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DEPLOYMENT OF SMART STREET LIGHTING SYSTEM USING SENSORS

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ABSTRACT

The main aim of this work is to reduce energy consumption and at the same time to create an automated system which eliminates manual operations that often lead to mechanical faults and breakdown of equipment. Technological advancement has brought about the need for automation in almost every system. Machines and devices do not need to be manually controlled. Automated systems present the user with ease and comfort as well as reduced cost in the long run. The smart street lighting system is the integration of automation into the generic street lighting system across the world. The system is packed with motion detectors, light detector and an online management system for remote monitoring and control. The system compares savings in energy consumption between Light Emitting Diode (LED) and halogen bulbs. Result shows that LED bulb saves 86.67% of energy compared to halogen bulb while implementing the smart street lighting system yields 14.59% reduction in energy cost consumption.

Keywords: IoT Sensors, Microcontroller, Automation, Smart city, Street lighting

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1. INTRODUCTION

Streetlights are an essential part of road layouts. They illumine roads and a typical driver gets to see and avoids any obstacle in his/her way. A streetlight reduces the rate of accidents that occur at night as well as the safety of the pedestrians. A street light is a raised source of light, usually on poles, situated at the sides of the road to provide proper illumination for the passers-by (vehicles, pedestrians, bicycles) at night or in dark conditions such as cloudy weather, heavy rainfall, blizzards, eclipse and so on. Usually, these street lights require periodic monitoring and maintenance (such as replacement of bulbs, testing of sensor modules and other preventive tests that may be necessary) by the technical unit assigned to such duties.

The smart street light is an automated version of the typical street light. It provides proper illumination at required periods in time by integrating specific sensors and Light Emitting Diodes (LED) bulbs. This version of the system bridges quite a number of gaps ranging from automation to energy conservation.

The energy conservation issue in developing countries like Nigeria is a major battle that is being fought on many fronts(Ali, Khan and Khan, 2017; Pau *et al.*). Energy conservation is an important phenomenon nationwide. The process used to curtail the energy wastage issue is called the energy management. Energy management involves the implementation of methods that increase energy efficiency as well as create an avenue to monitor the performance ratings (Soledad Escolar, 2014). ISO 50001 is the energy management standard in this respect. It was put in place by the International Organization for Standardization (ISO). The ISO 50001 standard saves money and conserves energy resources. It supports the use of energy efficiently through the development of an energy management system. The standard is recognized all over the world and it is advised to be adopted for better administration of the energy sector (Leen G Mkhaimer, 2017).

It is projected that, by 2050, about two-thirds of the world's population would be residing in cities across the world and this will cause the world's energy consumption rate to increase by 70% (Gul Shahzad, 2015). Hence, counter measures are to be put in place to reduce energy consumption before the projected date. The smart city, amongst which smart lighting is a component, is a ploy to ease daily activities as well as reduce energy consumption and greenhouse gas emissions. The street lighting system is one of the major power consuming factors in nations around the world, constituting about 19% of the global energy consumption in present times (Gul Shahzad, 2015). The street lights are usually kept ON all through the night until day breaks, thereby, consuming its full rated power even when it is not needed. This proposed method will help combat this issue largely as automation is a trend which developed countries are imbibing in order to minimize faults and maximize efficiency (Idachaba, Olowoleni, Ibhaze and Oni, 2017; Pau *et al.*; Uzairue, Ighalo, Matthews, Nwukor and Popoola, 2018).

2. RESEARCH MATERIALS AND METHODS

In this work, Light Dependent Resistor (LDR) and passive infrared sensor (PIR) sensor are the key proposed components to ensure proper workability. These components help to ensure that the system reduces energy consumption. The Smart Street Light System (SSL) remains in the OFF state during the day even when the IR sensor detects the motion of cars and pedestrians because the LDR gives the overriding command and controls the switching of the lights. The LDR will not be ON unless the surrounding is dark but will switch during cloudy conditions/weather and blizzards. Figure 1 shows the block diagram in which this work is categorized.

