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Design and construction of an automatic streetlight controller using microcontroller and LDR

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Abstract
Due to the growing insurgency and increase in crime rate in the country, provision of adequate and functional streetlights as one of the security measures have become necessary in Nigeria for the protection of life and property. In this study, we designed and constructed an Automatic Streetlight Controller using a Microcontroller and Light dependent resistor (LDR). The Microcontroller was programmed using Arduino C language and simulated using Proteus 8.0. The prototype of the circuit was constructed by soldering the components permanently on a Vero Board according to the design specification. The device was tested for proper functioning and optimum performance. Results show that on testing the device for Specificity, Response Time and Accuracy gives 96.77%, 0.02sec and 96.67% respectively. The device can be of great importance if implanted in existing street lights or newly built ones so as to improve the condition of our street lights to proper illuminate our streets for an improve security system.

Keywords: automatic control, microcontroller, proteus, street lighting, light dependent resistor, circuit design

1. Introduction

Security of our environment which includes protection of life and property is one of the major priorities of every nation [1]. A street lighting is any electrical lighting that is fixed outside house for the illumination of the environment or a raised source of light on the edge of a road or walkway, which is turned ON at a certain time every night [2]. Street lighting is very important as it aids in illumination of our streets and serve for beautification or the environment at nighttime. According to [3], streetlights increased the aesthetic beauty of an environment as well as increase security, but the sorry state of our streetlights in Nigeria due to lack of proper maintenance has become a thing of concern. Failure and irregularities in power supply hinders the continuous illumination of our streets due to manual operation of the streetlights results in increasing crime on our streets and support for evil activities [4].

There are three main uses of streetlight, each requiring different types of lights and placement, they are beacon light, road way light and security light [2]. Streetlight is also applicable in industries, homes, universities, farms, convention grounds and other public places. The streetlight ensures safe, fast and efficient movement of people and goods from one place to another [4]. Street lighting is a particularly critical concern for public authorities in developing countries such as Nigeria because of its strategic importance for economic and social stability due to reduced crime rates, accidents and other evil activities that takes place at dark hours [5].

Inefficient lighting wastes significant financial resources every year, and poor lighting creates unsafe conditions [6]. In a properly lit society, manual control street lighting systems consume quite a large sum of the city‘s power supply, which is obviously due to its constant operation during the night [7], and more so some of this streetlights shine into the day because of its manual nature. Manual control is prone to errors and leads to energy wastages and manually dimming during midnight is impracticable. Also, dynamically tracking the light level is manually impracticable. The current trend is the introduction of automation and remote management solutions to control street lighting [8].

According to [8] energy efficient technologies and design mechanism can reduce cost of the street lighting drastically. There are various studies that have attempt to proffer some control strategy and methods in controlling the streetlight system such as Complex Programmable Logic Device (CPLD) based solar power saving system for streetlights and automatic traffic controller [8], automatic streetlight intensity control and road safety module using embedded system [9], Intelligent Street Lighting System Using GSM [1], energy consumption saving solutions based on intelligent street lighting control system [10] and Automatic Lighting Control System for a Wireless Sensor Network with Increased Sensor Lifetime and Reduced Sensor Numbers [11]. Our study is focused on Automatic Street lighting control system using an LDR and microcontroller.

A microcontroller is a computer control system on a single chip. It has many inbuilt electronic circuits, which can decode written instructions and convert them to electrical signals, then step through these instructions and execute them one by one [8]. Microcontrollers are now changing electronic designs. Instead of hard wiring a number of logic gates together to perform some function we now use instructions to wire the gates electronically. The list of these instructions given to the microcontroller is called a program [8]. An LDR is a component that has a variable resistance that changes with the light intensity that falls on it [12]. It works on the principal of photo conductivity which allows them to be used in light sensing circuits. Whenever there is sufficient light falling on the LDR, it exhibits high resistance and acts as an insulator and in darkness the LDR behaves as low resistance path and allows the flow of electricity [8]. According to [12] using the LDR in streetlight control system eliminates manual effort as it will automatically switches ON when the sunlight goes below the visible region of our eyes and switches OFF when ample amount of sunlight is available.

