University of Moratuwa
Department of Electronic and Telecommunication Engineering

EN2090 - Laboratory Practice - II

Lux Meter Project - Group 9

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<u>CONTENTS</u>

1. ABSTRACT

This report is regarding the design and development of a Lux Meter that can measure white and colored LED light under standard laboratory conditions. Lux meters are used to measure the brightness or illuminance of said light, and are used in fields dealing with biomedical instruments, photography, robot navigation, illumination engineering etc. For this project, a phototransistor was used for sensing light and the errors were minimized using analog techniques. This report explains the design of the lux meter, the methods implemented, the test results and conclusions drawn for building such a device.

2. INTRODUCTION

A lux can be defined as the amount of luminous flux per unit area(lx/m2). It is also known as illuminance. The human eye, although very sensitive to illuminance, cannot measure it accurately. Hence, a device to measure the illuminance accurately was needed, and thus, the lux meter was conceptualized. If we observe standard lux meters in the market, they are made from numerous advanced digital components and other complicated parts. For this project, we were given the task to design a lux meter using basic analogue electronic components such as diodes, transistors, op-amps etc.

Firstly, we had to decide upon how we would measure the light, that is, what kind of component we would use for that function. After much deliberation, we decided on using the TEMT6000 photo-transistor module for this purpose. The basic reasons for this being that the module can measure light-intensity in a variety of ranges and is affordable and commonly available in the market as well. For processing the measured results, we had used the Atmega328P microcontroller. Since we already had prior experience using the Arduino Uno in which this microcontroller is used, we decided that it would be optimal to reprogram as needed for our project. To act as the user interface, we had used a standard 16x2 LCD Display. With regards to designing the circuit, the various available amplifiers, rectifiers, clippers were looked at and implemented as necessary.

This report shows the methodologies we followed when developing the lux meter, the various block diagrams we had used, the relevant mathematical calculations done in the process of development, the results obtained, and conclusions drawn from the completion of this project.

3. METHODOLOGY

3.1. Components Used

- Light Sensor

- ○ TEMT6000 Photo-transistor
- Amplification circuit
    - ○ LM741 General-Purpose Op-Amp
    - ○ 100ohm/ 100k ohm/ 2k ohm Multiturn Potentiometer Trimmer
    - ○ 3P4T Rotary Switch
    - ○ 100pF Ceramic Capacitors
- Clipper circuit
    - ○ LM358N Dual Differential Input Op-Amp
    - ○ 1N4148 Diodes
- Microcontroller circuit
    - ○ Atmega328P Microcontroller
    - ○ 100nF/ 22pF Ceramic Capacitors
    - ○ 16MHz Crystal Oscillator ○
    16 x 2 LCD Display

3.1.1. **Light sensor**

● TEMT6000 photo transistor is used to detect the light intensity of the surrounding in this lux meter projector. The use of a phototransistor over an LDR is justified due to its high sensitivity and built-in amplification. The TEMT6000 phototransistor is also optimized to measure visible light similar to the human eye by having a peak sensitivity at wavelength 570 nm.

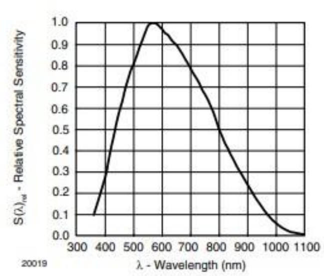


Figure 2: TEMT6000 Sensitivity

Figure 1: TEMT6000 Phototransistor

3.1.2. **LM741 General-Purpose Op-Amp**

● The LM 741 is a general-purpose DC coupled high gain electronic voltage amplifier. This IC consists of only one op amp and it is intended for a wide range of analog applications. The reason we chose this is for its high gain and wide range of operational voltage. This also features short circuit protection, Temperature stability and internal frequency compensation which is ideal for this project.

