Semi-Automatic System of Lumen Measurement of LED Lights in an Embedded Box

Inspiring Excellence

A Thesis Submitted to the Department of Electrical and Electronic Engineering of **BRAC University**

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DECLARATION

We do hereby declare that the thesis titled "Semi-Automatic System of Lumen Measurement of LED Lights in an Embedded Box", a thesis submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelors of Engineering in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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List of abbreviation

LED:	Light-emitting diodes
CFL:	Compact fluorescent lamp
lm:	Lumen
FLUX:	Derived from Latin fluxes meaning “flow”
Meridian Angle:	The angle, measured eastward or westward through 180°
Sum:	Summation
LX:	LUX
LCD:	Liquid Crystal Display
P.V.C.:	Poly Vinyl Chloride
MC:	Micro controller
DC:	Direct current
AC:	Alternating current
M:	Meter
cm:	Centimeter
rpm:	Revolutions per minute
AVR:	Alf and Vegard's RISC processor.
VCC:	Refers to the voltage from the positive terminal of a power supply.
GND:	Indicates the ground terminal or the negative terminal of a power supply.
GaAs:	Gallium arsenide or

CdSe: Cadmium selenide

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ABSTRACT

Due to an exceptional geographical location, Bangladesh can produce significant amount of solar energy, which is 1840-1575 kWh/m^2 annually. Because of that solar home system (SHS) is gaining enormous popularity in our country in social as well as business sector in our country. Since verities SHS components manufacturers, overall quality of LED lamps fluctuates from organization to organization, and as a result an increment in unsteady quality with the number of SHS installation occurs, which eventually causes system ineffectiveness. There are two existing lumen testing procedures - integrated sphere and goniophotometer method are quite costly in our country's perspective. So we have to come up with handmade cylindrical box with different dimension and sizes in CARC lab of BRAC University. Researches already included the testing results and also have established equations based on the measurement of total lumen of light sources. In our thesis we will make automatic luminous measuring embedded box based on these equations using a micro-controller, which will show the output of the system on the screen of the embedded box.

Chapter 1

Introduction

1.1 LED BULBs

In the present era of the world, LED bulb is one of the widely used light source during the absence of daylight. A LED bulb is a cost effective electric lamp that produces light using light-emitting diodes (LEDs). It has a lifespan and electrical efficiency which are several times greater than the available bulbs in the market. It consumes less power and gives more light. According to Japanese experts, a LED light bulb can save 80 percent electricity with a working life of 40000 hours [1]. The LED lamps are very much friendly to the environment unlike the CFLs due to the use of mercury inside the CFL [2]. It is well known that, mercury is toxic and creates serious long-term problems. So, use of LED Bulbs can cut the mercury emission to the environment it the CFLs are replaced. Because of their mentioned facilities, the idea of using LED Bulbs is growing rapidly all over the world, especially in Bangladesh.

1.2 Why Lumen measurement is important

The lumen (lm) is the SI derived unit of luminous flux, a measure of the total quantity of visible light emitted by a source. In easier words, as Watts measure the amount of energy consumed by a light, Lumens measure how bright the light shines.

Firstly, it is the mostly used parameter to define the light's brightness depending on which, we the people use to buy bulbs according to our requirement. For a larger room or space, bulb with more lumen will be needed and for a comparatively smaller room or space, bulb with less lumen will be sufficient. So, to get the exactly needed bulb lumen measurement is necessary.

Secondly, to define the quality and effectiveness of a bulb, lumen measurement is very much important. We all are informed that, in the specification of a bulb two parameters are always written. One is "Watt" (power consumption of the bulb), another one is "Lumen" (The brightness or light emitting quantity of the bulb). The bulb with less watt and greater lumen is better than the others with more watt and same/less amount of Lumen. So, we can buy the efficient one or the best one in terms of lumen per watt and for this lumen measurement is a must needed thing.

Moreover, we know the brightness of a bulb decreases with respect to time. The older the bulb the lesser the lumen. To find the decay and to calculate the errors lumen measurement is necessary.

1.3 Commercial methods of Lumen Measurement

Various methods can be applied to measure the lumen or the brightness of LED bulbs. There are some expensive devices available to measure the lumen. Beside this, Hemisphere method can be used to determine Lumen. Spatial integral of illuminance $E(\theta, \phi)$ on a spherical surface is used to determine the luminous flux. The measurement of Atotal luminous flux is done by measuring the illuminance at different locations (meridian angle θ and parallel angle ϕ) from the light source after placing it at the center of the imaginary hemisphere [3].

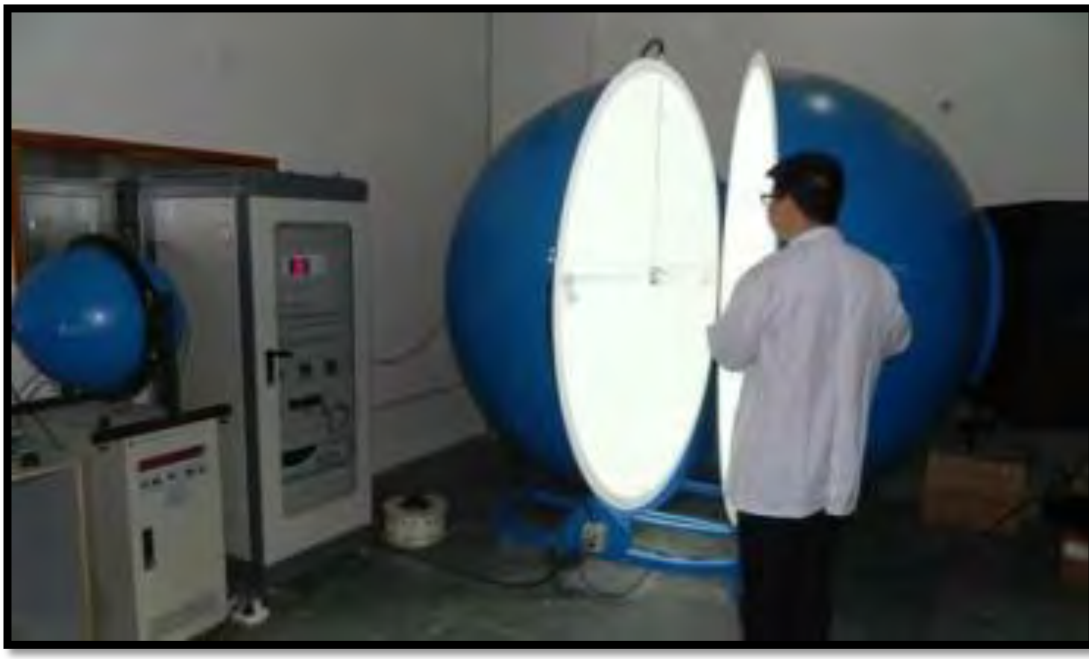


Figure 1: Commercial LED light testing using globe method.

1.4 Cylindrical method

We have carried out our research for the testing of lumen through the cylindrical method. Through extensive trials it has been found that using a cylinder instead of a hemisphere and taking into account specific conditions, the measurements were very close to the original values of lumen. This was not only an accurate method but was also found to be very cost effective and durable. This method will be described thoroughly in the later chapters.

1.5 Motivation and objective

The traditional method used for testing the luminous intensity costs too much as mentioned before. This may not be that significant to the household users of LED bulbs. What people are concerned with is whether the product they buy provides the expected results or not. On the packaging of the bulbs several technical specifications are mentioned, and the users may not know how credible the specifications are. It was brought to our attention that the lumen rating of the LED bulb of a renowned company was inconsistent with what was claimed. In addition to the cost of manufacture, the accuracy of the rating is also important. To sustain the accuracy, measurement of luminous intensity is important. There may arise the possibilities of power wastage too, and this country cannot afford this mishap. If the production of LED bulbs is reduced through this method, then the price of the product would eventually go down. It is necessary that this cost be reduced so that the increasing demand of lighting in both commercial and industrial sectors of Bangladesh can be dealt with.

1.6 Brief overview of the following chapters

The rest of the paper is divided into the following chapters:

Chapter 2: Components Required in the System

This whole chapter is based on breakdown of all the components used to assemble the device, including their individual purpose.

Chapter 3: Existing Methods of Lumen Measurement

In this chapter, we demonstrate the available method of calculating lumen of LED lights also we will explain our selected method.

Chapter 4: Automation System Mechanism

In this is based on our mechanism of our whole project. There we explain working principle of whole system.

Chapter 5: Effects of Temperature on LED Lights

This chapter is about mechanism of LED lights and temperature effect on LED lights performance.

Chapter 6: Conclusion and Future Work

There we summarized our whole work and discuss our future work also.

Chapter 2
Components Required in the System

2.1 20*4 LCD

A 20*4 LCD is used as the output device of the system. It prints the value of the lumen corresponded to the value of lux. The LCD contains 20 characters wide and4 rows. It shows white text on blue background. There are 16 numbers of pins to be connected and 12 of them are used in this particular project. It has a data bus line containing 8 pins named D0-D7, one data read and write pin, one enable pin, one register select pin, one contrast control pin and rest of the pins are connection pins. It runs by 5V dc power supply and contrast controlling is inversely related to the voltage. The less the voltage is the less the contrast will be.

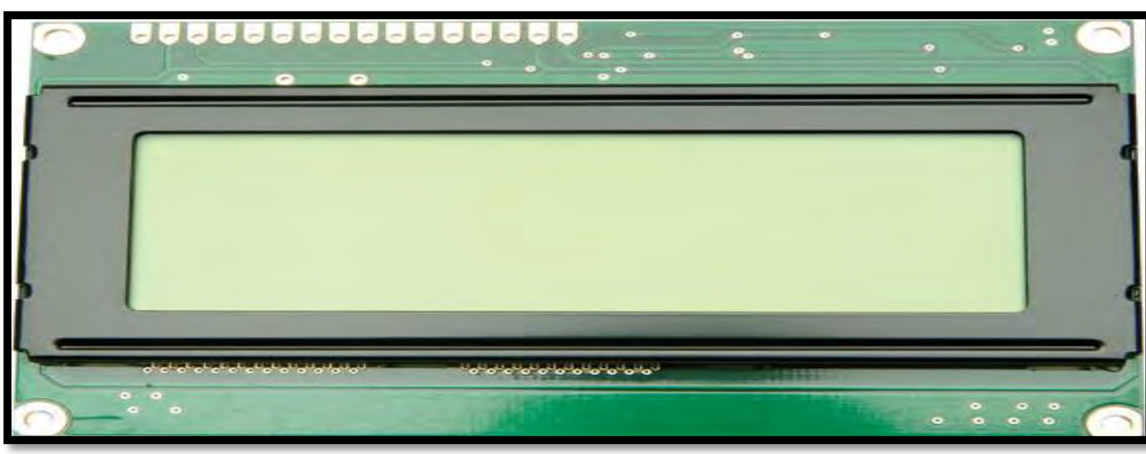


Figure 2: 20x4 LCD Display

2.2 ATmega32A

ATmega32 is a microcontroller unit developed by Atmel. It is a high-performance, low-power Microchip 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 54/69 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for boundary-scan and on-chip debugging/programming, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a universal serial interface (USI) with start condition detector, an 8-channel 10-bit A/D converter, programmable watchdog timer with internal oscillator, SPI serial port, and five software selectable power saving modes. [1] The MCU runs between 1.8-5.5 volts. In this project, 5V dc is used to operate the device.