The study is beneficial to urban and rural area, as it enhances human sights for those pedestrians on the walkways at night and for drivers which leads to reduce accidents, reduced crime/robbery, reduces human effort most especially government agencies that are directly involved in traffic control, and improve social and economic benefits of the people like long distant travelers and night markets.

2. Materials and Methods

2.1 Materials

The materials and their specification that were used for the design and construction of Automatic Streetlight Controller includes PIC12F675 Microcontroller, C945 Transistor, IN5711 Diode, 15V Relay, 12V DC Battery, LDR Light Sensor, LEDs, Resistors and Capacitors assorted. The PIC12F675 Microcontroller pin out can be shown in Figure 1.

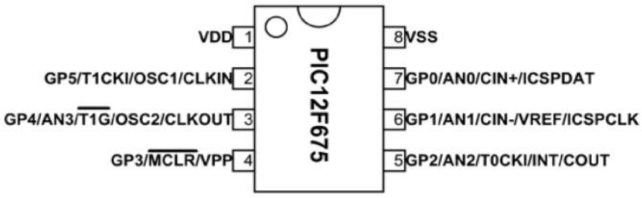

Fig 1: PIC12F675 Microcontroller Pin layout [13]

2.2 Methods

The method for the implementation of the Automatic Streetlight Controller System is in four (4) stages including design analysis, simulation, construction, and testing. The design is carried out using LDR light sensor and PIC12F675 microcontrollers. The microcontroller is programmed using the Arduino C language and simulated using Proteus 8.0 software. The construction of the prototype was carried out on a Vero Board. The device was tested for Specificity, Response Time and Accuracy to ensure optimum performance.

2.2.1 Design Method

The design of the Automatic Streetlight Controller was carried out stage by stage following the block diagram in Figure 2.

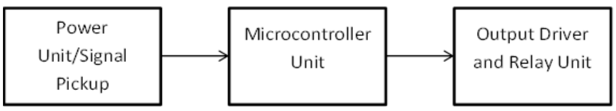

Fig 2: Block diagram of automatic street light system

Power/Signal Pickup Unit: This unit consists of a step-down transformer, Rectifier Bridge, C_1 smoothening capacitor, D_1 diode which ensures movement of current in just one direction, 7805 and D_2 Zener diode voltage regulators, R_1 voltage limiting resistor to the LED and C_2 and C_3 capacitors. To obtain the value of the C_1 smoothening capacitor we use the formula:

$$D_V = \frac{I}{F_r C} \qquad (1)$$

where; D_V = Ripple voltage (Since the transformers output voltage is 15v, the ripple voltage considered is 3v).
I = Load current (expected to be 1.5A)
F_r = Ripple frequency (500MHz for the full wave rectification)
C = Capacitance value
Also, to calculate the voltage limiting resistance (R_1) to the LED we follow the work of George [14] as follows:

$$R = \frac{V_S - V_f}{I} \qquad (2)$$

Where; V_S = Supply voltage
V_f = Forward voltage
I = Forward current
R = Resistance Value
To calculate the capacitance of the capacitor C_2 we use Eqn. 3 as follows:

$$C = \frac{I}{V} \qquad (3)$$

Where; C = Capacitance in Farad
I = Output current of the 7805-voltage regulator
V = Output voltage of the 7805-voltage regulator

Microcontroller Unit: This consists of Pic12F675 microcontroller, LDR, LED and resistors. To calculate the values of the voltage limiting resistors R_2 and R_4 for LDR and LED respectively, we use Equations 4 and 5 as follows:

$$R_2 = \frac{V_o R_{LDR}}{V_{in} - V_o} \qquad (4)$$

Where; V_o = LDR output voltage
R_{LDR} = Internal resistance of the LDR
V_{in} = Input voltage from the 7805-voltage regulator

$$R_4 = \frac{V_S - V_f}{I_S - I_f} \qquad (5)$$

Where; V_S = Supply voltage
V_f = Forward voltage for a red LED
I_S = Supply voltage from the PIC12F675 datasheet
I_f = Forward Current from the LED