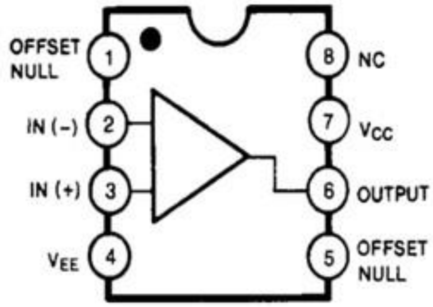


Figure 3: 741 Internal flow diagram

When we use 5v for the supply voltage of the sensor it gives milli volte range output for small lux values. Therefore, it needs to be amplified. Since we are using 3 intensity ranges, we need to have 3 amplifying stages. In all these rangers we are amplifying the sensor output voltage to 0 – 5 V. For this we are using the LM 741 Amplifier because of its high gain and we are using only one of these ICs in the non-inverting stage. By using three potentiometers and changing their values we can build the three amplifying stages for our satisfaction.

3.1.3. LM358N Dual Differential Input Op-Amp

- The operational amplifier LM 358 is an operational amplifier with very high gain, very high input impedance, very low output impedance and internal frequency compensation. This is a dual op amp IC integrated with two op amps powered by a common supply.

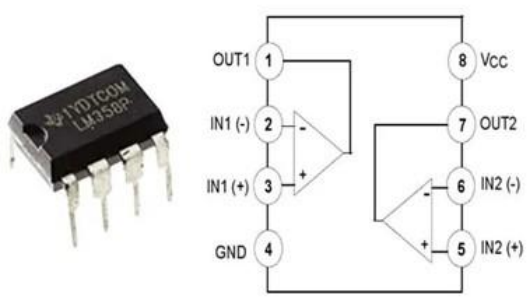


Figure 4: LM358 internal flow diagram

- The necessity for a clipper circuit comes with the ATMEGA328P microcontroller as it cannot handle voltages greater than 5V. After the amplifier stage the output can be greater than 5V. So we have to pass it through our clipper circuit before giving it to the 328P IC. In here we have built our clipper circuit using two LM 358 IC

3.1.4. **ATMega32 microcontroller**

- The ATMEGA328P is a high performance, low power controller from Microchip Technology Inc. ATMEGA328P is an 8-bit microcontroller based on AVR RISC architecture. It is the most popular of all AVR controllers as it is used in ARDUINO boards. The reason for using this chip is its vast availability, low price and ease of programming using the AVR serial programmer.