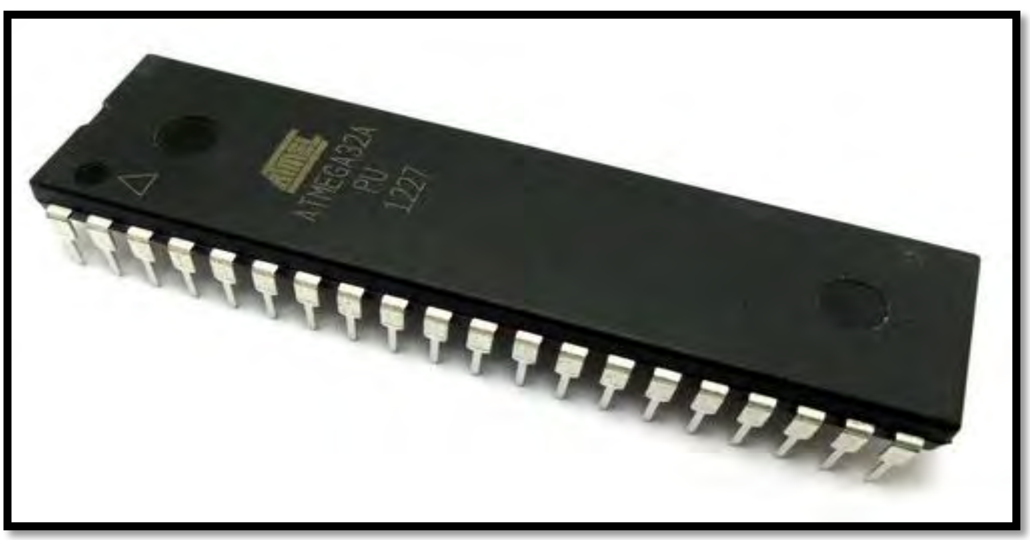


Figure 3: At Mega 32 Chip

2.3 4x4 keypad

4x4 keypad is the inputting device of the system. The lux value will be given to the MCU using the 4*4 keypad. It has 16 buttons containing 4 rows and 4 buttons in each row. The first step to interface the 4*4 keypad is to write all logic 0's to the rows and all logic 1's to the columns. In next, the software has to scan the pins connected to columns of the keypad. If it detects a logic 0 in any one of the columns, then a key is pressed was in that column. Once the column corresponding to the key pressed is located, the next thing that the software has to do is to start writing logic 1's to the rows sequentially (one after the other) and check if the corresponding column becomes high. The logic is that, if a button in that row was pressed, then the value written to that row will be reflected in the corresponding column as they are short circuited.

Figure 4: 4x4 keypad

2.4 The elevator

The construction of the elevator was a challenge. It had to be able to lower the suspended light source up to the designated point. When it was time to test a new source, the device had to elevate it again. The elevator was constructed in a box and fixed at the top of the lid of the cylinder, making sure that the tip of the motor was in the middle of the lid. (Figure [5]) The following components aided in this process.

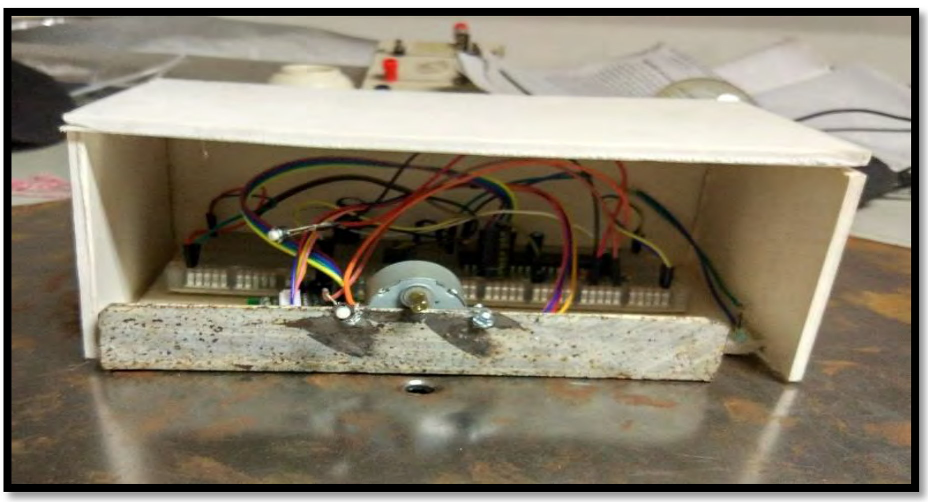


Figure 5: The elevator

2.4.1 Gear stepper motor

An ordinary motor is able to rotate with the help of a commutator seamlessly. Although a lot of well-known equipment use ordinary DC motors to perform heavy duty tasks, in our work we had to use a gear stepper motor to achieve our objective. Unlike the aforementioned motor, a stepper motor can rotate with precision, i.e., the movement and speed can be controlled.

A stepper motor consists of rotor and stator, and the combination of both helps the motor to turn in steps. The main reason for the use of this motor was that it could be programmed to rotate according to the requirement. Through programming the motor, we could lower the LED bulb and raise it. The angle at which the motor rotates is close to 2 degrees, hence the step error remains so low. The gear stepper motor was chosen as it allowed greater control over the revolution of the motor with an increased torque even though the speed was very slow. [13] The slow speed was an advantage as it restricted any sudden movements. When the motor was in motion, the steady speed was responsible for the light to be able to cut the sensor at the bottom. When the motor was not in use, it was able to keep the light holder in place.

2.4.2 Motor driver

The motor driver used was a ULN2003 motor driver. The driver was mounted on a PCB board. It also includes LED indicators lights that indicate the different steps of the motor. The microcontroller functions at a very low current and this is not enough for the motor. This driver amplifies the current of the microcontroller and drives the motor. Only 4 bit command is received from the microcontroller. This can supply a voltage ranging from 5V to 12V.

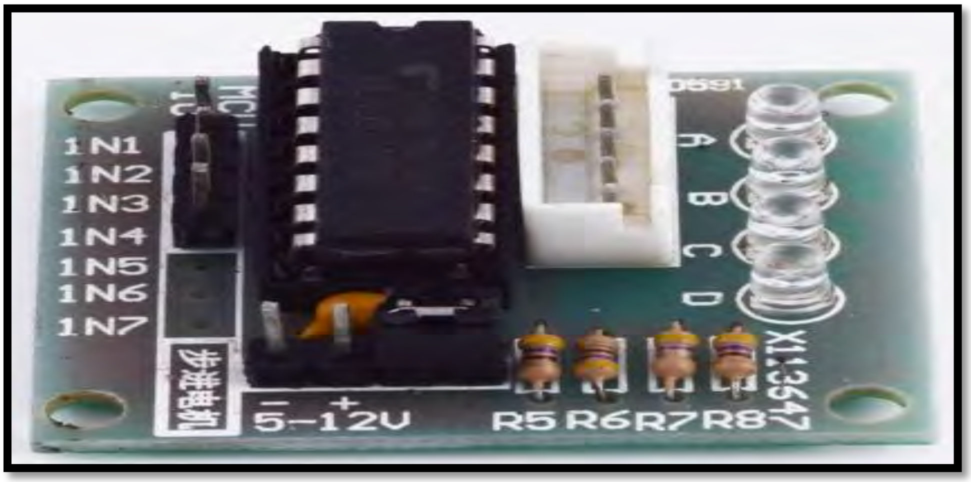


Figure 6: Motor Drive

2.4.3 Sensors

Two sensors were required to run the elevator; one to stop the light source from lowering any further, another to bring it to the top without jeopardizing the motor. Both of the sensors were A HC-SR04 Ultrasonic sensor. The sonar sensor has only four pins (VCC,GND,Trigger and Echo) and this makes it very easy to configure. There is also a transmitter, a receiver and a control circuit. When the sonar sensor is functional, it sends several signals of frequency

40kHz and checks for reflecting pulses. The first sonar sensor was mounted inside the cylinder exactly at 84.5 cm. The range of this sensor was fixed to 40 cm through programming as we had to make sure the distance was less than the diameter of the cylinder. As soon as the light bulb interrupted this sensor, the motor stopped turning.

The purpose of the second sonar sensor was to indicate the top most position the holder can reach and to stop it there. To make this possible the sensor had to be fixed face down under the lid. A circular obstruction was created using a PVC board and fixed with the holder. This sensor detected the obstruction when it came closer, i.e., the highest reachable point, and the feedback from this halted the motor. This sensor had a range of 3 cm.

2.4.4 Additional components

The operation of the motor required a supply of 12V and 2A current. An adapter was used to sustain this supply. Switches were used to control turn the motor in both clockwise and counter clockwise directions. Another switch was used to reset the entire system. A LED bulb was implemented in the circuit to signal when the elevator as stopped.

2.5 Lux Meter

Figure 7: A Lux meter

A Lux meter was required to measure the illuminance of the individual lights. In our experiments we used Lutron LX-1102 Digital Lux Meter. This fixed at the side of the cylinder so that the measured values can be observed easily. It is accompanied by a light sensor separately has a photo diode and color correction filter. The cosine correction allows the sensor to detect the light from an angle. The sensor was placed inside the cylinder directly at the center.

The lux meter is a very portable device that operate with a 9V battery. The range of this meter varies from 40 to 400,000 lux but we only had to use the range of 4000 lux as the highest lux in our experiment was 707 lux. The large LCD display provides a clear reading on the meter. The hold button at the top can be used to freeze the reading. Any zero error can also be adjusted using this meter.[14]

2.6 Others:

Along with the mentioned components breadboards, jumper wires and plastic sheets are used for connection and decoration purpose.

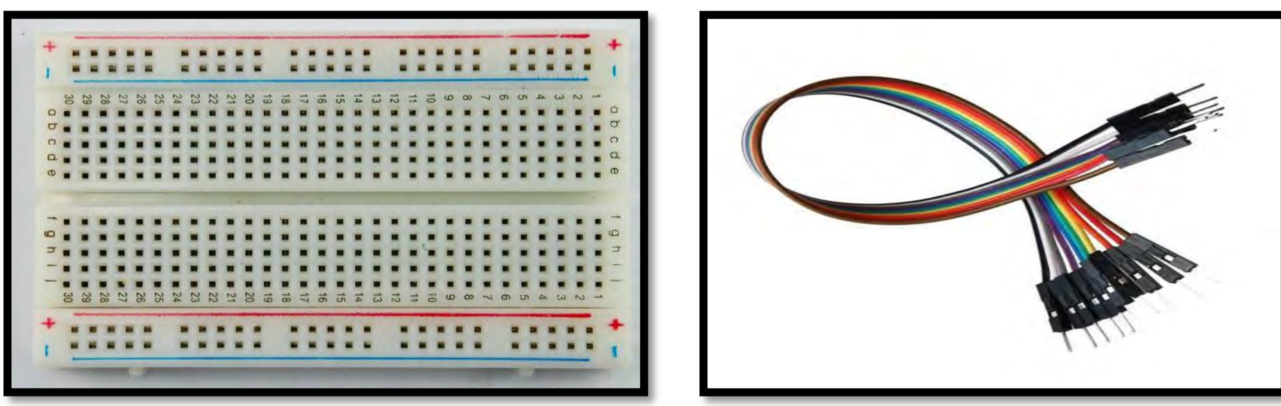


Figure 8: Bread board and jumper

Chapter 3

Existing Methods of Lumen Measurement

3.1 Luminous Measurement Using Hemisphere Method

The luminous flux of led light can be measure by a hemisphere shape cube. This system includes an integrating hemisphere which has a hemisphere shape and an inner wall. The inner wall has a light diffusing material applied. In this method, illuminance of LED light is measure from different point and angle of hemisphere. Goniophotometer is used to measure the illuminance of different point of hemisphere. Goniophotometer is used for measurement of the light emitted from an object at different angles.

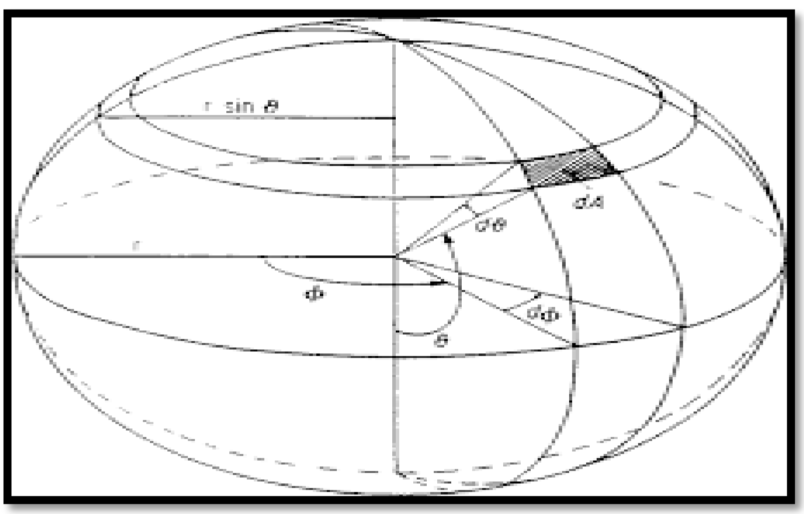


Figure 9: Different axis of hemisphere method [3]

In this method source LED

Light is place in center of the hemisphere, from this point illuminace measured for different location of hemisphere. In this process we calculate illuminace of a small area and we chose the area by changing the meridian angle and parallel angle of the hemisphere. In this case meridian angle (h) is the angle between the plane on which the LED is placed and the goniophotometer head [3]. On the other hand, parallel angle (u) is the angle between the reference axis of the plane and the line along which the goniophotometer.

