Solar-Powered Led Streetlamp with Microcontroller-Based Illumination System

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Abstract: Streetlighting is one of the important systems within a community that allows people to see their surroundings, which helps to reduce pedestrian accidents and the crime rate. The illumination of streets can becostly due to the energy it consumes. Therefore, there are various studies conducted on how to reduce the consumption of streetlights by introducing intelligent lighting systems. The study aims to reduce the power consumption of a solar-powered LED streetlamp byintroducing a prototype that allows the LED to automatically adjust its luminosity. Both streetlamps have the same specifications and a microcontroller called Arduino Uno, but the prototype utilized a BH1750 light sensor while the other used a photoresistor. After a series of tests and experiments, the proposed streetlamp minimizes the power it consumes compared to the conventional streetlamp while maintaining the standard illumination in the local road setting.

Keywords: Solar powered LED streetlamp, Arduino Uno, BH1750, Intelligent Lighting System

I. Introduction:

Street lighting is one of the important systems in people's everyday lives since it artificially extends the hoursof light sources around them, thus promoting security and allowing them to do their activities that require lighting. According to a reference website, *Road Safety Toolkit*, streetlights or streetlamps are a light source that is frequently mounted to a pole that is erected on roads where humans and their vehicles pass through, and it helps to reduce pedestrian crashes by approximately 50%, giving them assurance of safety while walking in the streets since it allows them to see through their environment despite nighttime. In addition, this reduces the crime rate during the nighttime outdoor index by 36%, as per the experiment conducted by Chalfin et al. in 2021. In recent years, LEDs, or Light Emitting Diodes, have been used in street lighting due to the numerous benefits they provide compared to conventional bulbs. A study titled "*Design and Implementation of Smart Solar LED Street Light"* claims that LED lamps have an estimated lifespan of 10 to 15 yearsin service and have an operational lifespan of 50,000 hours to 100,000 hours, making them a reliable choice for lighting systems around the world. In addition, LEDs are being proved to be more energy efficient compared toconventional bulbs used on street lighting since they have an efficacy of 100 to 120 lumens per watt (Bhairi et al., 2017).

Solar powered LED streetlights are widely used forlighting systems in roads and streets due to their efficiency, low maintenance cost, and smart features (*Intelligent Street Lighting System using Automatic Solar LED Lamps, 2015*). It employs LEDs to reduce power consumption, while the energy is supplied by a photovoltaic system, which is amonocrystalline silicon panel with a higher conversion rate than a polycrystalline panel, and the energy produced from solar radiation is stored in a battery (Design and Implementation of Smart Solar LED Street Light, 2017), and a photoresistor to detect the light intensity on the system's surroundings in order to know when the systemwill turn on or the human labor within the system.

The system complies with the standard entitled "*Bureau of Street Lighting"* from the Department of Public Works, which serves as the minimum requirement for the illumination requirements of streetlamps. The LED light must reach the minimum standard lux level required by the BSL within the streetways depending on the type of roadway where it is installed. The LED output is adjusted using BH1750 as the sensor for the natural light of the surroundings, and when the surroundings become darker, the brightness of the LED will increase to a certain level andvice versa. This process was programmed and executed using a microcontroller. The system is powered by a solar panel and for the energy storage, a lithium-ion battery isused for the study since it is proven to be more advantageous due to its high energy density, light weight, and offered longer lifetime (Bhairi, M., et al., 2017).

The paradigm above shows the relationship between the variables in the proposed system. Natural light from the sun affects calibration for the microcontroller, power generation, and the illumination level of the roadway.