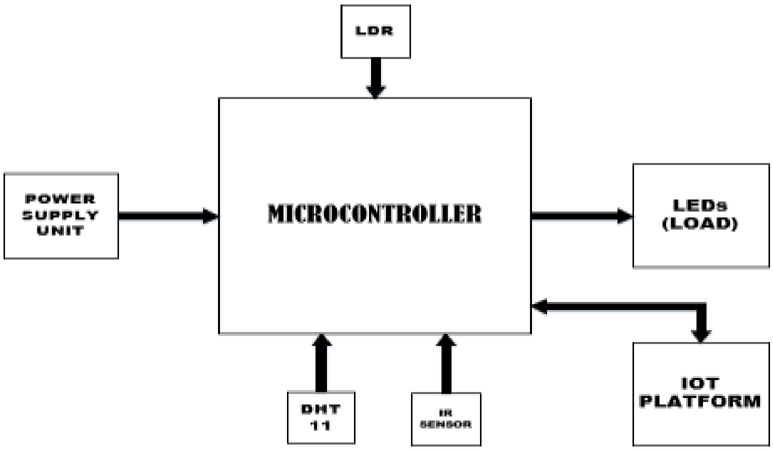


Figure 1 System's block diagram

2.1. Power Supply Unit

Power supply is a device that supplies electrical energy to one or more electric loads or systems. This section of the system is responsible for powering the rest of the system. The source voltage 220-240V ac is stepped down to a more suitable voltage value, within the range of 9-12V.

2.2. Arduino Uno Microcontroller

Arduino Uno is one of the numerous boards produced by Arduino. Atmel Corporation is an open source computer hardware and software company that designs and manufactures microcontroller kits for building digital services all over the world. This microcontroller board is based on the ATmega328P which consists of 28 pins, each with its unique purpose and can be grouped as follows:14 digital input/output pins (of which 6 can be used as Pulse Width Modulation (PWM) outputs), 6 analog inputs, 3 ground pins, 1 power input pin (Vin), 2 power output pins (3.3V and 5V), an AREF (Analog Reference) pin and a Reset pin. The board also consists of a 16-MHz quartz crystal wired to its clock pins, a USB connection, a power jack, an In-Circuit Serial Programming (ICSP) header and a reset button. Each of the 14 digital pins on the Uno operates at 5volts, and by using different functions, is set as either an input or output. Each pin receives between 20-50 mA as the recommended operating condition and has an internal pull-up resistor of 20-50k ohms. A maximum value of 40mA must not be exceeded on any I/O pin to avoid permanent damage to the microcontroller (Blum, 2013).

2.3. Load: Light Emitting Diode (LED)

The LEDs, as shown in Figure 1, are the source of illumination which operates based on the signal received from microcontroller. They serve as the load in this work. LED is preferable when compared to halogen lamp and other light bulbs because of its energy saving properties amongst other numerous advantages. Table 1 gives the comparison between LED and Halogen.

Table 1 Comparison between LED and Halogen lamps (LEDevolution, 2018)

Features	LED	Halogen
Heat Emission	10%-20% of total energy	80%-90% of total energy
Power Consumption	Average of 8 Watts	Average of 60 Watts
Lifespan	100,000 hours	5000 hours
Average Cost	N6,000-N10,000/bulb	N500-N1000/bulb
UV Emissions	None	Minimal

There are other aspects of quality, of which the LED stands out and shows why it should be considered over other options. As compared to the incandescent bulbs which consume about 3,285KWh of electricity per year, the LED consumes 329KWh of electricity per year (al Irsyad and Nepal, 2016).

2.4. Management System

The management system of this project consists of the hardware and software blocks. The system is made fully functional using the Internet of Things, which allows the hardware components (Arduino uno and sensors) communicate with another as well as with the cloud. There are peripherals for the Arduino boards called shields, which enable the board with specific abilities such as internet connectivity and Bluetooth connectivity. The shields are connected to the Arduino boards via the pin-headers; there are wire-wrap headers that extend out of the shield and enter into the Arduino board. The Wi-Fi shield allows the Arduino board to connect to the internet using the 802.11 wireless specifications (Al-Kadi, Al-Tuwaijri and Al-Omran, 2013). More than one shield can be used per time, the shields are stacked on top of one another thereby increasing functionality and not consuming design space. The Arduino shield possesses its own library, which contains non-volatile resources to develop software. Types of Arduino shields include Motor shield, Wi-Fi shield, Bluetooth shield, Xbee and Sensor shield.