From the reference journal [3] we know that the source LED lamp is placed on a highly reflective plane of hemisphere, which radius is 1m from the source LED.

Calculation procedure of total Luminous Flux of LED light by hemisphere method is.

An average illuminance E0 (θ, ϕ) is calculated for each meridian angle. [4]

1. E0 (θ, ϕ) is then integrated over the respective meridian interval to give to illuminance E (θ, ϕ) over a small meridian line dl at ϕ°

$EI(\theta, \phi) = \int E0(\theta, \phi) \sin\theta d\theta$ lumen/m2 [4]

2. EI (θ, ϕ) for the different meridian intervals is then summed to give the illuminance $E(\phi)$ over the meridian line.[4]

$E(\phi) = \Sigma EI(\theta, \phi)$

3. E (ϕ) is integrated over 2π to find the total luminous flux, ΦV incident on the surface of the hemisphere. [4]

$\Phi V = \int E(\phi) d\phi$ lumen

3.2 Luminous Flux measurement using Integral Sphere

An Integrated Sphere consisting of a hollow spherical cavity such as an optical tool [3]. Its interior is covered with a diffuse white coating, with holes in both entrance and exit sides. When light comes to one point of the inner surface, it is distributed to all other points by multiple scattering reflections, as well as effects of the direction of the original lights are minimized [3]. An integrated sphere is also can be considered as an optical device which preserves power but also destroys spatial information [3]. It has the advantage over a Goniophotometer for measuring the light which is produced by a source and can obtain the total power using a single measurement [3].

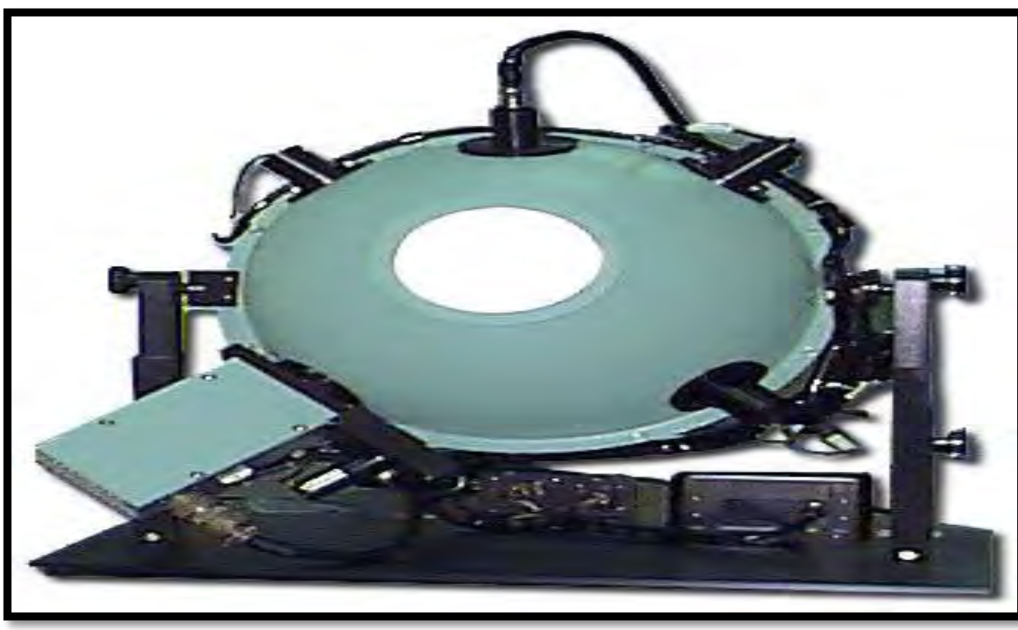


Figure 10: A Commercial integrating sphere

The theory of integrated spheres are based on this two assumptions [3] -

1. Light that hits side of the sphere is scattered in a diffuse way.

2. Only light that has been diffused in the sphere hits the ports or detectors used for probing the light.

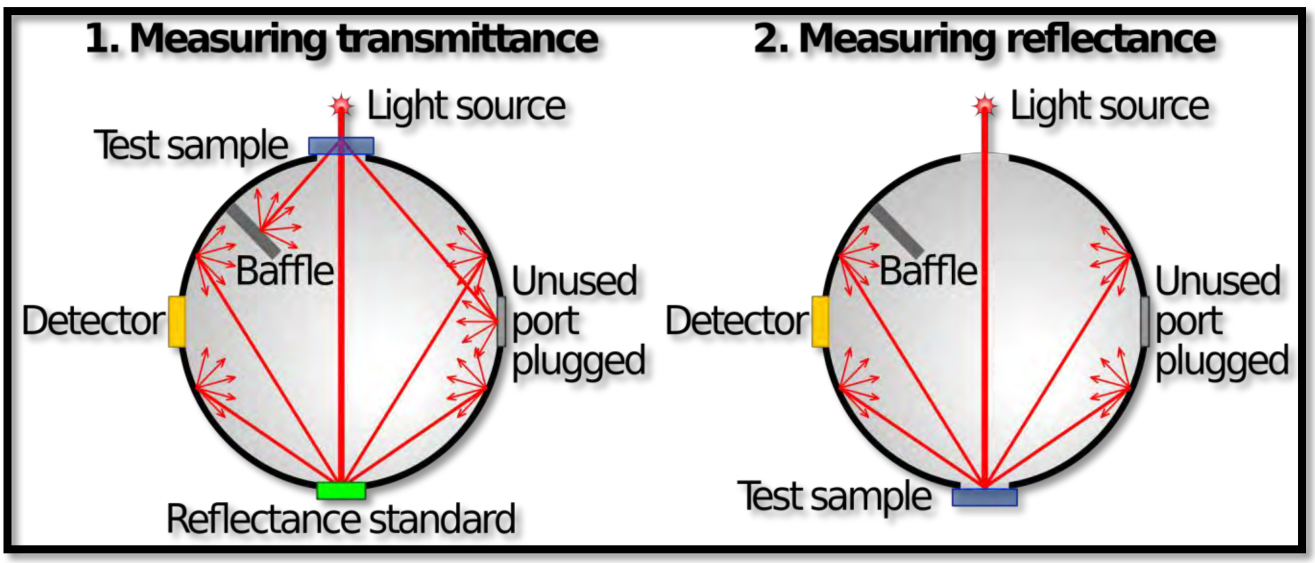


Figure 11: Simplified principle of the use of an integrating sphere

Light scattered is evenly distributed over all angles by the interior by the interior of the integrating sphere. Total power of the source of the light can be measured with high accuracy caused by the directional characteristics of the source [3], or the measurement device. Integrated spheres are used to measure the total light radiated from all angle of the source of the light. Using an average over all angles of illumination and observation, an integrated sphere can measure diffuse reflectance of surface [3]. With a detector connected to an integrating sphere the sum of all the ambient light incident on a small circular aperture can be measured, when all the light incident on the input port is collected [3].

3.3 Luminous Measurement Using Cylindrical Method

In the cylindrical method of luminous measurement, two cylinders had been constructed taking the reference from the previous research. The first cylinder, to be considered as the small cylinder in the rest of the report, was of 50 cm in radius. The second cylinder, which is the medium cylinder, was of 60 cm in radius. From the bottom of the cylinder to the top of the lid, the height of both cylinders was set to 1 meter. The material used to make the body of the cylinder was Polyvinyl Chloride (P.V.C) boards as it was easy to bend into a cylinder. Three metallic rings were used to support the body. The lid was made of metal with a hole exactly at the center big enough for a wire. The stepper motor, that was the part of making the system automatic, was attached at the top of the lid with nuts and bolts securely at point D].Inside the cylinder, two sonar sensors were fixed. The first one was adjusted exactly 84.5 cm from the bottom at point E and the second was placed under the lid, inside the cylinder at point D[Figure 10.The purpose of this sensor will be described in the later sections.

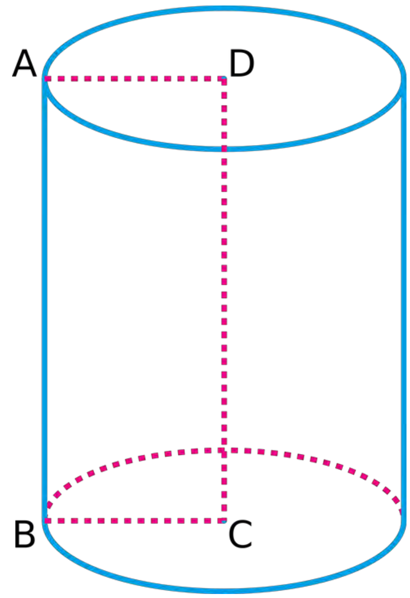


Figure 12: Simplified version of the cylinder

The exterior surface of the cylinder was painted white to make it reflective, while black paint was used to cover the interior surface to make it an absorbent surface. The bottom part of the cylinder was also made of a replaceable metallic lid with a hole at point C. The hole was kept to insert the photoconductor to measure the lux of the light. Light is incident on the photoconductor at one angle, directly below the light source. It is not reflected from any other surface as light is absorbed by the black coating. Taking the reading from the lux meter the value is inserted to the keypad. The keypad showed the output, that is, the lumen of the corresponding bulb. The value of lumen that is obtained from this method has an accuracy of ±5 %. This is a tremendous improvement as this method is less costly to make, and most importantly, accurate. The next chapter will describe detailed procedure of the cylindrical method and how this is useful in terms of efficacy and efficiency.

Chapter 4

Automation System Mechanism

4.1 Introduction

For a developing country like Bangladesh, both efficiency and cost effectiveness are major parameters. It is impracticable to exclude or ignore any of them. To ensure industrial production quality as well as for accurate commercial usage, low cost efficient method for lumen measurement of a LED bulb is very much essential in all developing countries. On the other note, this low cost efficient method can be adopted by the developed countries as well. As a result, the expensive measuring devices and methods will be replaced and the cost of quality/efficiency will be reduced which will minimize the production cost of LED bulbs. The retail price of LED bulbs will decrease in consequence of the minimized production cost. So, the affordability of LED bulb will increase. As mentioned in earlier chapter, the entire device is a low-cost device. We have used the equation of a straight line written in microcontroller where we have only one variable (LUX) which value will be retrieved from sensors and that will be putted manually into the equation using keypad. The microcontroller will process the equation then and show the output into LCD display. Another automation process is done which will keep the height of the LED constant from the photo conducting sensor.

4.2 Hardware

4.2.1 Equation

It was important to derive equations for both the small and medium cylinders so that we are able to test LED bulbs of any rated values. The equations were derived in the previous research. At first two LED bulbs and a LED tube was used. Only the small cylinder was used to find the luminous flux. Each of the lamp was placed in the middle of the cylinder and the illuminance was measured. The rated value measured form the hemisphere method of the individual lamps was taken as references, and through the following equations the luminous flux of the tested lamps were calculated.

$\phi V = EindV * k$ [1]

$k = \phi N / EindN$ [2]

In these equations is the luminous flux of the reference lamp and ϕV is the luminous flux of the tested lamp. The variables EindN(illuminance of the luminous flux ϕN) and EindV(illuminance of luminous flux ϕV)[3] were measured using the LUX[4] meter. Here, k was the shape factor of the cylinder.

These data were inserted in equation 2 and k was calculated. After taking an average of the three values, through equation 1 the luminous flux was figured out. It was observed that the deviation of the rated and the tested luminous flux remained within ±5 %. This proved the method to be and effective and hence a graphical analysis was made to derive the equation.

Several readings were required to plot a graph of the correlation of the rated lumen vs lux. For the small cylinder, the illuminances of 4 LED lamps were measured and for the medium cylinder, the illuminances of 6 LED lamps were measured. The value that was considered to rated was the value of the luminous flux obtained from goniophotometer method. After plotting the values of lux in the x-axis and the rated lumen in the y-axis in MATLAB, a linear curve was obtained for both the cylinders. Following equations that have been derived:

1. **For the small cylinder: Total luminous flux =3.9 * illuminance+ 98:3**[5]
2. **For the Medium cylinder: Total luminous flux =6.08* illuminance - 37.7**[6]

In equation 1, 3.9 is the k factor and 98.3 is the offset value. Similarly, in equation 2, 6.08 is the k factor and -37.7 is the offset value.