Output Driver and Relay Unit: This consists of R_5 and R_7 resistors, LED, Relay and an NPN transistor. To calculation the value of resistor R_7 we use equation 2 while that of R_5 is similar but relabeled as in Equation 6 as follows:

$$R_5 = \frac{V_B - V_{BE}}{I_B} \qquad (6)$$

Where; R_5 = Base resistance
V_B = Base voltage
V_{BE} = Base Emitter Voltage
I_B = Base current

Transformer Parameters Values: In obtaining the parameters values we follow the work of Assad [15] as follows:

Primary Winding Calculations: For a Primary voltage V_P = 230V, the Primary current can be calculated from equation 7 as follows:

$$I = \frac{V_A}{V_P} \quad (7)$$

Designing a transformer of 95% efficiency,

$$I_1 = \frac{V_A}{\frac{95}{100} X\, V_P} \quad (8)$$

Number of Turns: The number of turns for the primary can be calculated using equation 9 as follows:

Total number of turns N_P = turns per volts × primary side voltage (9)

Size of Conductor: The size of the conductor is calculated using equation 10 as:

Current density = $\delta = \frac{I}{A}$ (10)

As for copper, current density is assumed to be 3A/mm^2 so, for area of copper conductor;

Secondary Winding Calculations: For a secondary voltage of V_S = 15V, the secondary current can be calculated from equation 11 as follows:

$$I_S = \frac{V_A}{V_S} \quad (11)$$

Area of secondary conductor is calculated using equation 11.

Number of Turns: The number of turns for the secondary can be calculated from equation 12 as follows:

Number of secondary turns, N_S = turns per volts × secondary volts. (12)

Weight Estimation of Windings: The following steps and equations are followed for weight calculations.

1. Approximate length of copper wire = Perimeter of bobbin × Number of turns.
2. Cross sectional area of copper conductor
3. Volume = Approximate length × cross sectional area
4. Mass = density of copper × Volume

Density of copper = 8960Kg/m^3

2.2.2 Simulation Method

Programming of the microcontroller was done using the Arduino software while the circuit design was done using Proteus 8.0. The programmed microcontroller and the bread boarded circuit were tested with the help of a computer system. The flowchart of the simulation is as shown in Figure 3.

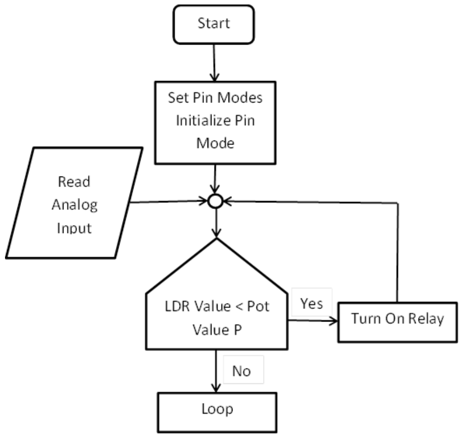

Fig 3: Flow chart of the system

2.2.3 Construction Method

The circuit was constructed based on the block diagrams in Figure 2. First a bread board construction was carried out by fixing in the components before carrying out a more permanent soldiering on a Vero board.

2.2.4 Testing and Analysis Method

The following tests were carried out on the device to ascertain its functionality.

