order to compute the amount of energy saving. The developed system's testing condition involves different operating hours which is mainly selected based on the traffic condition on the street.

5.1 Simulation Results

In order to find the effectiveness of the system four different simulation condition has been considered from 7 PM to 7 AM. These four different simulation conditions are considered based on the traffic condition in the road. In particular, the traffic condition is usually considered to be in pick during 7 PM to 10 PM and after that it decays almost exponentially till 7AM. In this research, the lowest traffic condition is considered from 1 am to 4 am and moderate traffic condition is considered from 10 AM to 1 AM. Moreover, for the purpose of the research a typical two-way road is considered, where 500 LED based street lamps are present. The distance between two lamps are considered as 20m. Moreover, a comparative analysis has been done in this study between developed the street lighting system with the motion detection system and the conventional street lighting system. This comparative analysis also shows the strong performance of the developed system in terms of saving the energy. The overall system is developed based on the conditions listed below in table 3.

Table 3 Data of the Simulation Considerations

Consideration	Value
Total length of the street	10 km
Total number of street lights considered	500
Nominal distance between the lights	20 m
Operation hours of the street lights	12 hours (7 pm to 7am) =3600s
Rated power by a single LED light bulb	1 kW

Power consumption by a single light bulb during operating hours	12 kWh
Total power consumption by 500 light bulbs during operation	6000 kWh
Speed of a single vehicle	40 km/h
Required time to cross one street light	1.8s

So, every street lights will operate with 100% intensity for only 1.8 s and rest of the 3598.2 seconds it will glow with 50% of its total intensity. When a street light radiates with its maximum intensity it consumes 1000 W for 3600 s. Thus, it consumes 0.278 watts for 1 second with 100% intensity and 0.139 watts with 50% intensity. The description the simulation is provided below.

5.1.1 Scenario 1

In the first simulation scenario, the operating time of the street is considered from 1AM to 4AM when motion is detected from a single vehicle is passing through the street. Hence, one street light will be turned on with full intensity for 1.8s of time and rest of the 3598.2s of total 3600 s the light will have half of the intensity. Hence, in this 1.8 s of time the one LED street lamp consumes 0.5W of power and during 3598.2s the street lamp consumes 500.6 W power. Thus, one street having 500 street lights will consume around 251.5kW of power.

5.1.2 Scenario 2

The considered operating time for scenario 2 is from rom 4 AM to 7 AM and 12 AM to 2 AM, when 10-time motion is detected from the crossing vehicles. Since, 10 vehicles are considered to passing through the streets each street lights will be switched on for 18 s and switched off for rest of the 3582 s. Hence, in this operating time of 18 s the lights will glow with full intensity and consume full power, so total consumed power in this time period is 5 W. Moreover, for the 3582 s of operating time the consumed power will be around 498 W which will empower a single LED light with 50% of its rated intensity. Thus, the 500 street lights will consume 250.3kW of power.

5.1.3 Scenario 3

In this considered simulation scenario the traffic condition is considered around 10 times more than the previous condition which comprises 100 vehicles. Hence, the operating hour of one LED light will also increase by 10 times from the previous condition which is 180s. Therefore, LED bulbs will be turned on with full intensity for 180 s while consuming full power and total consumed power is around 50 W. However, the lights are turned on with 50% of its intensity for 3420 s, when consumed power by single light is 475.4 W. Thus, the power consumption of 500 street lights will be 262.7 kW of power.

5.1.4 Scenario 4

During the simulation scenario, the considered operating hours are from 7PM to 10PM when the traffic condition is most high. Hence, the traffic is considered 10 times more than the previous condition and 1000 time more than the condition in scenario 1. Since, 1000 vehicles are passing through the streets, each of these lights are operating for 1800 s at full intensity and full power. During the remining 1800s the lights are operating with 50% intensity and consuming 50% of its full power. Hence, the consumed power is around 500 W during 1800 s and the remaining 1800 s the consume power is 250 W. Thus, total consumed power by each of the LED during this scenario 4 height which is around 750 W. Thus, the power consumption of 500 street lights will be 375kW of power. Table 4 below shows the calculation of power consumption for a single LED street lamp and total power consumption by 500 street lamps. Moreover, the Figure 4 below depicts the comparative analysis between the conventional LED based street lighting system and the developed motion detection based smart street lighting system.

Table 4 Power calculation during the considered simulation scenarios.

Simulation scenarios	Operation hours	Number of vehicles	Operation time (s)		Power consumption (W)		Power consumption by one street light (W)	Total power consumption by all street lights (kW)
			Full intensity	Half intensity	Full intensity	Half Intensity		
Scenario 1	1 AM to 4 AM	1	1.8	3598.2	0.5	500.15	500.6	250.3
Scenario 2	4 AM to 7 AM	10	18	3582	5	3582× 0.139	502.9	251.5
Scenario 3	10 PM to 1 AM	100	180	3420	50	3420.2 × 0.139	525.4	262.7