4.2.2Automation of LED light's Height Adjustment

4.2.2.1 Why it is important

In our tests, we have chosen to use LED bulbs manufactured in Bangladesh specifically. During our experiments with the cylinder we have noticed that the size of the bulbs varied. The table [1] lists the different types of bulbs we have used and how much the lengths differ from each other.

Name of bulb	Rated Power(watt)	Length(cm)
Superstar	15	15
Superstar	12	15
Superstar	9	13
Superstar	7	11
Superstar	5	11
EnergyPac	15	12.5
EnergyPac	12	14
Click	15	14
Click	11	11.5
Transtec	13	11.5
Transtec	7	10.5
Philips	12	11
Philips	9	10
Sparkle	18	15

Table 1: Height of the sample LED light

It can be seen that despite having the same rated power of 15W, the lengths of the bulbs of different companies are not the same. For the bulbs of the brand Superstar, there was also a significant decrease in size as the rated power decreased. At first, we carried out our experiments without maintaining the same height. It was observed that the percentage error of the lumens of every LED lights was inconsistent. Then we started to hold the position of the bulbs in such a way that the distance of the bottom of all the bulbs and the light sensor placed at the bottom were approximately the same. Through extensive tests of trial and error it was resolved that keeping the tip of the bulbs at a height of 84.5 cm from the bottom of the cylinder, the luminous flux measured was accurate. Initially we have faced some difficulties to maintain this height. After adjusting the bulb, we had to go inside the cylinder and using a ruler of 1 meter we adjusted the height. This task required the help of at least two people and was quite a hassle. Even then the height may not have been accurate due to human error. So, it was necessary for us to devise a plan to control the height of the LED bulbs without any disturbance, and most importantly, precisely.

4.2.2.2 Step for fix LED light's height

The devices that were used to make the adjustment of height are as follows:

1. **Sonar sensor**
2. **A stepper motor**
3. **A Microcontroller**

As mentioned before, a sonar sensor was fitted inside the cylinder. This sensor can send and receive ultrasonic signals. If there is any obstacle, the sonar sensor is able to detect that. In our test, the LED bulb was the obstacle. It would have been quite impossible to know where the bulb should be placed. The purpose of this sensor was to signal when the bulb is at the desired height. The feedback of the sensor was received by the Arduino board as an interrupt. The stepper motor was used to elevate or lower the bulb. Basically, a stepper motor is a DC motor that can be used to control the displacement and speed. When the stepper motor is turned on, it will continue to lower the bulb until it reaches the sonar sensor. As soon as the height was reached, the sensor was activated, and the bulb would stop there. The elevator box would indicate this with a blue light. In this way the bulb was adjusted accurately.

When it was time to raise the holder to replace a new bulb, and button was pushed to lift it. When the holder had reached the top, the second sensor would prevent the holder from going any further. Hence, the user would not have to be concerned about the motor stressing.

4.2.2.3 Code for Arduino Pro Mini

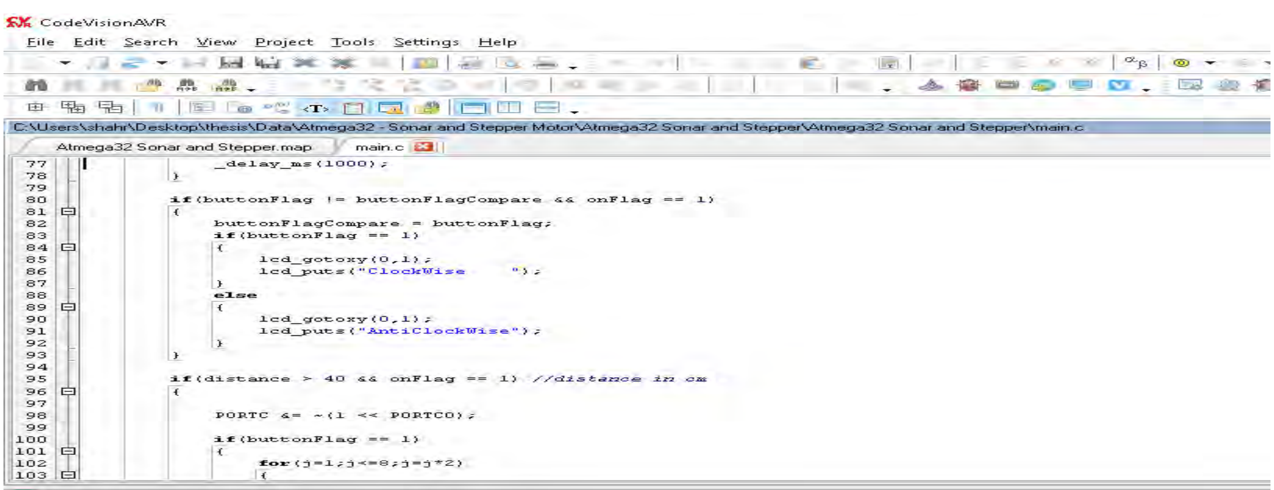
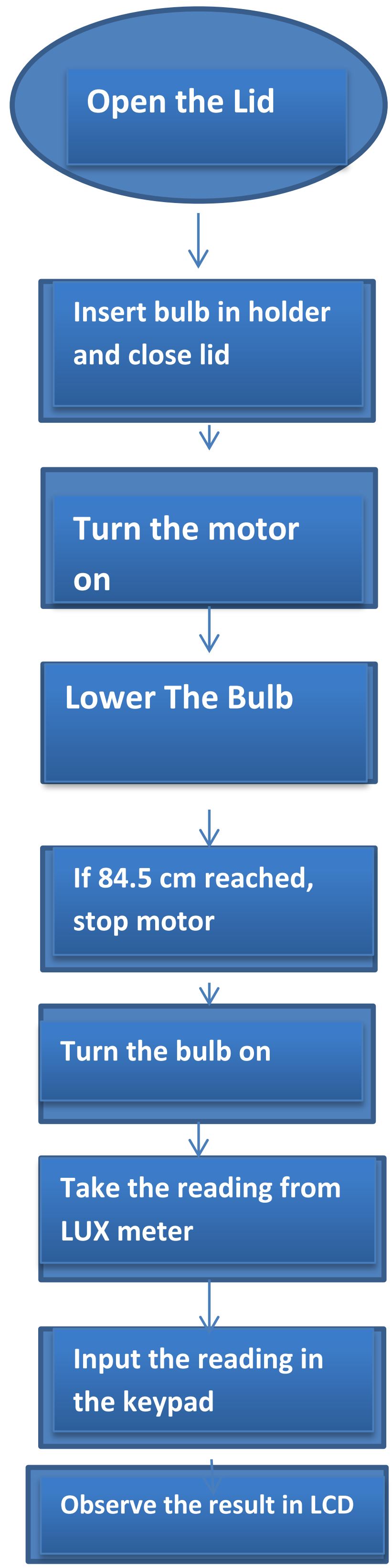


Figure 13: Code of Stepper motor

4.2.3 Overall process



To measure the luminous intensity, some steps had to be followed. At first the lid was opened and the bulb inserted in the holder. After the lid was closed, the chain was pulled up so that the holder touched the lid and then the stepper motor was turned on. The motor began to lower the bulb up to the point where the IR sensor was placed. When the motor stopped, the light was turned on and the reading on the lux meter was typed on the keypad. Finally the LCD display showed the value of the lumen of that certain bulb.

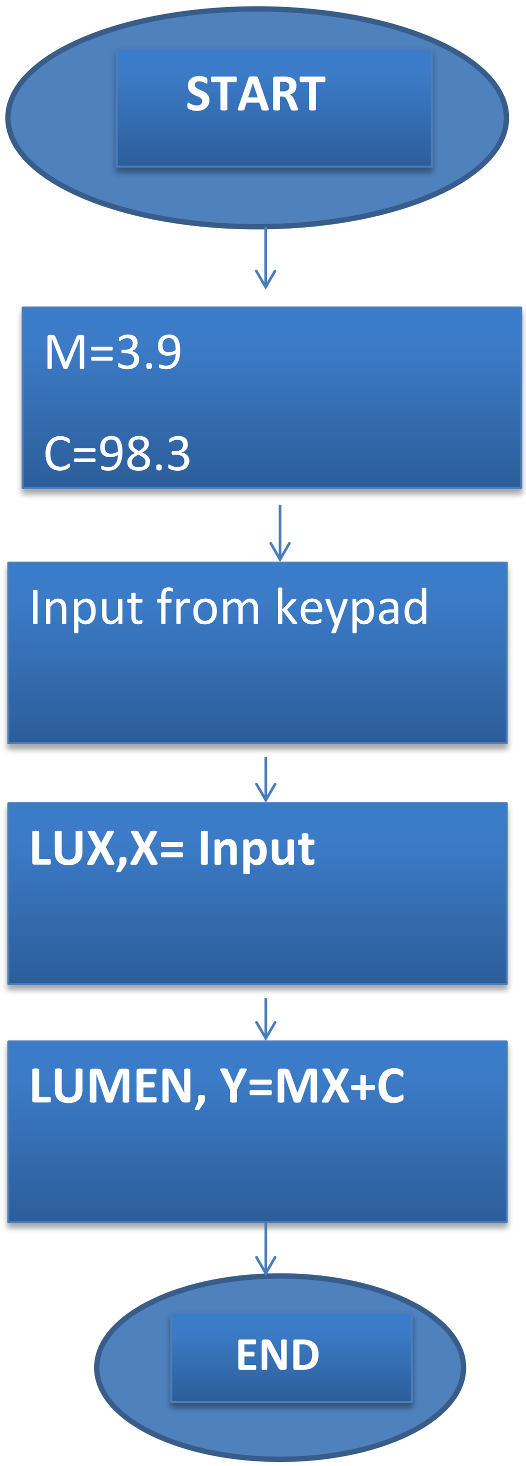
4.3 Software

4.3.1 Code for AVR Atmega32A

As the ATMega32A chip is been used as the data processing unit of the system, an algorithm is developed and according to the algorithm the code is build. For coding purpose Atmel Studio 7.0 has been used. The equation which is used to convert the LUX value to LUMEN value is, Y=MX+C [8]. Here Y is the lumen value, X is the lux value, m and c are constants. At the beginning of the code the port/pin initialized. Then the variables are declared. After declaring the variables, the values of constant M and constant C are put. They are, M = 3.9 and C = 98.3. Thereafter, it is checked that whether the buttons are pressed or not. If the value is given by using keypad then it will be saved in X. Then the value of X will be used and the Y value will be printed which is the lumen of the tested LED.

4.3.2 Block Diagram

The block diagram of the code is given below:



4.3.3 Simulation

The next part is the testing of the code by simulation. Proteus 7 Professional is used for the purpose of simulation. At first, the circuit was designed. Thereafter the code is given inside the microcontroller of the circuit and the code runs perfectly.