The Wi-Fi shield and the PC/mobile device make up the hardware block while the codes and the online platform (Cayenne) for monitoring and controlling make up the software block.

2.5. Systems Design

Figure 2 presents the block diagram for the Smart Street Light (SSL) system. When the Day/Night sensor (LDR) sends signals to the Arduino module, there is a voltage comparator on board. The comparator compares the input from the LDR with the selected VCC (either 5V or 3.3V) as made available by the Arduino module. The comparator then allows current to flow to the rest of the circuit and the LED bulbs. The IR sensors start emitting IR rays via IR transmitters. Immediately any vehicle crosses or obstructs the path of IR rays and prohibits it to reach the IR receivers, the microcontroller starts getting the blockage signals. The signal is then interpreted by the microcontroller and in turn, the intensity of the bulb increases. This system is put in place to minimize electric power consumption by street lights.

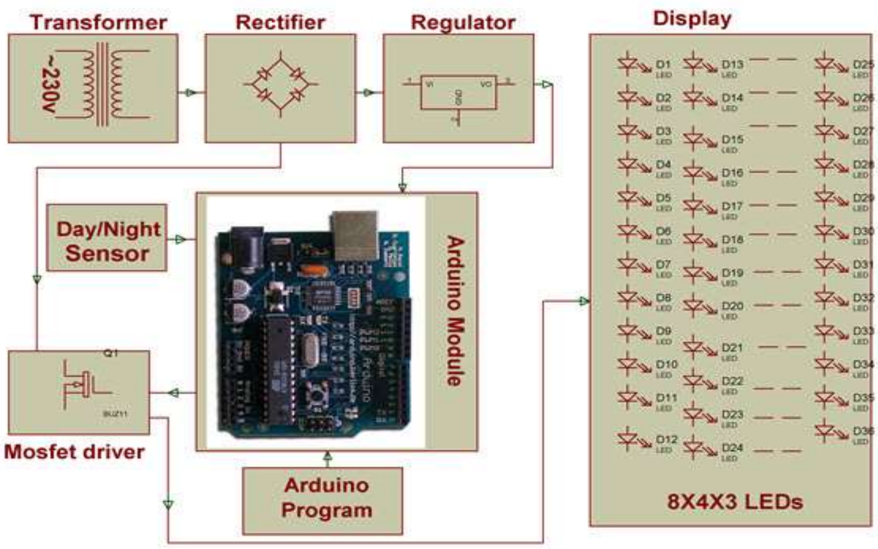


Figure 2 Schematic diagram of the project.

2.6. System Operation

A flowchart describing the operation of the system is as shown in Figure 3(a & b). The illustration includes the activities of the system components such as the WiFi module, LDR, RTC, LEDs and Motion detector and how they all interact.

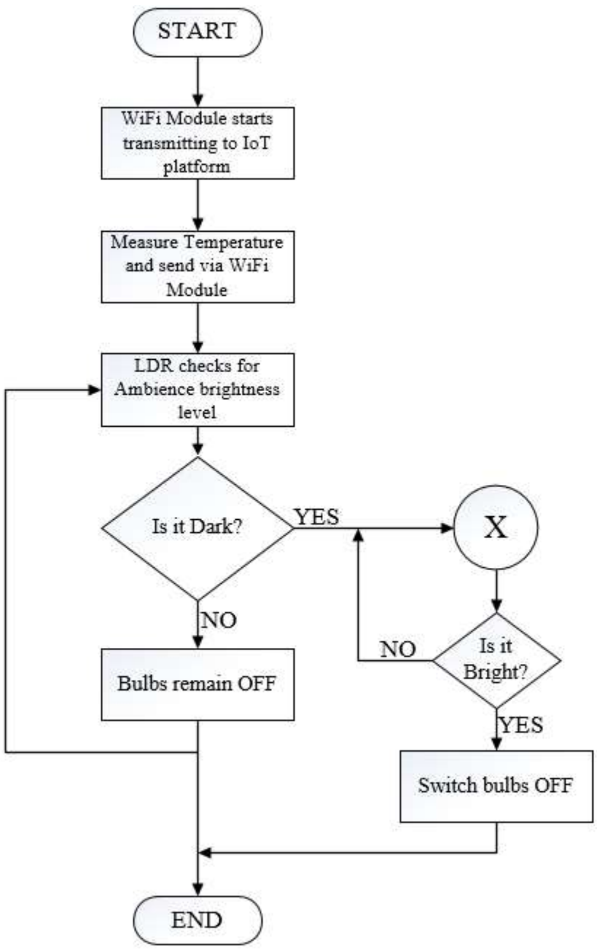


Figure 3a Flowchart of the system.