1. **Specificity Test (S_P):** This tests the ability of the system to specifically detect signals (instructions) internally.

$$S_P = \frac{N_T}{N_T + N_F} X\, 100 \quad (13)$$

And for the time taken to execute single instruction (response time);

$$T = \frac{1}{F} \quad (14)$$

Where, N_T = Number of Trials
N_F = Number of Fails
F = Frequency (of the PIC12f675 External oscillator)

2. **Accuracy Test**: Though specificity test checks how the system specifically detects signals, this test checks how accurate this detected signal are.

$$Acc = \left[1 - \left(\frac{N_T - N_{PO}}{N_T}\right)\right] X\, 100\% \quad (15)$$

Where, N_T = Number of Trials
N_{PO} = Number of positive outcomes

3. Results

3.1 Design Analysis

3.1.1 Power Supply/Signal Pickup Unit

This unit is made up of the transformer, rectifier, C1 smoothening capacitor, D1 diode, 7805 voltage regulator and 12V DC battery, C1 and C2 capacitors, Zener diode and resistors. The circuit is as shown in Figure 4.

Smoothening Capacitor: The capacitance of the capacitor is achieved calculated using equation 1 as follows:

$$C_1 = \frac{1.5}{3 \ X \ 5 \ X \ 10^8} = 100nF$$

Zener Diode: The 5.1V Zener diode was chosen as it also functions as a voltage regulator and a possible backup for the 7805-voltage regulator IC.

Resistor (R_1): The resistance of the voltage limiting resistor was calculated using equation 2 as follows:

$$R_1 = \frac{5-2}{3 \ X \ 10^{-3}} = 1000\Omega = 1k\Omega$$

Capacitor (C_2): The capacitance of the capacitor was calculated using equation 3 as follows:

$$C_2 = \frac{5 \ X \ 10^{-3}}{5} = 1mF$$

Transformer Design: Given that the frequency of power systems F = 50Hz. Using Magnetic Flux density B_m = 1.2T and current density of copper wire taken as 3A/mm^2 [16]. Then

$A_i = 9.384 \times 10^{-4} \simeq 1.45inc^2$
Using a bobbin of 2.25inch (1.51 X 1.51) or 0.00145161m^2, we calculate turns per volts T_e as follows:

$$T_e = \frac{1}{4.44 f B_m A_i} = \frac{1}{4.44 \ X \ 50 \ X \ 1.2 \ X \ 0.00145161} = 2.6 \ (turns \ per \ volt)$$

Primary Winding: Using equations 8, 9 and 10 the primary current I_P at a 95% efficiency, Number of primary turns N_P and size of conductor were calculated thus;

Primary current $I_P = \frac{V_A}{V_P} = \frac{50}{230} = 0.218A$
Designing a transformer of 95% efficiency,

$$I_P = \frac{V_A}{\frac{95}{100} X \ V_P} = \frac{50}{\frac{95}{100} X \ 230} = 0.23A$$

Therefore, Primary current = 0.23 (approx.)
Number of turns N_P = 2.6 × 230 = 600 *turns* (approx.).

Area of primary conductor = $A_P = \frac{0.23A}{3Amm^{-2}} = 0.08mm^2$

So, primary conductor size = 28AWG.
From the standard American Wire Gauge (AWG) table choosing wire of same thickness. It is seen that required primary side wire is of 28 gauge which can inherently conduct required current.

Secondary Winding: Using Eqns. 11, 12 and 13 the area of secondary conductor (A_S) secondary current I_S and Number of secondary turns N_S were calculated.

Secondary current $I_S = \frac{V_A}{V_S} = \frac{50}{15} = 3.33A \ (approx.)$

Area of secondary conductor =

$$A_S = \frac{3.33A}{3Amm^{-2}} = 1.11mm^2 (approx.)$$

It can be seen from the standard table for copper wire that wire of this approximate thickness is of 17gauge. So for the secondary winding we need 17gauge wire.
Number of Turns N_s = 2.6 × 15 = 39 (approx.)