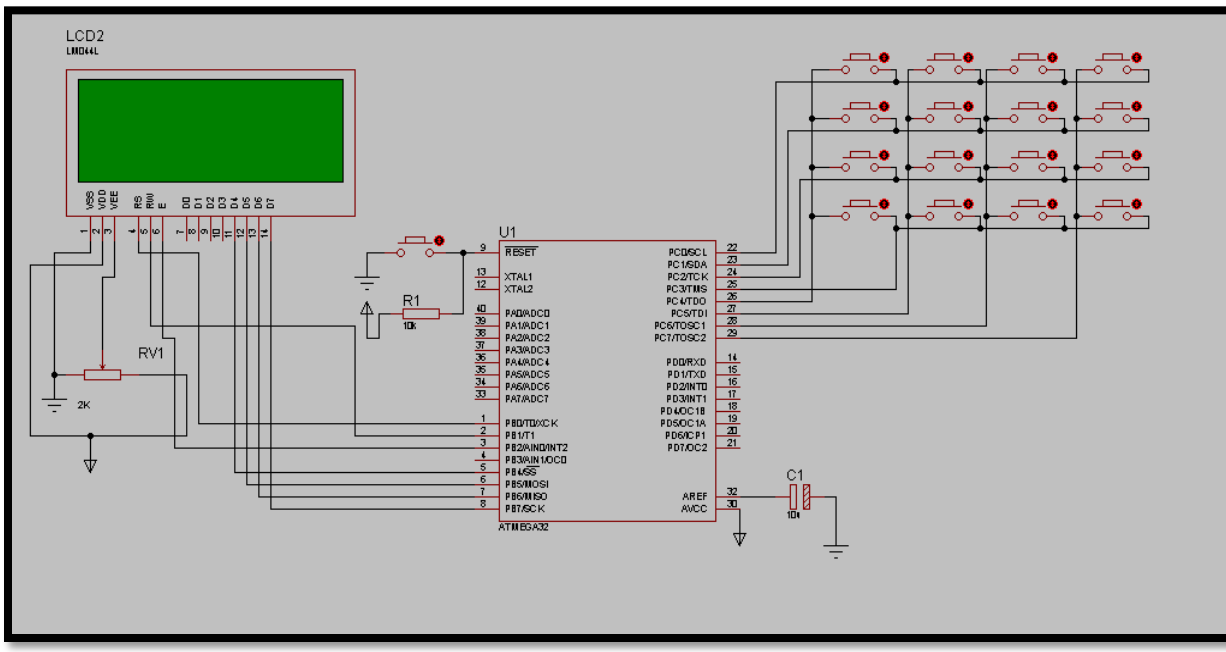


Figure 14: Circuit diagram for AVR and Keypad

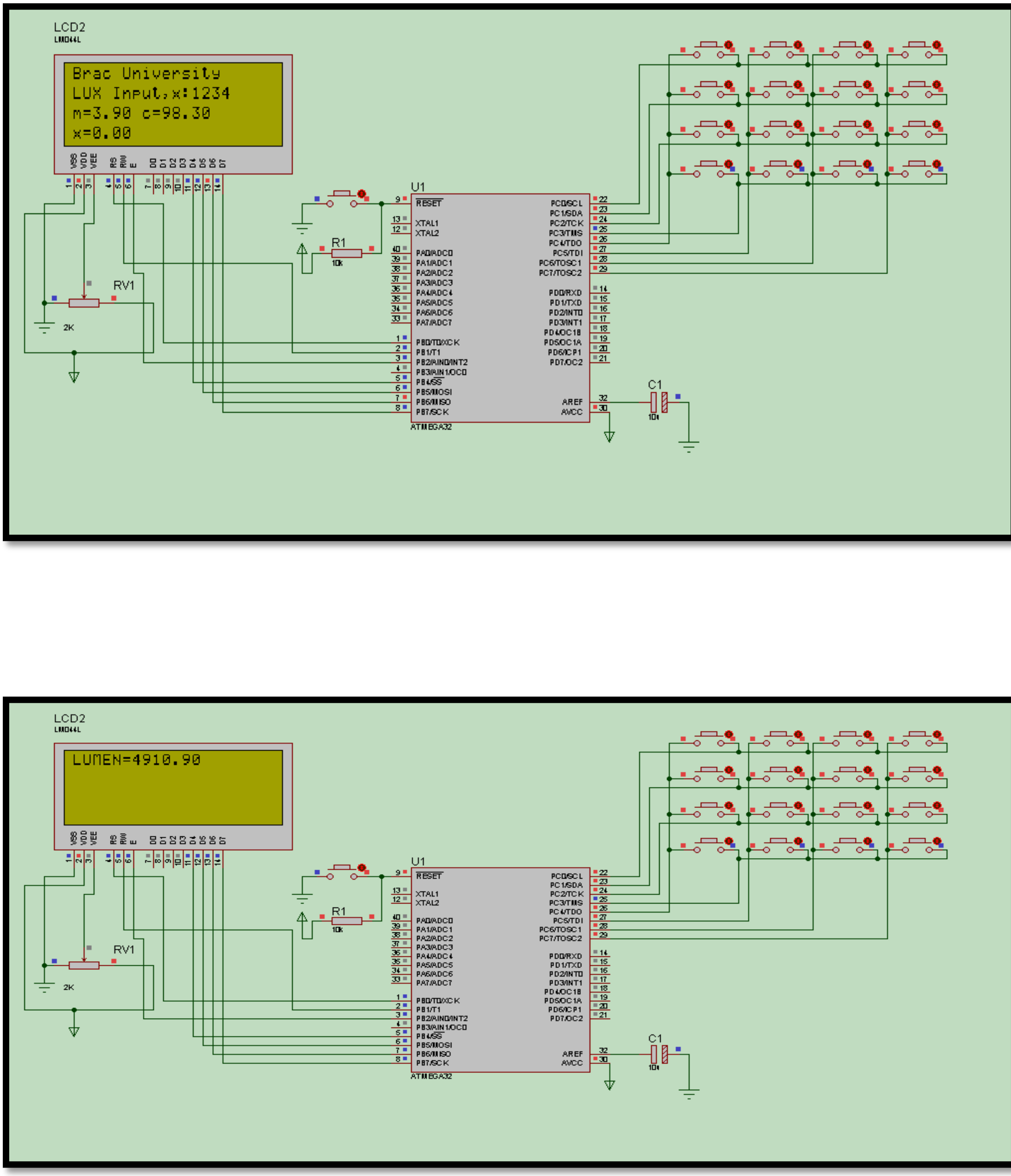


Figure 15: Working Circuit

4.3.4 Implementation

After the successful simulation next part is the implementation of the circuit and burning of the code into microcontroller. For burning purpose, the Extreme Burner 1.3 is used. By using the components mentioned in earlier chapter, the full circuit is build. A PCB is designed according to the simulation file and using that, the full circuit is implemented and covered by a box. When the full setup is completed it is mounted to the wall of the cylinder.

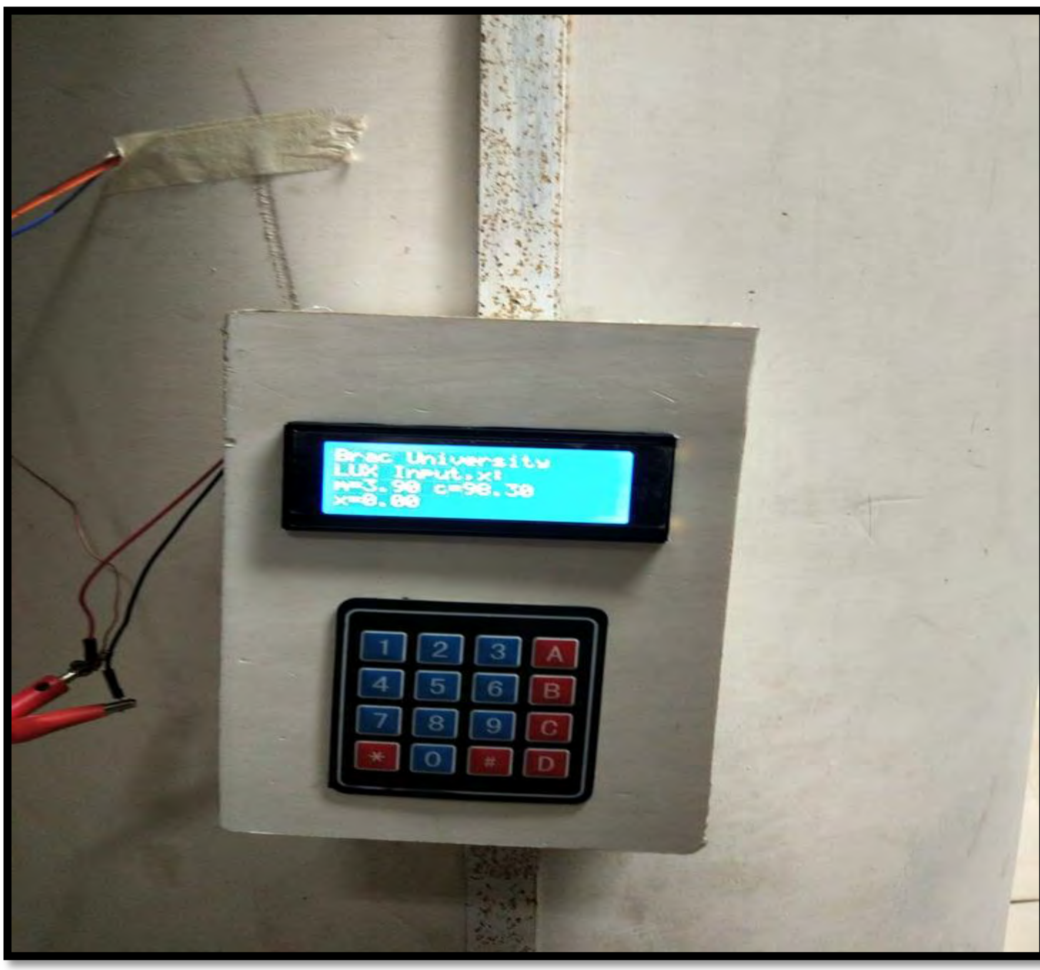


Figure 16: Keypad box

4.3.5 Input/output

Basically, this is the calculation part by which the code is being executed or the Lux value is transforming into Lumen value.

Equation: Y(LUMEN)=M*X(LUX)+C

Where, M=3.9, C=98.3

Let, X(Lux) value=1234 Lux

So, Y(lumen)=3.9*1234+98.3

=4910.90 Lumen

Here, the input is the lux value which is being got from the reading of lux-meter. Then the lumen value is being calculated using the lux value in the microcontroller by the straight-line equation. Thereafter, the output will be got which is Lumen value and will be displayed to the LCD.

4.4 Result

Data before Automation:

Name	Watt	Rated Lumen	Experiment Lux	Experiment Lumen	Error
Super Star	15	1350	305	1287.8	-4.607407407
Super Star	12	1105	222	964.1	-12.75113122
Super Star	9	839	180	800.3	-4.612634088
Super Star	5	483	99.2	485.18	0.451345756
Energypac	15	1500	370.6	1543.64	2.909333333
Energypac	12	1100	272	1159.1	5.372727273
Transtac	13	1300	324	1361.9	4.761538462
Transtac	7	630	143.2	656.78	4.250793651
Click	11	1000	277	1178.6	17.86
Click	15	1500	307.7	1298.33	-13.44466667
Phillips	12	1200	429	1771.4	47.61666667
Phillips	9	825	301	1272.2	54.20606061
Sparkel	18	1710	707	2855.6	66.99415205

Table 2: Date before Automation

Data after Automation:

Name	Watt	Rated Lumen	Experiment Lux	Experiment Lumen	Error
Super Star	12	1105	231.6	1001.54	-9.362895928
Super Star	9	839	180.9	803.81	-4.194278903
Super Star	7	630	141.3	649.37	3.07
Super Star	5	483	97	476.6	-1.32505176
Energypac	15	1500	369	1537.4	2.493333333
Energypac	12	1100	290	1229.3	11.75454545
Transtac	13	1300	334.8	1404.02	8.001538462
Transtac	7	630	140.8	647.42	2.765079365
Click	11	1000	290.2	1230.08	23.008
Click	15	1500	337	1412.6	-5.826666667
Phillips	12	1200	457	1880.6	56.71666667
Phillips	9	825	299	1264.4	53.26060606
Sparkel	18	1710	763	3074	79.76608187

Table 3: Date after Automation

Average Error Percentage:

Name	Watt	Error After Automation	Initial Error	Difference of error
Super Star	12	-9.362895928	-12.7511	3.39
Super Star	9	-4.194278903	-4.61263	0.42
Super Star	7	3.07	1.031746	2.04
Super Star	5	-1.32505176	0.451346	1.77
Energypac	15	2.493333333	2.909333	0.41
Energypac	12	11.75454545	5.372727	6.39
Transtac	13	8.001538462	4.761538	3.24
Transtac	7	2.765079365	4.250794	1.485
Click	11	23.008	17.86	5.14
Click	15	-5.826666667	-13.4447	7.63
Phillips	12	56.71666667	47.61667	9.1
Phillips	9	53.26060606	54.20606	0.94
Sparkel	18	79.76608187	66.99415	12.772
				Total: 54.727
				Average Error : 4.209

Table 4: Average Error

4.5 Budget

Name of the Component	Quantity	Unit Price(TK)	Total Price (TK)
Lux Meter	1	8000	8000
Cylinder	1	6000	6000
4*4 Keypad	1	102	102
LCD Display	1	350	350
Steeper Motor & Driver	1	1200	1200
Upper and lower lid of the cylinder	2	1100	2200
Atmega32A	1	202	202
Arduino Pro Mini	1	450	450
Sonar Sensor	2	130	260
PVC board	3	150	450
5 V and 1 amp Power Supply	1	130	130
Bread Board	3	110	330
Light holder and wire	1	150	150
Registers		30	30
Paint		1000	1000
Labor Cost		500	500
Others			646
			Total= 22000 TK($260)

Table 5: Approximate cost

This Project will cost around 22000 TK ($260).