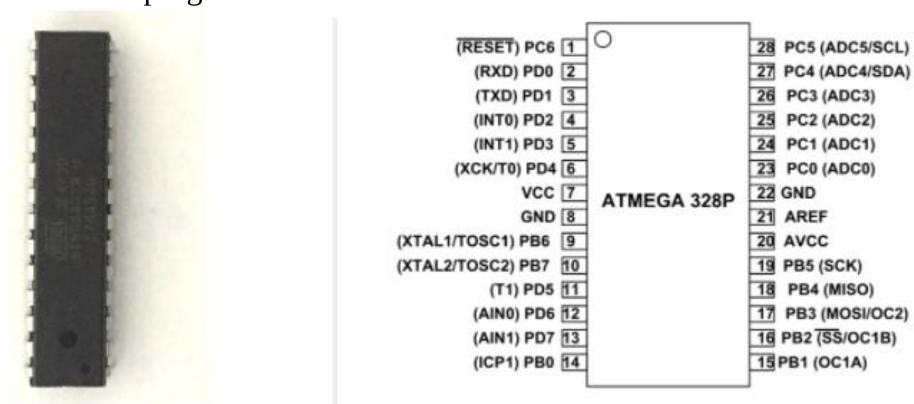


Figure 5: ATMega328P Pinout

3.1.5. Block Diagram

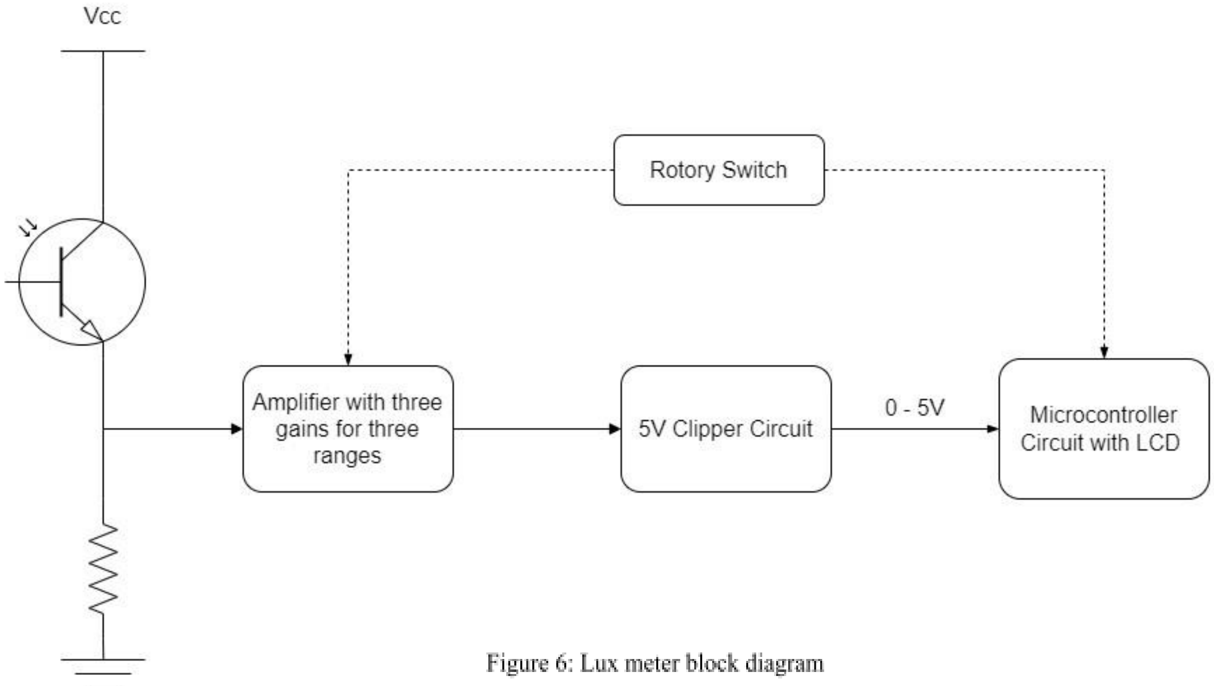


Figure 6: Lux meter block diagram

The signal voltage from the photo transistor is fed into the 741 amplifier which has three separate potentiometers which can amplify the voltage with three different gains which are calculated below. The gains are switched by a 3 pole 4 position rotary switch which can parally switch the resistor and send the signal to the microcontroller as well to identify which range is selected. For the three ranges we have different functions to extrapolate the lux value in relation to the clipped signal voltage coming from the analog part of the circuit. The microcontroller then outputs the calculated lux value through the LCD I2C module.

3.1.6. PCB

We use Altium Software for designing PCB. The initial prototype was built on a breadboard. Testing and calibration are done to get a more accurate result with a commercial lux meter. With that finalized circuit we made the PCB design. PCB design is done in a double layer and has the dimension of nearly 70mm x 80mm., which can be placed inside the main enclosure design. The schematic design includes an amplifier circuit, clipper circuit and microcontroller circuit. We planned to provide a power supply
externally to the lux meter. The figure shows the 2D design of our PCB. The Schematics and 3D view of the PCB design are attached in the appendix. The figure shows the printed PCB design