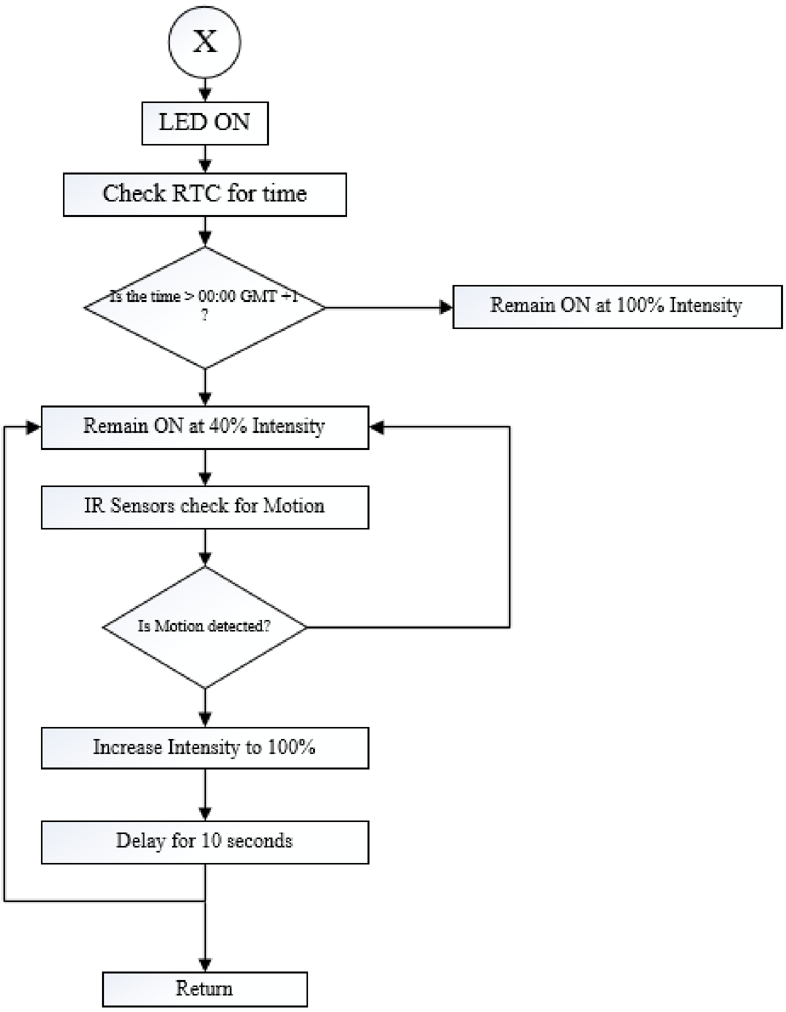


Figure 3b Flowchart of the system.

3. SYSTEM IMPLEMENTATION

The system was well packaged in a 3D model of a miniaturized street, with streetlights and road tracks included in the model. The model was made with basic materials such as straw boards, modelling grass and trees, cardboards, straws and a few others. Figure 4 shows the CAD drawing of the model.