Primary Weight
Perimeter of bobbin = 1.75 × 4 = $7inc$ = $0.1778m$
So, Length of one turn = $0.1778m$
Total length of all turns of primary = L_1.
Therefore, L_1 = Length of one turn ✕ total number of turns = 0.1778 × 600 = $106m$ (approx.)
Since area of primary conductor = 0.08mm^2 = $0.08 \times 10^{-6}m^2$
Volume of copper wire $V_1 = area \times length$
$V_1 = 0.08 \times 10^{-6}m^2 \times 106m = 8.48 \times 10^{-6}m^3$
So, Weight = density ✕ volume
$W_1 = (8960 \times 8.48 \times 10^{-6})$ Kg = $75980.8 \times 10^{-6}Kg$
$= 75980.8 \times 10^{-3}grams = 75.98grams$

This implies that approximately, we need 76grams of 28gauge wire.

Secondary Weight
Perimeter of bobbin = 1.75 × 4 = $7inc$ = $0.1778m$
So, length of one turn = $0.1778m$
Total length of all turns of secondary winding = L_2.
This implies, L_2 = length of one turn x total number of turns of secondary
$L_2 = 0.1778 \times 39 = 6.9342$m $\simeq$ 7m
Since area of secondary conductor = 1.11mm^2 = $1.11 \times 10^{-6}m^2$
Volume of copper wire = area ✕ length = $(1.11 \times 10^{-6} \times 7)$ $m^3 = 7.77 \times 10^{-6}m^3$
Therefore, Weight = density ✕ volume
$W_2 = 8960 \times 7.77 \times 10^{-6} \ Kg = 69619.2 \times 10^{-6} \ Kg$
$= 69619.2 \times 10^{-3} \ grams = 69.6192 \ grams \simeq 70$ grams
So approximately, 70grams of 17gauge wire is used.

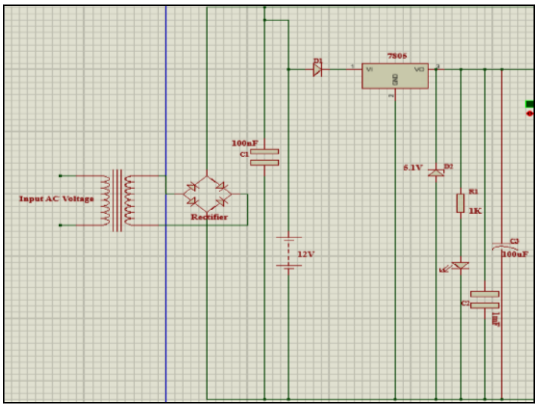

Fig 4: Power supply/Signal Pickup Unit

3.1.2 Microcontroller Unit
This unit contains the PIC12F675 microcontroller and the LDR, with LED and resistors R2, R3, R4 and R6. The circuit diagram for this unit is as shown in Figure 5.

Voltage Limiting Resistor (R2) for LDR: This is calculated Using Equation 4 as follows:

$$R_2 = \frac{3.2 \, X \, 200}{5-3.2} = 355.6\Omega$$ (Used 390Ω standard value)

Voltage Limiting Resistor (R4) for LED: This was calculated using Equation 5 as:

$$R_4 = \frac{5-2}{25 \, X \, 10^{-3} - 3 \, X \, 10^{-3}} = 136\Omega$$ (Used 150Ω standard value)

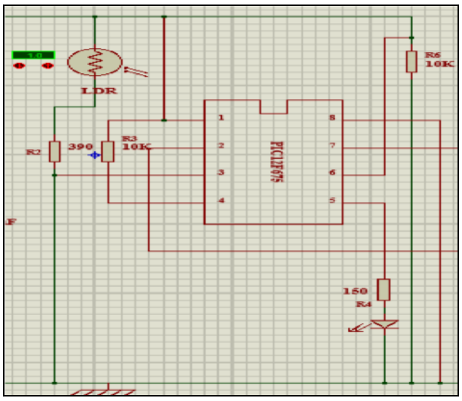

Fig 5: Microcontroller unit

3.1.3 Output Driver and Relay Unit

This unit is the changeover unit which completes the path to the street light or disconnects it when it‘s dark or day respectively. Figure 6 depicts the circuit diagram. This unit comprises of R5 and R7 resistors, LED, Relay and NPN transistor.