Scenario 4	7 PM to 10 PM	1000	1800	1800	500	1800 × 0.139	750.2	375

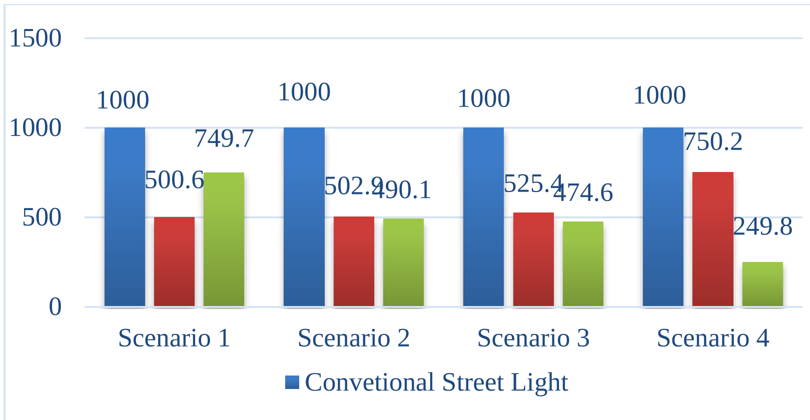

Figure 4 Power Consumption comparison between LED and HPS Street light

The power consumption results listed in the Figure 5 shows that, the motion detection based smart street lighting system is able to save a considerable amount of power than the conventional system. For the purpose of the research, LED lamps in the conventional system is considered to be switched on for 12 hours from 7PM to 7AM. Therefore, the total considered power by the 500 street lamps are 1000kW, which is same for all of the four simulation scenarios. From the figure 5 above it is also observed that, the power consumption of the developed system is entirely dependent on the number of traffic by their detected motion. In this process, height amount of power can be saved during the off-pick hours when there is least number of vehicles on the street, which is around 50% less than the conventional system.

However, during the height traffic condition considered in scenario 4 the power consumption by the LED lamp is around 75%. Hence, around 25% energy can be saved in this developed system than the conventional system can be saved by 25%.

5.2 Results from the Developed Prototype

The developed prototype is also capable of performing as intended. Moreover, to notice movement or obstruction the passive infrared sensor is used. PIR and LDR are functioning concurrently, where the PIR only performs while the LDR threshold is under set threshold. The figure 5 below provides the performance of the developed smart street lighting scheme. LDR threshold value is to 200. When LDR identify threshold lesser than 200 the street light routinely switched on and when LDR sensor detects the value greater than this threshold value the street lamps are switched off. It is evident in the Figure 5 that the light dependent resistor (LDR) sensors playing main role for switching the LED lamps on and off. Figure 5(a) shows the street light is switch off because the rate is threshold is 321 which is greater than set threshold, while figure 5(b) shows the street light is turned on because the detected value by the LDR sensor is less than the threshold.

(a) (b)

Figure 5 LDR controlling the street lights **(a)** LDR threshold value is greater Set threshold **(b)** LDR threshold value is less than set threshold

In this research, the developed prototype of the motion detection based smart lighting system is able to detect the motion of the vehicle while it is passing through the street, which is evident in the Figure 6 below. Figure 6(a) shows that, when the PIR sensor is not detecting any motion and no vehicle is passing through the street the light intensity is kept to 50%. Figure 6(b) shows that the when motion is detected by the motion sensor, the light intensity is instantly increased to 100%. In this way, the light intensity of the LED street lamp is set to 50% and 100% successfully by the Arduino UNO microcontroller through PWM signal. The PWM signal controls the input voltage level of the LED lamps and hence the intensity of the lamps are controlled. In particular, Figure 6(a) shows that when the motion is not detected and Figure 6(b) shows the PIR detect obstacle, thus the light immediately turn brighter.

(a) (b)

Figure 6 Motion detection by PIR sensor **(a)** light intensity is 50% and **(b)** light intensity is 100%

The rate of outcome voltage differs as per the intensity of sunlight. The major function of charge regulator in this work is to manage and place the output voltage before it entering battery. It is significant to set output voltage before entering because the battery use for this development is only 12 V if the solar panel output voltage directly enter the battery it can cause harm to battery and the organization. Besides, by utilizing this charge organizer it can avoid backflow of current from battery to solar panel during night time and to provide constant current from solar panel. The utmost output voltage of 18-volt solar panel provides the value of 19.70 V during greatest sunlight shine on it. Figure 5 below shows the output voltage is set to 11.97 V to charge the battery.

Figure 5 Solar PV cell with the charge controller and battery

The manufacturing cost of the developed system is below RM 200 which fairly lower and complies with the research objective. The summary of the cost analysis of the developed model is listed in Table 5 below.

Table 5 Cost analysis table

NO	ITEM	QUANTITY	PRICE (RM)
1	Arduino UNO	1	25
2	Light Dependent Resistor Sensor	1	3
3	Passive Infrared Sensor	2	5
4	LED	6	0.3
5	Buck DC-DC Converter	1	13
6	Jumper Wire (FF/FM/MM)	3	3
7	Bread Board	4	10
8	Charge Controller	1	60
9.	Solar Panel 5W	1	30
10.	Lead Acid Battery	1	10
11.	Others	1	10
		TOTAL (RM)	187.8

6 Conclusions

In this research a low-cost photovoltaic source based smart street lighting system has been developed for empowering the LED street lights based on vehicle motion detection. In comparison with conventional motion detection less street lighting system the developed motion detection based smart street lighting system is able to reduce the energy consumption in a considerable amount during the considered simulation scenarios. In particular, the developed smart lighting system is able to reduce the power consumption is a significant manner when the traffic in the street are lower. The developed prototype is also able to perform well to detect the motion of the vehicle and change the intensity of the LED lights. However, one of the key outcomes of this research is successful utilization of solar energy as the power source as opposed to utilizing electrical power which saves a huge amount of energy which is more power saving and sustainable than the conventional system. Moreover, by utilizing the developed motion detection-based control algorithm it is possible to chop down half of the energy when not required, dissimilar conventional street light in most place in Malaysia, which still rely upon using power lamp and remain switch on from sunset till sunrise. However, the intended objective of this research is achieved successfully, which is reflected in the obtained results. Based on this research further development can be conducted for a commercial product. Further research development will therefore have great potential for real time implementation.

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