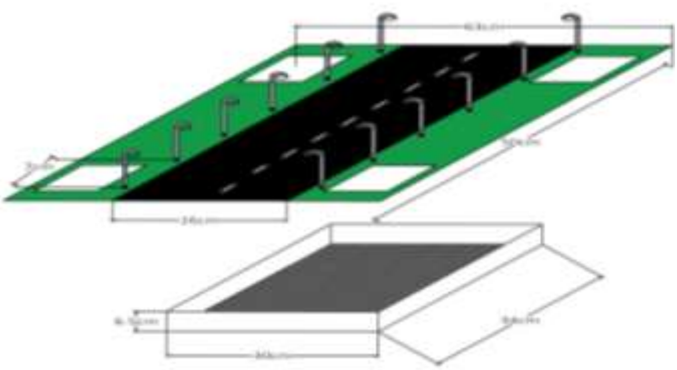


Figure 4 A 3D representation of the street lighting model

3.1. Electrical Circuitry

The system consists of a power supply unit, 3 voltage regulators, a LDR, DHT 11 senssor (*DHT11 Product manual*), 4 IR proximity sensors, a Real time clock, ESP8266 WiFi module, Resistors, LEDs and an Arduino Uno microcontroller board. The system, as shown in Figure 5, is powered by 220V ac supply which is further stepped down and converted to applicable voltage ratings (3.3V, 5V and 9V) using voltage regulators. After the regulation, various voltage outputs are routed to supply different components. The 3.3V supplies the ESP8266 WiFi module, the 5V supplies the IR proximity sensor, DHT11, RTC, LDR and the 9V supplies the Arduino microcontroller board. The sensors DHT 11, IR, RTC and LDR serve as input devices to the system. They measure physical phenomenon and serve as transducers. The LEDs respond based on the commands of the microcontroller. The positive terminal is connected to the board through a R rated resistor to prevent excess current flow, and the negative terminal of the LED is connected to ground. The VCCs of the sensors are connected to the 5-V supply and the data terminal of the sensors are connected to the Microcontroller board.

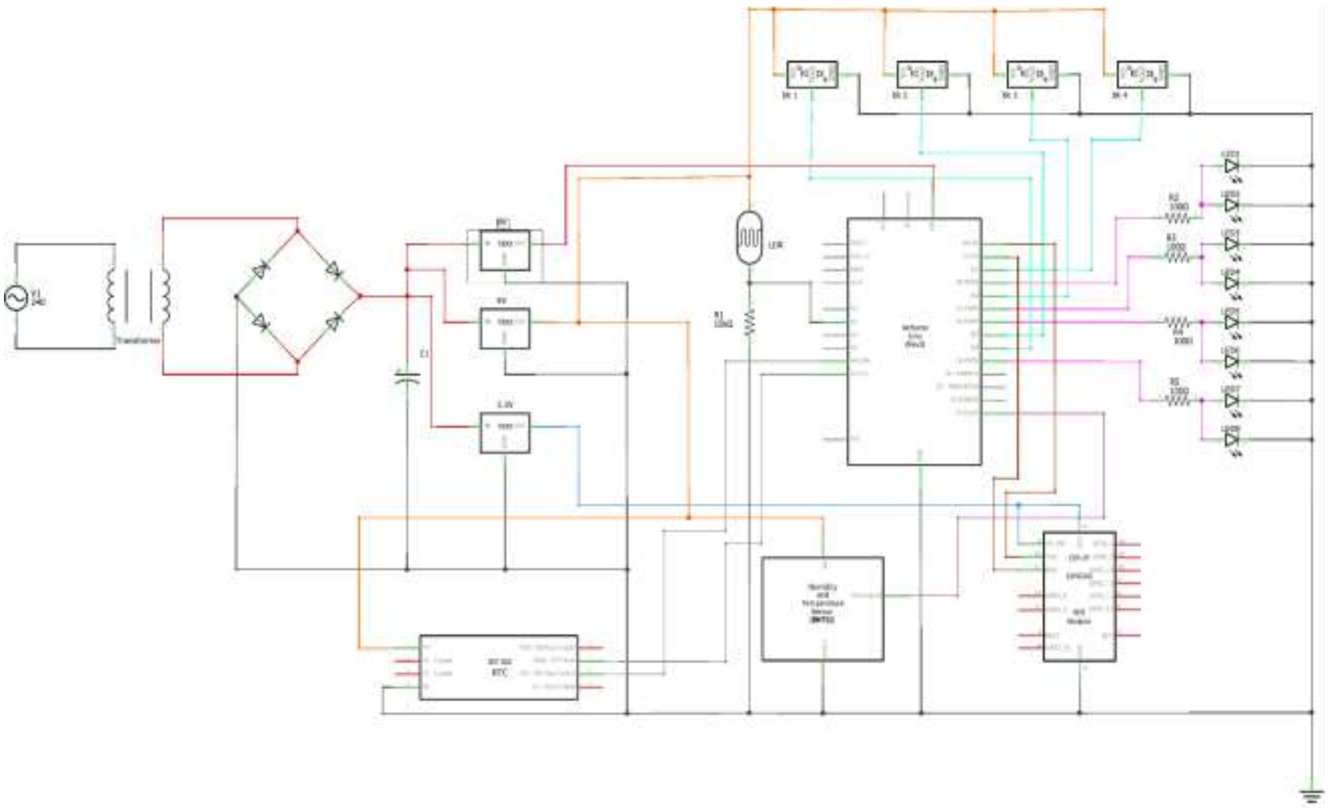


Figure 5 Circuit Diagram of the System

The value of the resistor used to protect the LED is obtained using this equation;