4.6 Conclusion

The main objective of this method was to reduce the cost of the entire process. Starting from the construction of the cylinder to implementing the code and making the automated height adjustment device, the expense was nothing close to the cost of the goniophotometer method. The cylinder was also very easy to make.

Chapter 5

Effects of Temperature on LED Lights

5.1 Working Principle of LED Lights

LED stands for Light Emitting Diode, which is basically a small light producing device that can be considered under active semiconductor electronic elements [16]. A Light Emitting Diode (LED) is one of the latest inventions and it is widely used now a days. The extensive use of these bulbs can be observed from our cell phones to large advertising display boards. Due to some exclusive features their popularity and application is rapidly increasing, specifically LEDs are very small in size and very efficient in sense of very low power consuming. A light-emitting diode is a two-lead semiconductor light source [16]. It is a p–n junction diode that emits light when activated [15]. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons [15]. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. Basically, a light-emitting diode is a two-lead semiconductor light source [15]. It is a p–n junction diode that emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons [16]. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

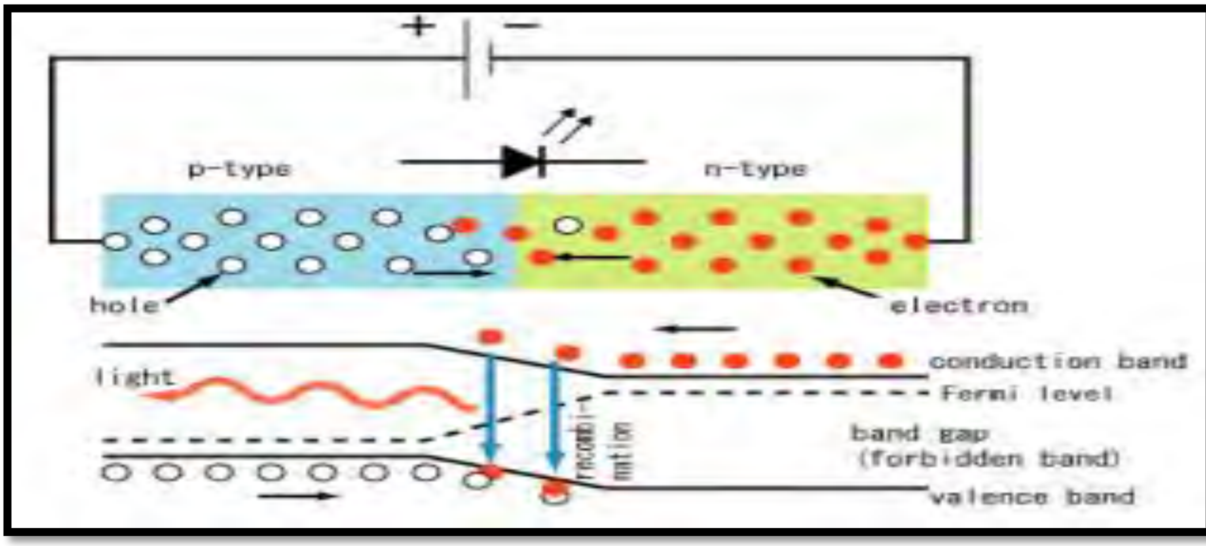


Figure 17: Working Principle of P-N Junction of LEDs

5.2 Relation between semiconductor and heat

Semiconductors are materials which have conductivity between conductors and insulators. Semiconductors can be pure elements, such as Si or Ge, or compounds such as GaAs or CdSe. In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material [10].

From semiconductor band structure we came to know that the outermost band of electrons, the valence band is completely full. As there is no empty spaces, no conduction occur if voltage is applied. The valence band electrons in the semiconductor need a small amount of external energy in the form of heat in order to jump from valence band to the conduction band.[9]

At zero temperature, all the valence electrons stay around the nucleus of an atom. At that time, there are no free electrons present in the conduction band, which help carry electric current from one place to another place. Therefore, the semiconductor behaves as a perfect insulator at absolute zero temperature.

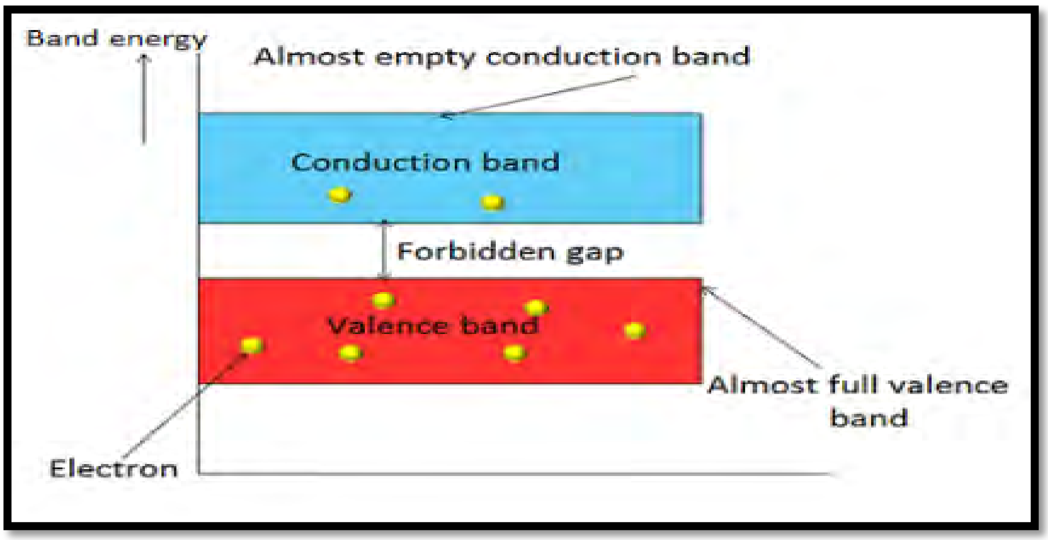


Figure 18: Band gap of semiconductor at 0° C[8]

When the temperature is increased from zero temperature, at that time some of the valence band electrons gain enough energy and they jumps into the conduction band. Those conduction band electrons are called as free electrons. When electrons leave the valence band for conduction band that time some empty space created at the electron position in the valence band. This empty space is called as hole.

Both the free electrons in the conduction and holes in the valence band are generated at the same time. The free electrons carry the negative charge or electric current from one place to another place in the conduction band whereas the holes carry the positive charge or electric current from one place to another place in the valence band.

Moreover if we applied more temperature or heat on the semiconductor it will increase number of empty space in valance band and they will jump into the conduction band. As a result it will increase in number of free electrons in the conduction band. Thus, a small increase in heat generates more number of charge carriers.

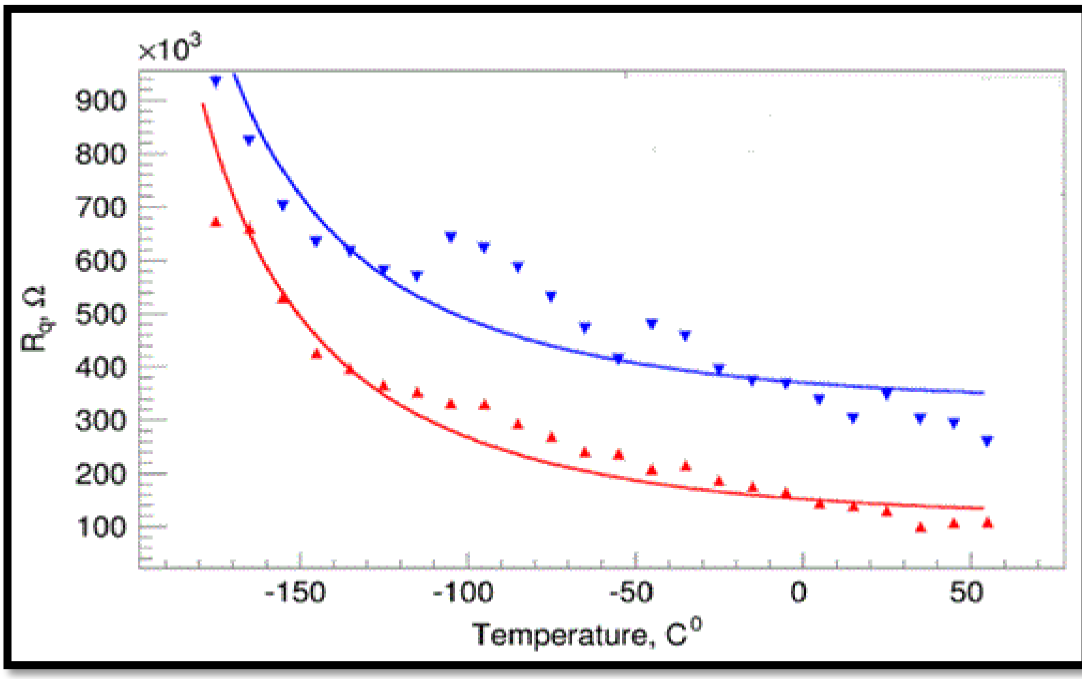


Figure 19: Relation between Temperature and Resistance

So increase of the heat increases the vibrations of atoms in the semiconductor. However, the vibrating atoms in the semiconductor oppose only few electrons and the remaining large number of electrons flows freely from one place to another place. This results, increase in current flow in the semiconductor [5]. The increase in current flow means decrease in the resistance. Thus, the electric current in the semiconductor increases with the increase in temperature

5.3 Impact of Temperature on Efficiency of LED Lights

In general, the cooler the environment, the higher an LED's light output will be. Higher temperatures generally reduce light output [6]. In warmer environments and at higher currents, the temperature of the semiconducting element increases. The light output of an LED for a constant current varies as a function of its junction temperature. Figure 1 [6] shows the light output of several LEDs as a function of junction temperature. The temperature dependence is much less for InGaN LEDs (e.g., blue, green, white) than for AlGaInP LEDs (e.g., red and yellow). Data are normalized to 100% at a junction temperature of 25°C

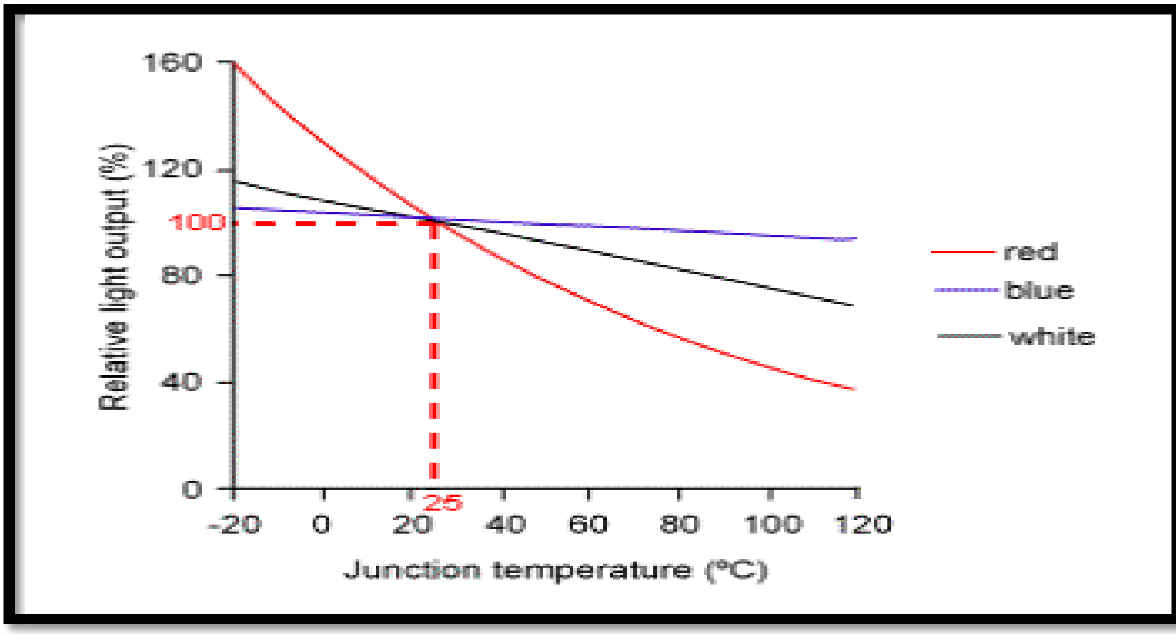


Figure 20: Relative light output of red, blue and phosphor-converted White LEDs as a function of the junction temperature [6].