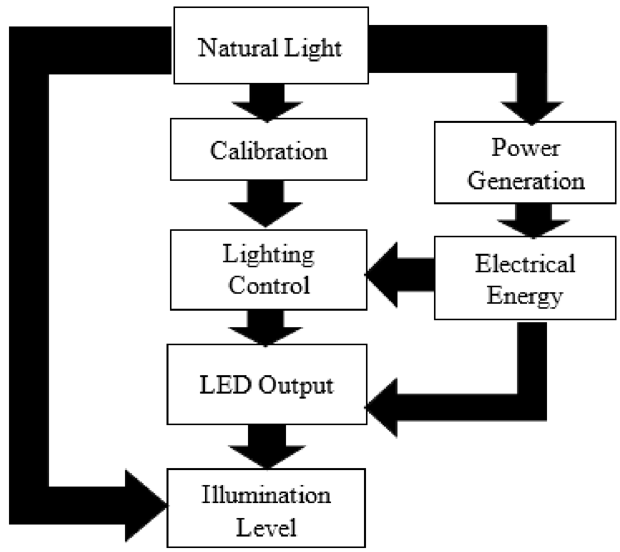

Figure 1.1 - Conceptual Framework

Firstly, the calibration from various tests affects thebehavior of the microcontroller or lighting control system in manipulating the output of the LED. The illumination level of the roadway will depend on both the LED output of the lamp and the natural light from the sun. Lastly, natural light will affect the power generation, or the energy conversion ofsolar energy into electrical energy, which is essential for the overall proposed device to operate and work properly.

There are numerous streetlamps that are being used nowadays and come with different configurations and specifications, such as the type of bulb used and features that are meant to control and deliver energy to the streetlamp. These configurations are being introduced and made for streetlamps to improve their efficiency in terms of how much energy is being saved, minimize human intervention by automatic control, and reduce maintenance. The existing technology only turns on or off the LED lamp, while the proposed streetlamp emits just the right amount of light by dimming or brightening the LED output with respect to natural light available. Therefore, the main problem of the study is that the proposed streetlamp and its lighting control system save more power compared to the consumption of the conventional streetlamp with conventional lighting control, by running both systems until their batteries get depleted.

The proposed study specifically aimed to answer thefollowing questions

1. How does the proposed system maintain the standard illuminance of a streetlamp with respect to changes in the amount of natural light before the battery depletes?
2. How does the power consumption of the proposed streetlamp compare to the conventional streetlamp?
3. How long can the proposed streetlamp last compare to the conventional streetlamp in terms of its run time?

Objectives of the study:

The study aimed to improve the control system of the solar-powered LED streetlamp by emitting the right amount of luminance, inversely proportional to the intensity of natural light. This is to maintain the adequate brightness needed within the area of coverage, which is a more power- saving method of illumination system.The proposed study aimed to achieve the following objectives:

1. To determine the effectivity of the proposed streetlamp in maintaining the standard illuminance with respect to the changing amount of natural light;
2. To determine if the proposed streetlamp saves more power as compared to the conventional streetlamp; and
3. To determine if the proposed streetlamp has a longer run time compared to a conventional streetlamp with respect to their equal battery capacity.

Literature reviews:

Solar powered LED streetlamps are being widely used for street and road lighting applications due to their various benefits and advantages compared to conventional streetlamps that have been used for a long time. A study titled "*Intelligent Street Lighting System using AutomaticSolar LED Lamps*" was conducted in 2015. Solar-powered LED streetlamps are known for:

1. Very low running cost due to their independency on grid power.
2. No manual switching since they can be automatically turn on or off.
3. Low maintenance cost due to durability of the components especially the LED lighting fixture of the streetlamp.
4. Provides energy saving features by preventing unnecessary lighting and wasted energy.
5. Saves a lot of human labor since the system can turn on and off when the lighting operation is needed.

In addition, solar-powered LED streetlamps use photovoltaic cells or solar panels to convert the solar energy to electrical energy, specifically DC electricity. The energy produced by the solar panel is used to charge the battery within the system for later use. Since daytime is the charging time of the solar powered LED streetlamp, when nighttime reaches where sunlight is not present, the system will operate and use the stored energy to power the LED lamp, making no operation cost since it is an off-grid system.