$$R = \frac{(V_s - V_{LED})}{I_{LED}}$$

where V_s is Source voltage, V_{LED} is the Voltage drop across the LED and I_{LED} is the current through the LED.

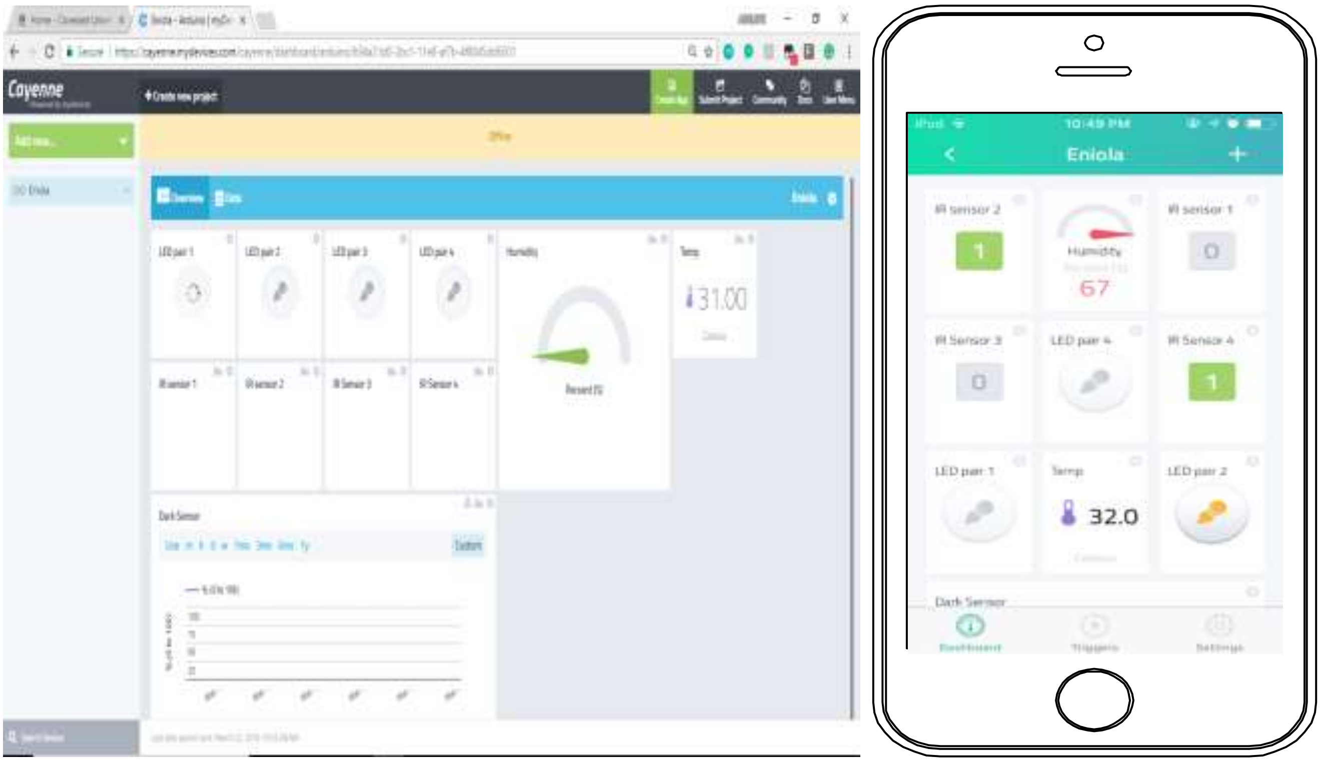
3.2. Microcontroller Programming

As stated in the previous sections, the Arduino uno is the microcontroller used for this work. It is the central unit of the project which controls other connected components. The microcontroller was programmed via an Integrated Development Environment (IDE) using the C language. Some initial steps had to be taken in order to get the codes running are listed as follows:

- Defining variables: The use of the "*int*" variable.
- Including libraries: DHT11, ESP8266, Cayenne libraries were used.
- Declaring variables: The *pinMode* and *void setup* functions were used. The pin mode function helps to configure a specified pin to act as instructed (output or input).
- Loop operation: The *void loop* function is used to run continuous operations. *AnalogWrite*, *digitalWrite* and delay are all sub-functions of the void loop.