Voltage Limiting Resistor (R7) for LED: This was calculated using Equation 2 as:

$$R_7 = \frac{15-2}{3 \, X \, 10^{-3}} = 4.33k\Omega$$ (Used 4.7kΩ standard value)

Transistor Base Resistor (R5): This was calculated using Equation 6 as follows:

$$R_5 = \frac{5-0.7}{25 \, X \, 10^{-3}} = 172\Omega$$ (Used 180Ω standard value)

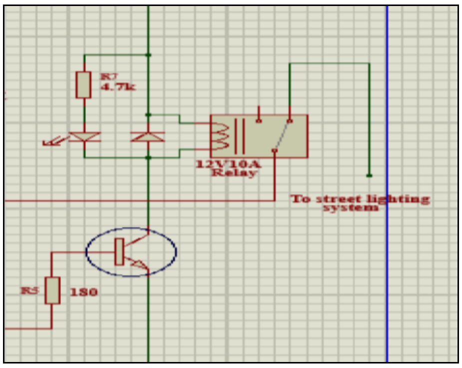

Fig 6: Output Driver and Relay unit

3.2 Circuit Simulation

Haven designed the circuit its workability was tested by simulation using Proteus 8.0. Figure 7 shows the final circuit design from the simulated output. At the start, the microcontroller is initiated and the LDR senses brightness/darkness, which serves as the analog input to the system. If the LDR senses darkness which is less than the pot value P, it switches ON the relay which completes the path into lighting the streetlight else, the system continues to loop.

3.3 Circuit Construction

The construction is carried out according to the specification of design. The system operates in such a way that at the Power Unit, the 200/230V AC is stepped down by the transformer to a 15V AC. After rectification the smooth 15V DC goes out in two ways; one directly to the Relay Unit and the other to the Microcontroller Unit through the 7805-voltage regulator which ensures only 5V DC goes into that unit. LED 1 and 3 indicates the flow of 5V and 15V DC respectively.

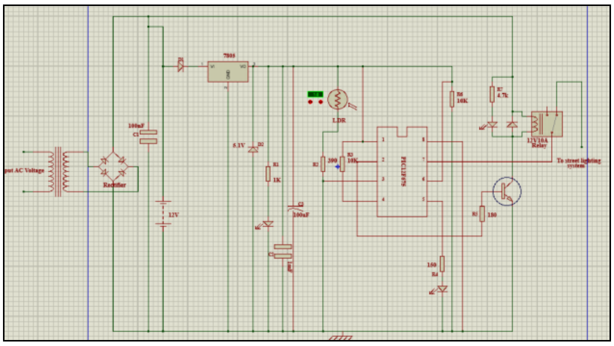

Fig 7: Complete circuit diagram of the automatic street light controller

The variable resistor and the Zener diode checks when the battery is below preset voltage level and when fully charged. So, when the LDR detects darkness, the microcontroller through pins 2 and 7 sets the transistor and the relay to create a straight path through for the illumination of the streetlight at which point the relay shifts to NC. While during the day, the LDR switches to NO which disconnects the lighting system automatically. The constructed circuit on a Vero Board is as shown in Figure 8, while the final packaged device is as shown in Figure 9.

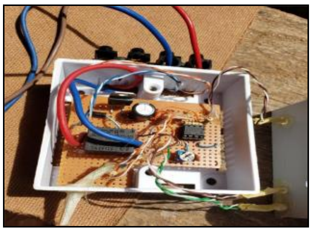

Fig 8: Constructed circuit on Vero boar

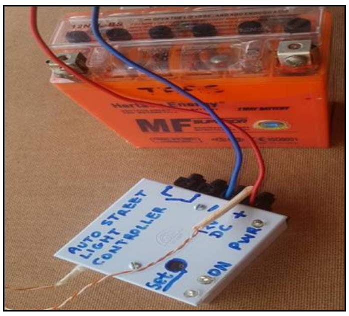

Fig 9: Complete packaged system

3.4 Output Test and Analysis
After construction, several tests by covering the LDR (To indicate darkness) and keeping it open to indicate (daylight) was carried out and the output result of Ten (30) trials was presented in Table 1. Then using equations 14, 15 and 16 the specificity, time taken to execute signals picked up by the microcontroller and the accuracy of the system were calculated.