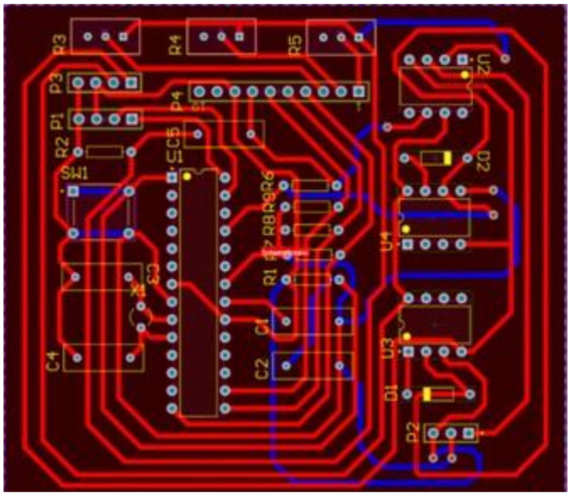


Figure 7: PCB render

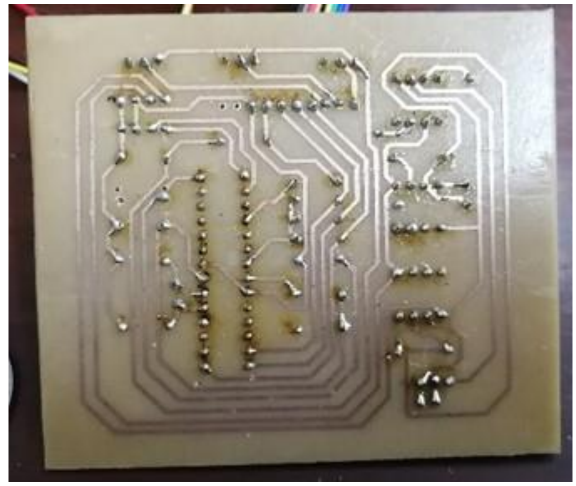


Figure 8: Manufactured PCB

3.1.7. **Enclosure Design**

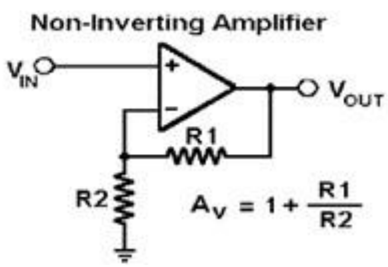
- We use Solid works software to design the enclosure. We planned to make a proper enclosure with easy user interface facilities. It includes an LCD, ON/OFF switch, and mode selection switch. In our lux meter design, we include three-mode for selection according to the different light intensity levels. Our enclosure design contains the main part and a subpart. The main enclosure contains the user interface part which includes an LCD and Switches and the subpart contains the sensor with the lens which is connected through a cable. We make the design such that we can hold the main unit and sub unit separately. But in our final

Figure 9: Solidworks render

demonstration, we use a black box as the enclosure for our prototype. The figure shows the enclosure design of our lux meter. Additional images and an Expanded view of enclosure designs are included in the appendix.

3.1.8. Calculations

Gain calculation of Non-inverting amplifier for 3 different modes of selection.



- Here we use feedback variable resistors (R1) with values of 100kΩ, 5kΩ and 100Ω. And the value of the R2 resistor is 10kΩ. from these different gains, the input signal is amplified to obtain the output in the range of 0-5V. The voltage of the light sensor for 3 modes is 0-0.53V, 0-4.1V and 0-4.89V.
- These input signal voltages are amplified by the Non-inverting amplifier in three different modes by selecting the proper gain mode. The approximate values of feedback resistors are 80kΩ, 1500Ω and 50Ω. The figure shows the gain calculation of a non-inverting amplifier. The gain calculation for three modes is as follows

Gains:

- Mode1=> 1 + 80k/10k = 9
- Mode2=> 1 + 1500/10k = 1.15
- Mode3=> 1 + 50/10k = 1.005

Calibration Method and Measurements

- Place the commercial lux meter and our light sensor close to each other and at the same horizontal level.
- Initially adjust the variable resistor value for each mode such that the output of the clipper circuit reaches 5V for each mode's maximum detectable lux value (200 lux,2000 lux,20 000 lux) and fix the resistor value.

- Then select each mode (M1, M2, M3) and get the voltage and lux meter values by varying the intensity of light in the surrounding environment.