3.3. Cayenne

The cayenne IoT platform is a Graphic User Interface (GUI) which has numerous features that aid IoT projects. The cayenne platform makes use of the light weight messaging protocol, Message Queuing Telemetry Transport (MQTT) (Barbon, Margolis, Palumbo, Raimondi and Weldin, 2016). The sensors and actuators are connected to the platform using WiFi module via channels provided by the platform. The sensors send input signals and the actuators (LED) act based on the inputs. The actuators are monitored and controlled from the cayenne IoT platform displayed in Figure 6.



(a) (b)

Figure 6 Cayenne IoT Dashboard – (a) Web, (b) Mobile app

4. RESULTS AND ANALYSIS

The system test included continuity test and sensor tests. Continuity was tested from sources to load components to ensure that every component is properly connected. The Infrared proximity (IR) sensors were supplied with 5V and the detection ranges were tested by placing opaque objects in front of the sensors and the ranges were adjusted using the on-board potentiometer. The LEDs were connected in series with a limiting resistor to regulate current inflow. The DHT11 was tested, humidity and temperature readings were displayed on the serial monitor of the IDE. The RTC and ESP8266 were duly tested as well and the cayenne IoT platform was operational.

The system yielded promising results as shown in the Tables 2 and 3 below. The system is applied to a case study scenario of a road with 20 street lights in Covenant University. Table 2 shows the energy consumed by the street lights on that road when the smart street lighting (SSL) system is implemented using LED bulbs. Table 3 shows the energy consumption of the street lights when the system is implemented using Halogen bulbs. There is a major difference in energy consumption from the analysis done and it can be concluded from this case study that the smart street lighting system is effective in curbing the issue of energy consumption on the high way road.

Table 2 Energy consumption based on Light Intensity of LEDs

Time Frame	**Energy consumed (kWh)**		**Varying Intensity (kWh)**
	At 100%	At 60%	
7pm - 12am	0.8	N/A	N/A
12am - 5 am	0.8	0.48	~ 0.6
5am - 7am	0.32	0.19	~ 0.24
7am - 7pm	N/A	N/A	N/A

In Table 2 above, the energy consumption at 100% is obtained by using the average rating of a single LED bulb which is 8W.

At 100% intensity, each bulb consumes 8W, therefore, total watt power consumed is

$$8 \times 20\ bulbs = 160\ W$$

Between 7pm to 12am is 5 hours

Hence, energy consumption in Wh is $160W \times 5\ hours = 800Wh = 0.8kWh$

The varying intensity comes into play when cars or bodies movements are discovered during that time frame. The motion detectors are triggered and the lights brighten. In order to determine the energy consumption for that brief period of varying intensity, the energy consumption at 100% is multiplied by a factor 0.75, which would give an approximate value of energy consumed during that period for varying intensity. Hence, energy consumption range during that period would be $0.48 \leq x \leq 0.8\ kWh$. This process is repeated for other levels of varying intensity, taking into consideration the various time frames.

Table 3 Energy consumption based on Light Intensity of Halogen bulbs

Time Frame	**Energy consumed (kWh)**		**Varying Intensity (kWh)**
	At 100%	**At 60%**	
7pm - 12am	6	N/A	N/A
12am - 5 am	6	3.6	~ 4.5
5am - 7am	2.4	1.4	~ 1.8
7am - 7pm	N/A	N/A	N/A

The same process carried out for LED bulbs in Table 2 above is repeated in Table 3. The energy consumption for Halogen bulbs (60Wh), which is exponentially higher than that of LEDs (8Wh) at the same time frame, is recorded in Table 3.