Street lights consume 15–40% of the total energy in a standard city (Wengli, 2021), and it costs a lot of energy andmoney because it is connected to the grid. This Smart Solar LED Street Light is a device that can generate power independently by using solar panels. This device is an off- grid power system since it does not use power that is connected to the grid. It is suitable in areas that are not covered by the national grid, such as remote areas, and off- grid systems have a low-cost operation. According to Stanislav Misak and Lukas Prokop (2010), for designing an off-grid power system, the first thing to be considered is the geographical and meteorological features of the area since they vary the power generated. This off-grid system uses batteries as storage for power generated. Mostly used solar panel in the solar powered LED street lamps is monocrystalline silicon photovoltaic cell that has higher conversion rate compared to polycrystalline silicon photovoltaic cell (Baburajan et al., 2016), has a stable performance (Wang, 2018) and has an efficiency value of 18% (Bhairi et al., 2017). The light dependent resistor can be replaced with BH1750 since the LDR sensor requires calculation to achieve the right value. Using BH1750, it is much more reliable in sensing the light intensity and more convenientfor its users. In the absence of calculations, the lux parameter can be used to measure the light intensity. There are also applications where BH1750 can be used for automobile sun visors and functions as the control system. The output of the sensor is in the unit of Lux, and it can detect a vast range at the highest resolution possible (1 to 65535 Lux). Microcontroller served as the brain system of a device (De Guzman, 2018) which commands what action must a system do with a given input. A study titled *Microcontroller based Automated Lighting Control System for Workplaces* conducted in 2018 which uses a microcontroller called the ATMega 168, which process the data from a light dependent resistor and adjust the dimming state based on the reading of the sensor. The study conducted aims to adjust the light intensity of the LEDs within the workplaces inversely proportional to the available natural light within the area of coverage. This method is possible through the help of a microcontroller and a light dependent resistor since the sensor is sensing the available light within its surrounding and the microcontroller interprets the electrical signal from the sensor allowing the microcontroller to command when to dim or brighten the LED lights. This is being widely used to solar powered LED streetlamp since it is suitable for embedded system (Wang, 2018), and studies such as *Design and Implementation of Smart Solar LED Street Light* conducted in 2017 use microcontroller called *Arduino,* specifically *Arduino Uno R3* which compose of ATM ega 328 microcontroller chips, that receives input from the sensors and control the streetlight base on the reading of the sensor and it operates base on the program built within the memory of the microcontroller. The programming processof *Arduino* use a compiler called *Arduino IDE* and run in C or C++ programming language.

Street lighting differs from place to place based on its intended use in the surrounding locale. Standards are inplace by certain bodies of a government to provide directionand to establish policies. In the city of Los Angeles, a manual produced by the department of public works details the recommended values of illuminance based on the type of road or surroundings. (Department of Public Works, 2007)

Road Type	Pavement Classification(Minimum maintained Average Values)			UniformityRatio Eav/Emin	Veili ng Lumi nance Ratio Lvma/ Lav
	R1 lux/fc	R2 &lux/fc	R4 lux/fc		
MajorRoad	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Collector Road	4.0/0.4	6.0/0.6	5.0/0.5	4.0	0.4
LocalRoad	3.0/0.3	4.0/0.4	4.0/0.4	6.0	0.4

Table 2.2 - Illuminance Method – Recommended Values

II. Methodology:

Research Design

Figure 3.1 – Model of both streetlamps mounted in single pole

The figure shows the model of both streetlamps and shows the different components used for their functions for the overall system.

LED Lamps – It is a lighting fixture that is used for streetlamps that emits artificial light to maintain luminance in the absence of natural light from the sun.

1. Circuit Box – It serves as the enclosure for the circuitry and the battery of the prototype

2. Pole – It is the mounting place of the components needed for the streetlamps that allow the lighting fixtures and solar panels to be raised at a certain height and illuminate the area. In addition, the height of the pole that is used is 2.2 meters where the two systems are mounted.