Table 1: Result of output test

N_T	N_F	N_{PO}
30	1	29

Specificity Test: This is calculated using equation 13 as follows:

$$S_p = \frac{30}{30+1} X\ 100\% = 96.77\%$$

Time taken to execute single instruction: This is calculated using Equation 14 as:

$$T = \frac{1}{50Hz} = 0.02sec$$

Accuracy Test: This was calculated using Equation 15 as follows:

$$Acc = \left[1 - \left(\frac{30-29}{30}\right)\right] X\ 100\% = (1 - 0.0333)\ X\ 100\% = 0.96667\ X\ 100\% = 96.67\%$$

From the calculated results it shows that the system has good detection of darkness and brightness, can respond almost immediately and is very accurate which implies a good functionality of the system.

3.5 Casing and Packaging
Casing of the circuit is very important as it prevents it from distortion from external harm. The casing was made of plastics with dimensions 9cm x 9cm x 4cm. Openings to the size of 0.5cm in diameter and 2cm x 1cm in circumference respectively were perforated to enable cooling. Figure 10 gives a representation of the casing and its dimensions.

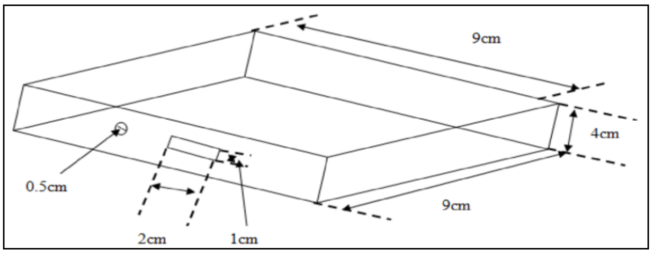

Fig 10: Casing and its dimensions

4. Discussion of Results
The Automatic Streetlight Controller Circuit is a simple effective device that can be effectively fixed into existing streetlight without much effort. The calculated results reveals the device performance showing a good detection of darkness and brightness leading to fast switching time as indicated by the response time which is almost immediately and the high accuracy of the device shows the effectiveness of the algorithm used and the programming accuracy which implies a good functionality of the system. This is much similar to the work of [8] because in both cases, microcontroller chip was used and the manual aspect of street lighting was automated. However, this research work differs in its simplicity to the works of [17], because their work depends on the presence of cars as a signal to lit up the streetlight, whereas, the present study work with the aid of LDR to lite the streetlight. Also, it differs from the work of [7] due to its complex nature as it includes a GPS and so more expensive and complex.
The output test and analysis of Specificity and Accuracy reveals 96.77% and 96.67% respectively, while it takes about 0.02sec to execute single instruction implies that the device has a good response. However, such analysis was not found in the previous works done in the literature which shows the uniqueness and contribution of this research work.

5. Conclusion
The importance of Automatic Streetlight Controller cannot be overemphasized as it drastically reduces human effort in directly controlling the streetlight. It can be installed in both existing and newly installed streetlights to eliminate wastage of scarce electricity as it automatically switches off the streetlight with the help of LDR as soon as the day breaks and switches it on as soon as it is dark to ensure continuous security for humans and businesses. Though it can be improved upon by incorporating a camera feed unit to enhance its security feature and also a charge controller circuit can be added to control the charging system of the battery.

Declaration
Contributors: All authors contributed to the conception or design of the work, the acquisition, analysis, and interpretation of the data. The first draft of the manuscript was written by [Samson Dauda Yusuf] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.
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