It can be inferred from Tables 2 and 3 that energy consumed for both 100% and 60% are conventional street lighting systems while varying intensity is SSL system. The difference between 100% and 60% energy consumptions is that nominal intensity of the bulb (which is

100%) is reduced by 40% to give 60% intensity. Total energy consumption of each of the two types of bulb considered is summarized in Table 4 below.

Table 4 Total energy consumption for a period of 12 hours (7:00pm to 7:00am)

Bulb	**Conventional System**		**SSL System**
	100% intensity	**60% intensity**	
LED	1.92kWh	1.47kWh	1.64kWh
HALOGEN	14.4kWh	11kWh	12.3kWh

With the current rate of ₦24.30k per 1kWh in Nigeria, daily cost of energy consumed over street light is also computed as shown in Table 5 below.

Table 5 Total cost of energy consumed for a period of 12 hours (7:00pm to 7:00am)

Bulb	**Conventional System**		**SSL System**
	100% intensity	**60% intensity**	
LED	₦46.66K	₦35.72K	₦39.85K
HALOGEN	₦349.92K	₦267.30K	₦298.89K

It can be deduced from results obtained that smart street lighting system yields an average of 14.59% decrease in cost of energy consumption as compared with nominal 100% luminous intensity of light for a period of 12 hours. Also, it is clearly seen that LED bulb saves 86.67% of the energy cost as compared with halogen bulb. Although, it is obvious that 60% luminous light intensity gives the cheapest energy consumption, the SSL system is more promising. This is because upon the application of SSL on the 60% luminous light intensity, the energy cost consumption will further reduce. The graphical representation of the comparison of energy consumption costs among 100% luminous light intensity, 60% luminous light intensity and SSL system for both LED and halogen bulbs is given in Figure 7.

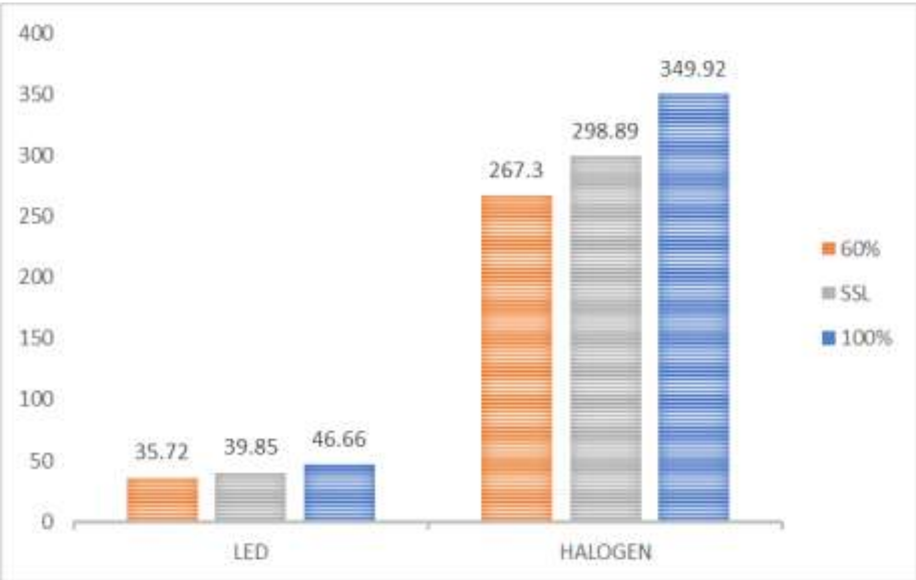


Figure 7 Graph showing the comparison between LED and halogen bulbs

The graph above shows the comparison between the 3 systems discussed. It can be deduced from the diagram that the Smart street lighting system with LEDs is the best option to opt for. It consumes less when compared to the others.

5. CONCLUSION

This work helps to reduce cost of energy consumption on street light. The SSL system conserves energy and also improves the efficiency issue of streetlight network. Integrating the system into the country's streetlight network on a large scale will drastically decrease street light network consumption from the grid. More money would be saved once this system is implemented on a large scale. According to the analysis carried out, it can be seen that implementing the smart street lighting system is beneficial in numerous ways. The system can further be improved on by including a hybrid energy generation system rather than relying solely on the grid for power. Solar energy can also be implemented. The system altogether is a leap into the future trend of technology, thereby moving Nigeria forward in its bid for technological advancement.

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