3. Photoresistor – It is the main sensor of the conventional streetlamp detects the current intensity
of natural light in its surroundings, allowing the system to respond to certain changes in natural light

1. BH1750 Light Ambient Sensor – It is the main sensor of the proposed streetlamp to detect natural light intensity in terms of lux that allows the prototype to determine when to turn on or not.

Solar Panel – It is used to harvest solar energy and convert it to electrical energy that will be stored in the battery for later use of the system. It is mounted on a frame that holds it in place. The solar panel used is a polycrystalline type.

For the dimensions, the pole is desired to elevate the lighting fixture based on Table 6.5.3 of the Roadway Lighting Guidelines of DOE. For minor roads, it is recommended that the mounting height of the streetlight be 8 meters, and 10 to 12 meters for both collector roads and major roads. The following standard height is too high to be conducted in an experimental setup. Therefore, the design will be considering section 6.2.2 of the said guidelines, which allows a reduction to a minimum height of 3 meters, but due to the limitations of I2C communication of the monitoring system, the final height of the pole is 2.2 meters to avoid inaccurate data reading since the sensors need to be electrically connected via conductor and the length of the conductor can reduce the accuracy of the parameters thatcan be read by the monitoring system.

Figure 3.2 - Mounting Height of the Pole

Circuit Diagram:

The figure below shows the circuit diagram of the proposed streetlamp where it uses a microcontroller for the illumination control system, which aims to save more energy compared to conventional solar-powered LED streetlights. The system is being powered by solar energy, which is being converted to electrical energy that will be stored in a battery for later use at nighttime when the streetlight needs to operate. The Arduino serves as the brain system of the circuit where it uses a BH1750 light ambient sensor to detect the lux value of the natural light in the surroundings and to identify what power percentage to use to emit just the right amount of light from the LED to maintain minimum standard illumination by commanding the output to the MOSFET to control the flowing current to the LED lamp by sending a PWM signal, allowing the LED to dim and brighten depending on the PWM being sent tothe MOSFET.

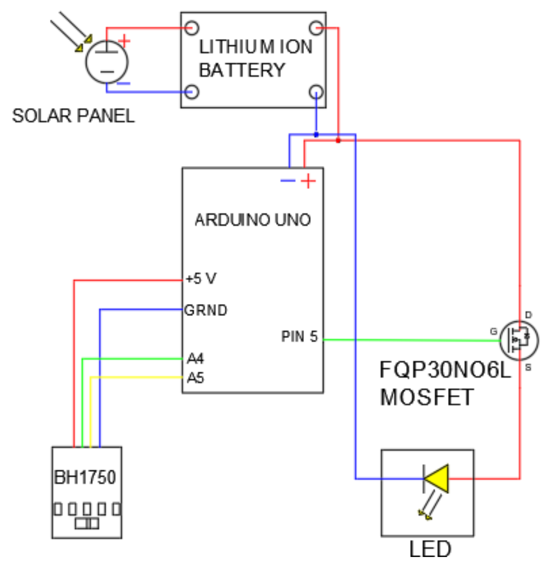

Figure 3.4 - Circuit Diagram of Proposed System

Program Flowchart:

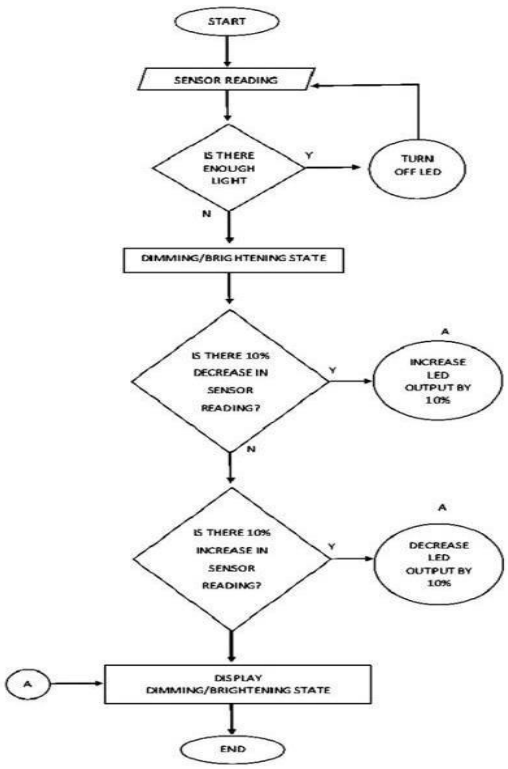

Figure 3.5 - Program Flowchart

BH1750 reads the lux values within the environment and allows the proposed streetlamp to detect what the lux values are present at a certain time. Once the system reads that the environment is less than 4 lux, the LED of theproposed streetlamp turns on with a minimum power consumption. Since the system detects that there is only 10 percent change from the triggering value of 4 lux, the microcontroller commands to emit only 10 percent of power from 0 percent power consumption. The process goes further with a 10 percent margin of change for both readings until the lux in the environment reaches 0 lux and the emitted output reaches "255", or the 100 percent outputpower of the LED.

Experimentation:

This consists of various experiments to determine if the proposed streetlamp can maintain the standard illuminance in a roadway with respect to the behavior of natural light within the surroundings, where the system is expected to emit just the right amount of brightness to save energy while maintaining the necessary illumination, and to identify if thesystem consumed less power compared to the conventional streetlamp by recording the power used by both systems and determining which system's battery lasted longer via drain test. The experimentation was conducted in a 2-week spanof data gathering

Experiment 1:

Researchers tested if the proposed streetlamp is maintaining the standard illuminance suggested by the *Bureau of Street Lighting* with respect to the changes in natural light in the prototype's surroundings by recording the lux values emitted in the area of illumination. The experiment lasted for two weeks.

Procedures:

1. Place the BH1750 light sensor (Sensor A) directly under the LED lamp of the system to measure the illumination level of the prototype. Place the other BH1750 light sensor (Sensor B) to measure the natural light in the surroundings. The sensors must not be covered by any shadows for accuratemeasurements.
2. Sensor A was programmed to save data when sensorB detects under 6 lux values to neglect the lux values outside the operational time of the system.
3. Initiate the monitoring system at 6 pm since the operation of the streetlamp is expected to function atthat given time.
4. Make sure that the sensors are electrically connected to the analog inputs of the monitoring system by checking the "LuxA" and "LuxB" on the LCD screen to identify if the system reading is normal.
5. Select the lux values from Sensor A to determine the average illumination

maintained by the proposedsystem.
Identify the average illumination that day and recordit in the table given to identify if the system maintains illumination near the standard.

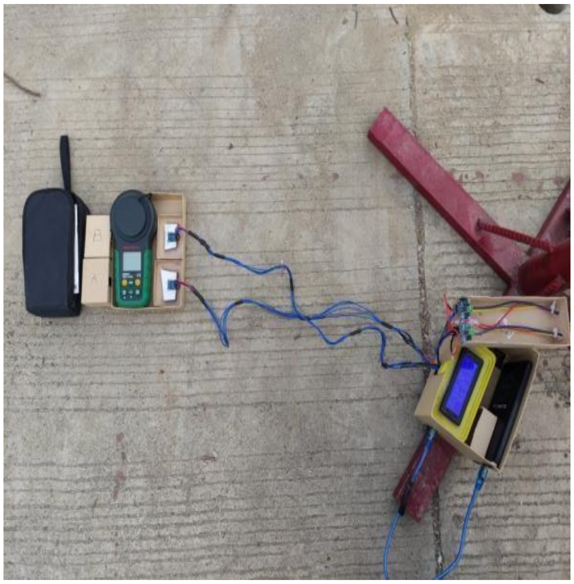

Figure 3.10 – Procedural Set up of Experiment 1

Experiment 2:
Researchers measured the power consumption of both streetlamps during their operational time. The data for both systems is tabulated and compared to each other. The resultsare determined if the proposed system is proven to be more power-saving. There are conditions to be followed to avoid being biased toward the proposed system.
Procedures:

1. Connect the INA219 sensor to the positive terminal between the battery and the load side for both systems to measure the current demand of both systems.
2. Connect the ground terminal of the INA219 sensor, battery, and load to measure the voltage supply for both systems.
3. Make sure that the sensors are electrically connected to the analog inputs of the monitoring system by checking the "Va"," Vb", "Ca", and "Cb" on the LCD, if the system reading is normal.
4. Upload the algorithm for both conventional lighting control and proposed

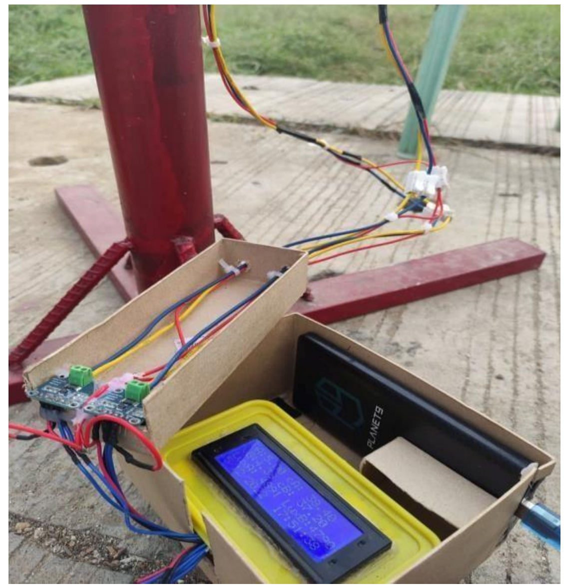

Figure 3.11 – Procedural set up for Experiment 2

lighting control to the Arduino of each system through the serial port.
Prepare the monitoring system at 6 pm since the operation of the system is expected to function at that given time.

Figure 3.12 - Data Gathering Setup using Monitoring System

DATA GATHERING INSTRUMENTS
Automatic Monitoring System

Figure 3.13 - Automatic Monitoring System

Researchers utilized an automatic data logging system to measure the real-time behavior of values necessary for data gathering. The microcontroller used for real-time monitoring is the *Arduino Mega,* which has more pins than the *Arduino Uno* since its modules and sensors need to attach to the component that serves as the processing unit that receives data from the attached sensors. Monitoring of lux level for the natural light and from the induced lux of the system is logged using a BH1750 light sensor that is capable of detecting illuminance level within its surroundings and sending data to the microprocessor referred to lux. The working voltage of the sensor is 2.4 V to 3.6 V, and it can measure up to 65535 lux units. This allows the monitoring system to record the lux values from the system and from the natural light in real- time.

Figure 3.15 – BH1750 Light Ambient Sensor

For the recording of power consumption, the INA219 module was used since it can measure current ranging from 0 to 3.2 A, voltage from 0 to 26 V, and the power flowing within the circuit, allowing the system to measure the power consumed by the prototype and record the consumption in real-time.