Some system manufacturers include a compensation circuit that adjusts the current through the LED to maintain constant light output for various ambient temperatures. This can result in overdriving LEDs in some systems during extended periods of high ambient temperature, potentially shortening their useful life [6].

Most LED manufacturers publish curves similar to those in Figure 1 for their products, and the precise relationships for various products will be different. It is important to note that many of these graphs show light output as a function of junction temperature and not ambient temperature [9]. An LED operating in an ambient environment at normal room temperature (between 20°C and 25°C) and at manufacturer-recommended currents can have much higher junction temperatures, such as 60°C to 80°C [9].

Controlling the temperature of an LED is, therefore, one of the most important aspects of optimum performance of LED systems [6].

5.4 Sample LED Light's Experiment Data

company name	watt	Lumen - 23 ◦C	Lumen - 24 ◦C	Lumen -28 ◦C	Lumen - 32 ◦C	Lumen - 35 ◦C	Lumen - 38 ◦C	Lumen - 37 ◦C	Lumen - 39 ◦C
Energypac	12	1480		1335	1305				
Transtec	13		1764	1527			1438		
Click	11		1115	1020			982		
Sparkle	18		1386	1351					1260
Super Star	5		666	585					
Super Star	15	637				620			
Phillips	9	264						236	

Table 6: Relation between lumen and temperature

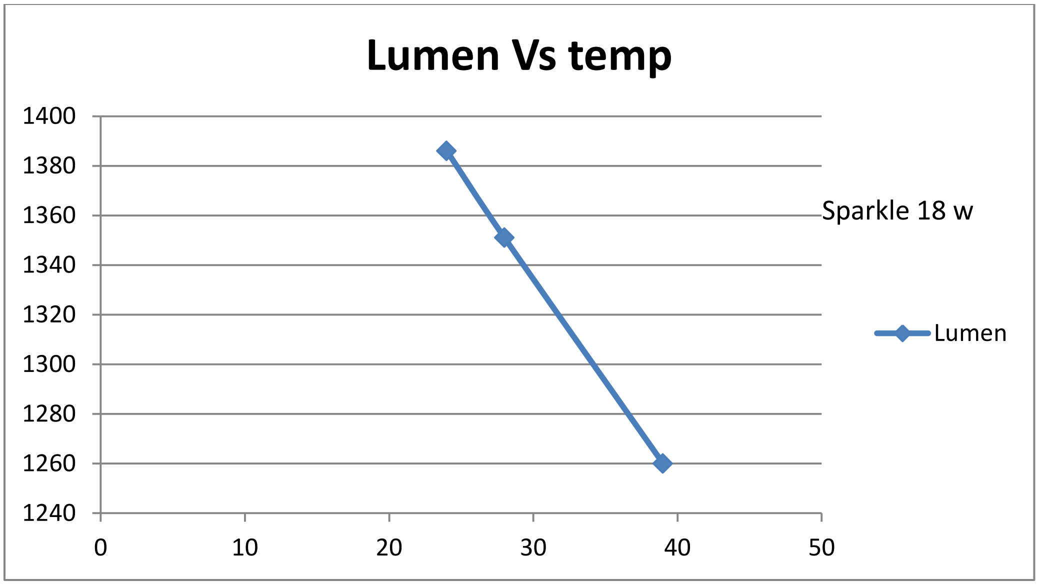


Figure 21: Lumen VS Temperature Graph for Sparkle Light

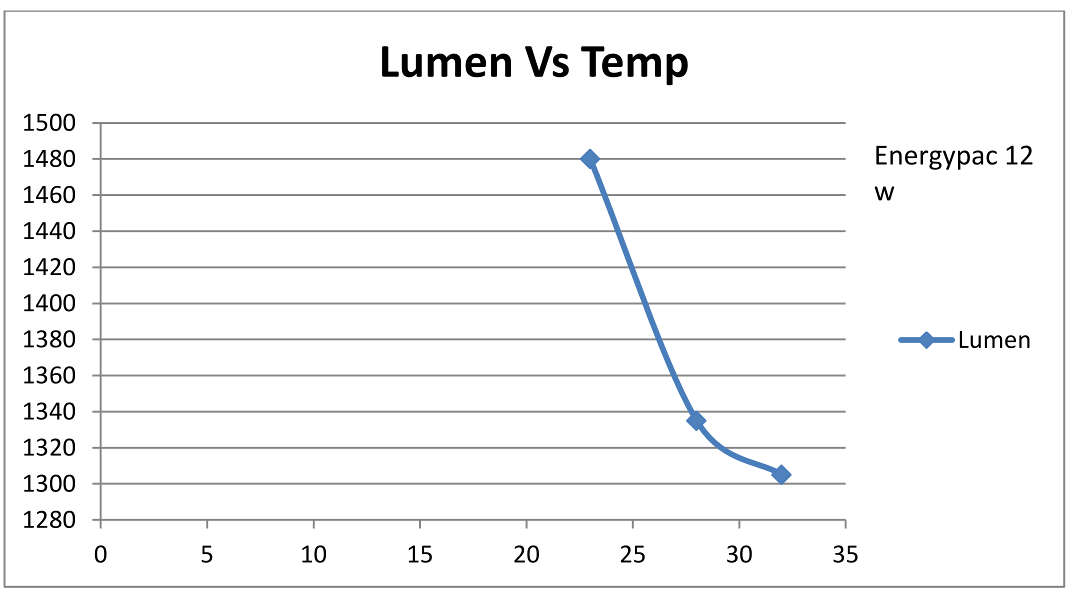


Figure 22: Lumen VS Temperature Graph for Energypac Light

Chapter 6
Conclusion & Future Work

Our main objective of this project was to make an automatic system that can measure LED light's lumen by cylindrical method. Also our focuses were to make the system both efficient and low cost. Our system is both efficient and low cost compare to the other systems that are available to measure lumen of LED light's in the market.

In recent day LED light become very famous in our country as it is low powered and performance of the light is good compare to CFL and tube lights. For that reason there are many company starts to produce LED light. But most of them did not ensure the quality of the product. The main reason behind this is, available systems are complex and very costly. Many small companies could not import it from country like China or Japan due to low budget. This is the main motivation for us to make our system cost efficient so that small company can use our product to ensure the standard of the product. So that people of our country can get a good quality LED lights.

After analyzing the result that we have got in our work we see that our system gives us error of ±5% from its rated value. Therefore we can say that our "Semi-Automatic System of Lumen Measurement of LED Lights in an Embedded Box" also ensure its quality and efficiency, which is most important for any product.

One of the major drawbacks of our system is that it cannot measure the lumen of bigger LED lights and LED tube lights. As our cylinder is 1m long and its diameter is 50 cm for this reason we could not fit bigger lights. From our calculation we see that we can only measure less the 16 cm long lights in our small cylinder In future we will develop this system in medium cylinder and big cylinder so that we can overcome this problem.

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Appendix

Appendix 1: Code for Steeper Motor and Sonar sensor

```
#include <Stepper.h>
#define STEPS 32

int up_pin = 2;
int dwn_pin = 3;

#define trigPin_up 4
#define echoPin_up 5

#define trigPin_dwn 6
#define echoPin_dwn 7

Stepper stepper(STEPS, 8, 10, 9, 11); //In1, In3, In2, In4 in the sequencee 1-3-2-4

int up_led = 12;
int dwn_led = 13;

bool up_state = false;
bool dwn_state = false;

float up;
float dwn;

float up_set = 5.9;
float dwn_set = 5.6;
```

```
void setup()
{
  Serial.begin(9600);
  stepper.setSpeed(200);

  pinMode(trigPin_up, OUTPUT);
  pinMode(echoPin_up, INPUT);

  pinMode(trigPin_dwn, OUTPUT);
  pinMode(echoPin_dwn, INPUT);

  pinMode(up_led, OUTPUT);
  pinMode(dwn_led, OUTPUT);

  pinMode(up_pin, INPUT);
  pinMode(dwn_pin, INPUT);

  up_fun();

  attachInterrupt(0, up_fun, RISING);
  attachInterrupt(1, dwn_fun, RISING);
}

void loop()
{
  dwn = distance_cm(trigPin_dwn, echoPin_dwn);
  up = distance_cm(trigPin_up, echoPin_up);

  Serial.print(up);
  Serial.print(" ");
```

```
  Serial.println(dwn);

  if (dwn_state == true && up_state == false)
  {
   while (dwn > dwn_set)
   {
     digitalWrite(dwn_led, LOW);
     stepper.step(300);
     delay(50);
     digitalWrite(dwn_led, HIGH);
     delay(50);
     dwn = distance_cm(trigPin_dwn, echoPin_dwn);
     Serial.print(dwn);
     Serial.println(" While_DWN");
   }
  }
  if (dwn_state == false && up_state == true)
  {
   while (up > up_set)
   {
     digitalWrite(up_led, LOW);
     stepper.step(-300);
     delay(50);
     digitalWrite(up_led, HIGH);
     delay(50);
     up = distance_cm(trigPin_up, echoPin_up);
     Serial.print(up);
     Serial.println(" While_UP");
   }
  }
}
```

```
void up_fun()
{
  digitalWrite(up_led, HIGH);
  digitalWrite(dwn_led, LOW);
  up_state = true;
  dwn_state = false;
}

void dwn_fun()
{
  digitalWrite(dwn_led, HIGH);
  digitalWrite(up_led, LOW);
  dwn_state = true;
  up_state = false;
}
float distance_cm(int trigPin, int echoPin)
{
  float duration, distance;
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = (duration/2) / 29.1;
  return distance;
}
```