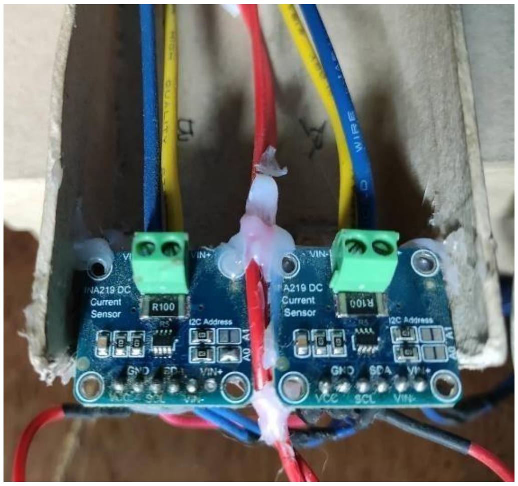

Figure 3.15 – BH1750 Light Ambient Sensor

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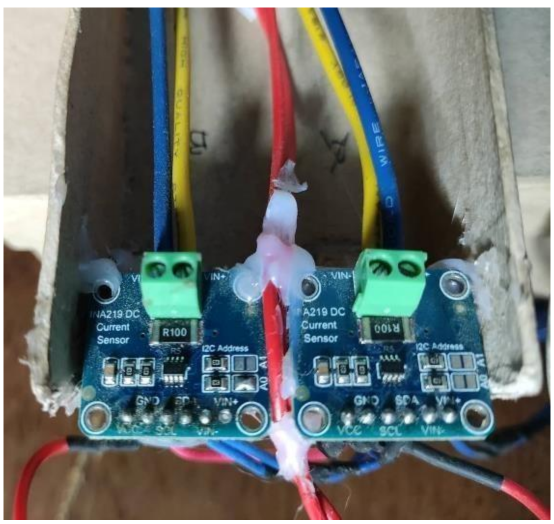

Figure 3.16 – INA219 Current Sensor

Table 4.16 – Test Statistics of Mann Whitney U Test

Lux meter

Test Statistics	
	Power
Mann-Whitney U	673068.000
Wilcoxon W	2165196.000
Z	-26.186
Asymp. Sig. (2-tailed)	0.000
a. Grouping Variable: System	

It is used to measure the illuminance with respect to the distance of the apparatus to the light source. The measured value is in terms of lux

Multimeter

It is used to measure electrical parameters within the electrical circuit of the system. Multimeters can be set to various modes, such as voltmeter for both AC and DC, ammeter, and ohmmeter.

STATISTICAL TREATMENT

Researchers used Wilcoxon Signed Rank Test todetermine if the proposed streetlamp maintains the standard illuminance within its area of illumination, Mann WhitneyU Test to determine the difference of conventional and proposed streetlamp in terms of their power consumption, and Independent T-test in determining the significantdifference of two streetlamps in terms of their run time

A statistical software program called SPSS was used on the study for statistical analysis to determine the mean battery runtime, p-value, and 95% confidence interval of the proposed device and the conventional lighting system. The significance level that was used in the statistical treatment is 0.05 or 5% because it is the accepted value used on researchpapers within the field of science.

III. Results and discussions power consumption

Illumination:

The Z statistic of-0.600 has an asymptotic significance p-value for 2-tailed of 0.549, which retains the established null hypothesis for the statistical treatment. This means that the measured lux values are statistically and significantly equal to the hypothesis standard value of 4 lux.

Table 4.23 – Test Statistics of One Sample Wilcoxon Signed Rank Test

Test Statistics[a]	
	Target_Lux - Lux
Z	-.600[b]
Asymp. Sig. (2-tailed)	0.549
Exact Sig. (2-tailed)	0.692
Exact Sig. (1-tailed)	0.346
Point Probability	0.133
a. Wilcoxon Signed Ranks Test	
b. Based on positive ranks.	

BATTERY RUNTIME

The Independent Samples Test Table for Levene's Test has a significance p-value of 0.741, which retains the null hypothesis of the test. Not rejecting the null hypothesis.

The test statistics use the variable system as a grouping variable for the table. The U value of 673068.000 and Z value of-26.186 has an asymptotic 2 tailed significance p- value of 0.000 or exactly 3.7876E-151, which rejects thenull hypothesis at a significance level of 0.05 at 95% confidence interval since the p-value is less than the significance level. Rejecting the null hypothesis stating that there is no significant difference between the power consumption across the conventional and proposed systems means accepting the alternative hypothesis, which states that confirms the alternative hypothesis that the two sample groups have no significant difference in terms of variance and are equal. This confirmation is necessary in selectingthe correct row to be used for data interpretation. For the t- test table, a mean difference of 7.069 minutes was found between the means of both systems. The 95% confidence interval of the difference has a lower bound value of 1.706 and an upper bound value of 12.432, indicating the range of mean differences between two mean runtimes. The range indicates that the possible mean difference between the conventional and proposed systems was approximately 1.706 minutes up to 12.432 minutes in a 95% probability range. The sig. (2-tailed) for equal variance assumed had a significance p-value of 0.012 and was less than the chosen significance level of 0.05 at 95% confidence interval, resulting in the rejection of the null hypothesis of the statistical treatment. Since the null hypothesis is rejected, the alternative hypothesis becomes accepted, stating that there is a statistical difference between the battery runtimeof the proposed and conventional systems.

Table 4.26 – Independent Samples Test Table

Independent Samples Test							
		Levene's Test for Equality of Variances		t-test for Equality ofMeans		
		F	Sig.	t	df	Sig.(2-tailed)
Runtime	Equal variances assumed	0.112	0.741	2.709	26	0.012
	Equal variancesnot assumed			2.709	25.999	0.012

The Independent Samples Test Table for Levine's Test has a significance p-value of 0.741, which retains the null hypothesis of the test. Not rejecting the null hypothesis confirms the alternative hypothesis that the two sample groups have no significant difference in terms of variance and are equal. This confirmation is necessary in selectingthe correct row to be used for data interpretation. For the t- test table, a mean difference of 7.069 minutes was found between the means of both systems. The 95% confidence interval of the difference has a lower bound value of 1.706 and an upper bound value of 12.432, indicating the range of mean differences between two mean runtimes. The range indicates that the possible mean difference between the conventional and proposed systems was approximately 1.706 minutes up to 12.432 minutes in a 95% probability range. The sig.(2-tailed) for equal variance assumed had a significance p-value of 0.012 and was less than the chosen significance level of 0.05 at 95% confidence interval, resulting in the rejection of the null hypothesis of the statistical treatment. Since the null hypothesis is rejected, the alternative hypothesis becomes accepted, stating that there is a statistical difference between the battery runtime of the proposed and conventional systems.

Conclusion:

Upon conducting several experiments for both streetlamps and data treatments, the power consumption of proposed streetlamp is significantly lower compared to conventional streetlamp since the proposed system does not consume full load power upon starting during dusk as shown at *Figure* 4.7, by having a lower mean rank at *Table* 4.16, and a p-value exactly at 3.7876E-151 between the dataof two system, which is lower than the 0.05 significant level at 95% confidence interval leading to a statistical result of rejecting the null hypothesis which satisfies the said parametric difference between the system. This is achieved while maintaining the selected necessary illumination from the *Bureau of Streetlighting* which is 4 lux at local road which presented at *Figure* 4.8 where the proposed streetlamp has an average illumination near the margin of 4 lux from day 1 to 14 of data gathering span, and further justified by *Table* 4.20 where there is significant value of
0.057 for overall operational time of

proposed system, and *Table* 4.23 that shows significant value of 0.0549 for operational time of proposed system during dusk therefore both establishing null hypothesis that signifies that proposed streetlamp maintains the illumination at 4 lux during dusk and across the nighttime until its battery depleted. The proposed streetlamp operates longer minutes compared to conventional streetlamp given that their battery is fully charged from day 1 to day 14 of the data gathering. *Figure* 4.9 shows the that the battery runtime of proposed streetlamp reaches higher margin compared to the battery runtime of conventional streetlamp, which further supported by *Table* 4.25 that shows the higher mean runtime minutes of 127 for proposed streetlamp compared to mean runtime minutes conventional streetlamp of 119.93 having a mean difference of 7.069 minutes and a significant value of 0.012 as per *Table* 4.26 which rejects the null hypothesis resulting to a significant difference between the runtime of both streetlamp having the proposed streetlamp lasts longer.

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This research is the product of the motivation and passion of the researchers. Finishing this study proved that knowledge can be further developed through the use of technology and ideas from different professionals. The proponents are grateful to everyone who contributed and to those who would further improve the study.

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