Appendix 2: Code for LCD

```
/*

 * GccApplication1.c

 *

 * Created: 2/9/2018 3:54:59 PM

 * Author : SHAFIUL & AFTAHEE

 */

#define F_CPU 8000000UL

#include <avr/io.h>

#include <string.h>

#include <stdlib.h>




/*Defines a macro for the delay.h header file. F_CPU is the microcontroller frequency value for the
delay.h header file. Default value of F_CPU in delay.h header file is 1000000(1MHz)*/


#include <util/delay.h>

/*Includes delay.h header file which defines two functions, _delay_ms (millisecond delay) and
_delay_us (microsecond delay)*/


#define          KEYPAD_PORT               PORTC

/*KEYPAD_PORT is the microcontroller PORT Register to which 4X4 keypad is connected. Here it is
connected to PORTC*/
```

```
#define KEYPAD_PIN PINC
/*KEYPAD_PIN is the microcontroller PIN Register to which 4X4 keypad is connected. Here it is
connected to PINC*/


/*4X4 Keypad Function Declarations*/
unsigned char read_keypad(void);



int main(void)
{

	_Bool keyPress = 0,de_point = 0,doMath = 0;
	uint8_t keyValue = 0,index=0;
	unsigned char keyString[8];
	unsigned char buffer[10],temp[8];

	float y=0.0,m=0.0,x=0.0,c=0.0;

	DDRC=0x0f;
	/*PortC's upper 4 bits are declared input and lower 4 bits are declared output(4x4 Keypad is
connected)*/

	PORTC=0xff;
	/*PortC's lower 4 bits are given high value and pull-up are enabled for upper 4 bits*/
```

```
unsigned char keypad_value;
/*Variable declarations*/


lcd_init();
lcd_clr();


lcd_gotoxy(0,0);
lcd_puts("Brac University");


lcd_gotoxy(0,1);
lcd_puts("LUX Input,x:");


m = 3.9;
c = 98.3;


lcd_gotoxy(0,2);
sprintf(buffer,"m=%.2f",m);
lcd_puts(buffer);


lcd_gotoxy(7,2);
sprintf(buffer,"c=%.2f",c);
lcd_puts(buffer);
```

```
        lcd_gotoxy(0,3);

        sprintf(buffer,"x=%.2f",x);

        lcd_puts(buffer);


        m = 3.9;

        c = 98.3;


//      temp[0] = '1';

//      temp[1] = '2';

//      temp[2] = '.';

//      temp[3] = '4';

//      temp[4] = '\0';

//      x =atof(temp);

//      lcd_gotoxy(10,3);

//      sprintf(buffer,"x=%.2f",x);

//      lcd_puts(buffer);

//      _delay_ms(1000);


        while(1)

        {




                keypad_value=read_keypad();
```

```
/*Scan's 4X4 keypad and returns pressed key value or default value*/


/*Checking if any key is pressed or not*/
if(keypad_value!=0xff)
{



    switch(keypad_value)
    {
        case 0:
            keyValue = '0';
            keyPress = 1;
        /*Displays 0 in 2nd row of LCD*/

        break;
        /*Break statement*/

        case 1:
            keyValue = '1';
            keyPress = 1;
        /*Displays 1 in 2nd row of LCD*/

        break;
        /*Break statement*/
```

```
case 2:
        keyValue = '2';
        keyPress = 1;
/*Displays 2 in 2nd row of LCD*/

break;
/*Break statement*/

case 3:
        keyValue = '3';
        keyPress = 1;
/*Displays 3 in 2nd row of LCD*/

break;
/*Break statement*/

case 4:
        keyValue = '4';
        keyPress = 1;
/*Displays 4 in 2nd row of LCD*/

break;
/*Break statement*/
```

```
case 5:

        keyValue = '5';

        keyPress = 1;

/*Displays 5 in 2nd row of LCD*/


break;

/*Break statement*/


case 6:

        keyValue = '6';

        keyPress = 1;

/*Displays 6 in 2nd row of LCD*/


break;

/*Break statement*/


case 7:

        keyValue = '7';

        keyPress = 1;

/*Displays 7 in 2nd row of LCD*/


break;

/*Break statement*/
```

```
case 8:

        keyValue = '8';

        keyPress = 1;

/*Displays 8 in 2nd row of LCD*/


break;

/*Break statement*/


case 9:

        keyValue = '9';

        keyPress = 1;

/*Displays 9 in 2nd row of LCD*/


break;

/*Break statement*/


case 10:

        keyValue = '.';

        keyPress = 1;

/*Displays * in 2nd row of LCD*/


break;

/*Break statement*/
```

```
case 11:
        keyValue = 'A';
        keyPress = 1;
/*Displays # in 2nd row of LCD*/

break;
/*Break statement*/

case 12:
        keyValue = 'B';
        keyPress = 1;
/*Displays A in 2nd row of LCD*/

break;
/*Break statement*/

case 13:
        keyValue = 'C';
        keyPress = 1;
/*Displays B in 2nd row of LCD*/

break;
/*Break statement*/
```

```
case 14:
    keyValue = 'D';
    keyPress = 1;
/*Displays C in 2nd row of LCD*/

break;
/*Break statement*/;

case 15:
    keyValue = 'E';
    keyPress = 1;

/*Displays D in 2nd row of LCD*/

break;
/*Break statement*/;
    }
}
else
;
/*Null statement*/

if(keyPress == 1)
```

```
{
	keyPress = 0;

	if(keyValue >= '0' && keyValue <= '9')
	{
		keyString[index] = keyValue;
		keyString[index+1] = '\0';
		index++;
		lcd_gotoxy(12,1);
		lcd_puts(keyString);

	}

	if(keyValue == '.')
	{
		if(de_point == 0)
		{
			de_point = 1;
			keyString[index] = keyValue;
			keyString[index+1] = '\0';
			index++;
			lcd_gotoxy(12,1);
			lcd_puts(keyString);
		}
```

```
}

if(keyValue == 'E')
{

        x = 0;
        x = atof(keyString);

        lcd_gotoxy(0,2);
        sprintf(buffer,"m=%.2f",m);
        lcd_puts(buffer);

        lcd_gotoxy(7,2);
        sprintf(buffer,"c=%.2f",c);
        lcd_puts(buffer);

        lcd_gotoxy(0,3);
        sprintf(buffer,"x=%.2f",x);
        lcd_puts(buffer);

        doMath = 1;
}
```

```
if(doMath == 1)
{
        doMath = 0;

        y=(float)m*x+(float)c;

        lcd_clr();
        lcd_gotoxy(0,0);
        sprintf(buffer,"LUMEN=%.2f",y);
        lcd_puts(buffer);

        index = 0;
        keyString[index] = '\0';
        lcd_gotoxy(10,1);
        lcd_puts(keyString);
        lcd_puts("        ");
}
if(keyValue == 'D')
{
        lcd_gotoxy(0,0);
        lcd_puts("Brac University");

        lcd_gotoxy(0,1);
        lcd_puts("LUX Input,x:");
```

```
                    m = 3.9;
                    c = 98.3;

                    lcd_gotoxy(0,2);
                    sprintf(buffer,"m=%.2f",m);
                    lcd_puts(buffer);

                    lcd_gotoxy(7,2);
                    sprintf(buffer,"c=%.2f",c);
                    lcd_puts(buffer);

                    lcd_gotoxy(0,3);
                    sprintf(buffer,"x=%.2f",x);
                    lcd_puts(buffer);
                }
            }

            _delay_ms(200);
        }
}
/*End of program*/
```

```
/*4X4 Keypad Function Definitions*/
unsigned char read_keypad(void)
{
	unsigned char keypad_input=0xff,keypad_output=0xff;
	KEYPAD_PORT=0xfe;
	_delay_us(2);
	keypad_input=KEYPAD_PIN & 0xf0;

	if(keypad_input==0xe0)
	keypad_output=0x01;
	else if(keypad_input==0xd0)
	keypad_output=0x02;
	else if(keypad_input==0xb0)
	keypad_output=0x03;
	else if(keypad_input==0x70)
	keypad_output=0x0c;
	else
	;

	KEYPAD_PORT=0xfd;
	_delay_us(2);
	keypad_input=KEYPAD_PIN & 0xf0;

	if(keypad_input==0xe0)
```

```
keypad_output=0x04;

else if(keypad_input==0xd0)

keypad_output=0x05;

else if(keypad_input==0xb0)

keypad_output=0x06;

else if(keypad_input==0x70)

keypad_output=0x0d;

else

;


KEYPAD_PORT=0xfb;

_delay_us(2);

keypad_input=KEYPAD_PIN & 0xf0;


if(keypad_input==0xe0)

keypad_output=0x07;

else if(keypad_input==0xd0)

keypad_output=0x08;

else if(keypad_input==0xb0)

keypad_output=0x09;

else if(keypad_input==0x70)

keypad_output=0x0e;

else

;
```

```
KEYPAD_PORT=0xf7;

_delay_us(2);

keypad_input=KEYPAD_PIN & 0xf0;


if(keypad_input==0xe0)

keypad_output=0x0a;

else if(keypad_input==0xd0)

keypad_output=0x00;

else if(keypad_input==0xb0)

keypad_output=0x0b;

else if(keypad_input==0x70)

keypad_output=0x0f;

else

;


return keypad_output;

}
```

Appendix 3: Lumen Data of Sample LED Light at 82 cm height by old method

Name	Watt	Rated Lumen	Experiment Lux	Experiment Lumen	Error
Super Star	15	1350	318	1338.5	-0.851851852
Super Star	12	1105	245	1053.8	-4.633484163
Super Star	9	839	188	831.5	-0.893921335
Super Star	5	483	100.2	489.08	1.258799172
Energypac	15	1500	388	1611.5	7.433333333
Energypac	12	1100	284	1205.9	9.627272727
Transtac	13	1300	346	1447.7	11.36153846
Transtac	7	630	154	698.9	10.93650794
Click	11	1000	295	1248.8	24.88
Click	15	1500	327.8	1376.72	-8.218666667
Phillips	12	1200	462	1900.1	58.34166667
Phillips	9	825	313	1319	59.87878788
Sparkel	18	1710	754	3038.9	77.71345029

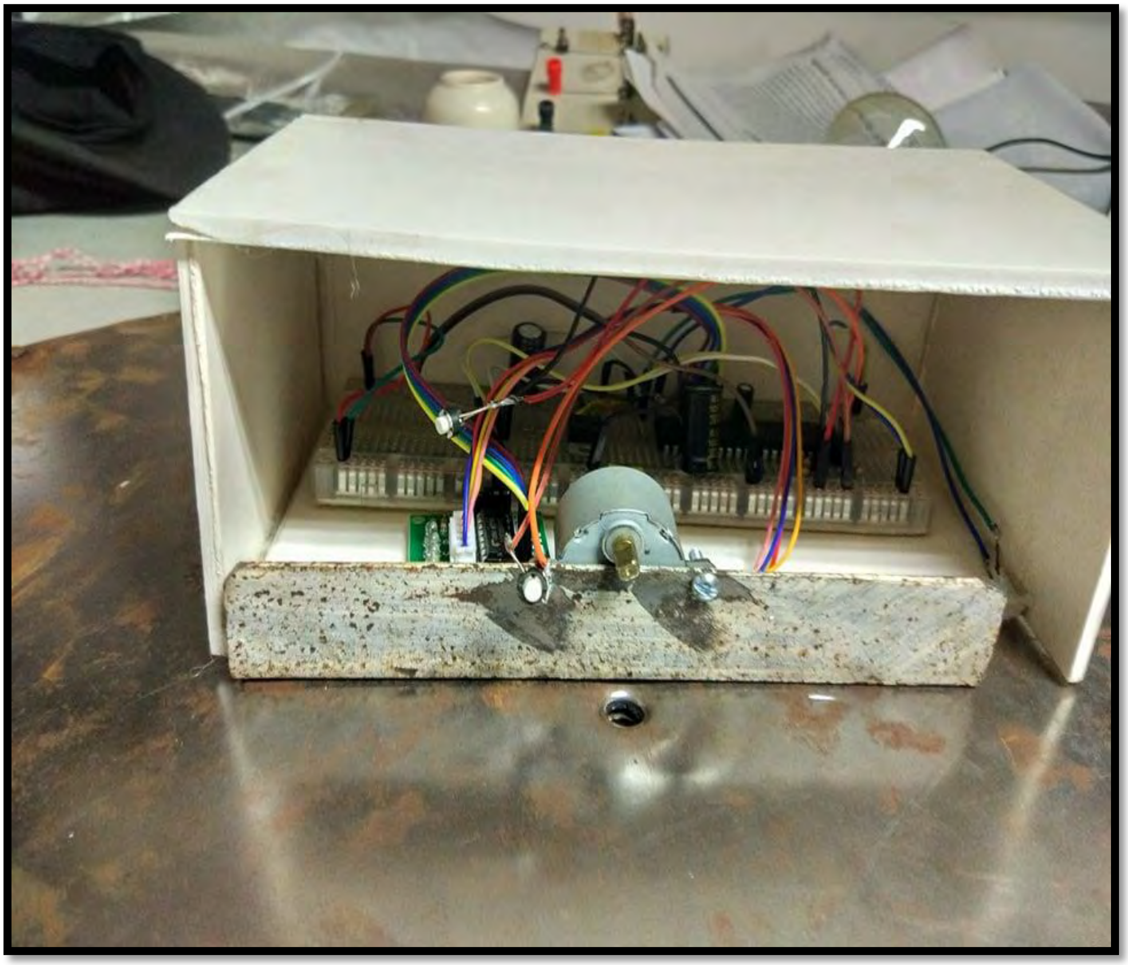
Appendix 4: Lumen Data of Sample LED Light at 84.5 cm height by old method

Name	Watt	Rated Lumen	Experiment Lux	Experiment Lumen	Error
Super Star	15	1350	305	1287.8	-4.607407407
Super Star	12	1105	222	964.1	-12.75113122
Super Star	9	839	180	800.3	-4.612634088
Super Star	5	483	99.2	485.18	0.451345756
Energypac	15	1500	370.6	1543.64	2.909333333
Energypac	12	1100	272	1159.1	5.372727273
Transtac	13	1300	324	1361.9	4.761538462
Transtac	7	630	143.2	656.78	4.250793651
Click	11	1000	277	1178.6	17.86
Click	15	1500	307.7	1298.33	-13.44466667
Phillips	12	1200	429	1771.4	47.61666667
Phillips	9	825	301	1272.2	54.20606061
Sparkel	18	1710	707	2855.6	66.99415205

Appendix 5: Watt calculation data of sample LED light by watt meter

Name	Watt	Calculated Watt
Super Star	15	15
Super Star	12	11
Super Star	9	9
Super Star	5	5.5
Energypac	15	14
Energypac	12	11
Transtac	13	12.5
Transtac	7	8
Click	11	15.5
Click	15	11
Phillips	12	10.5
Phillips	9	8
Sparkel	18	18

Appendix 6: Stepper motor and microcontroller circuit



Appendix 7: Complete Device

Appendix 8: Reading Box and Lux Meter alignment