    - Mode 1=>0 - 200 lux
    - Mode 2=>0 - 2000 lux
    - Mode 3=>0 - 20 000 lux

- From the obtained data points of voltage and corresponding lux values, we plot and obtain the corresponding equation of each curve.
- These equations are used in the microcontroller circuit to compute the lux values corresponding to their mode of selection.
- Initially, we used the light sensor directly for calibration. The figure shows the obtained graph plots and equations for three selection modes. From the obtained plots we found the nonlinear behavior in the 3rd Mode. But in the final prototype, we included a cap above the light sensor and did the calibrations again. From this change, we can closely reach the data points with the equations in the range of 20lux to 2000 lux. And the deviation of the graph in the 3rd mode is also very small compared with the previous calibration. The figure shows the graph plots and equations for three selection modes obtained for the final prototype. The obtained equations for the final prototype are

    - Mode 1=> $y = -3.4841x^2 + 59.39x - 2.4862$
    - Mode 2=> $y = 393.9x + 32.435$
    - Mode 3=> $y = 3E\text{-}32e^{16.623x}$

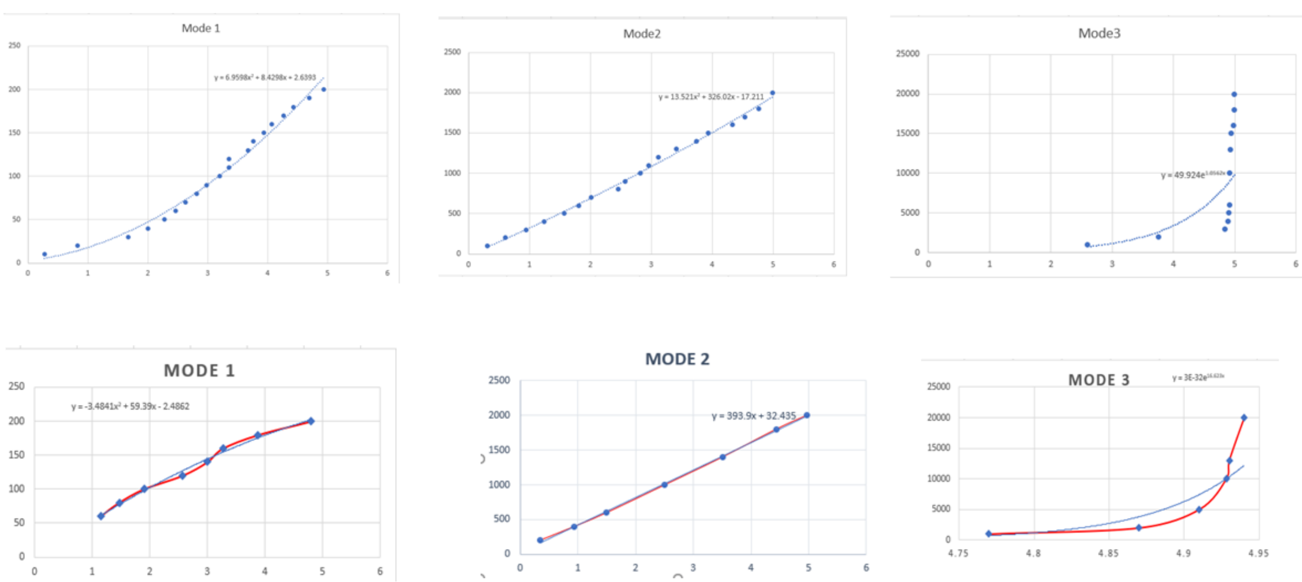


Figure 10: Value mapping curves

3.1.9. **Physical Implementation**

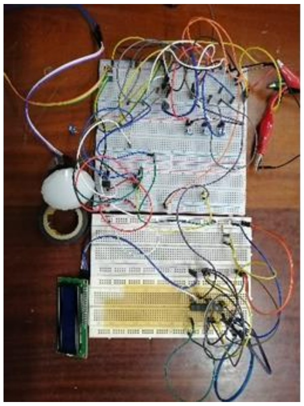
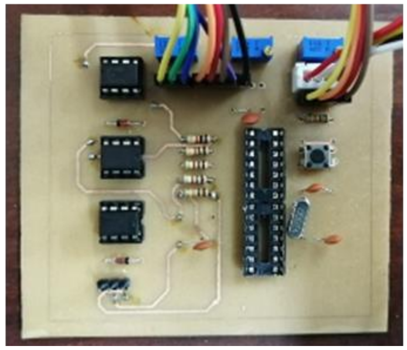
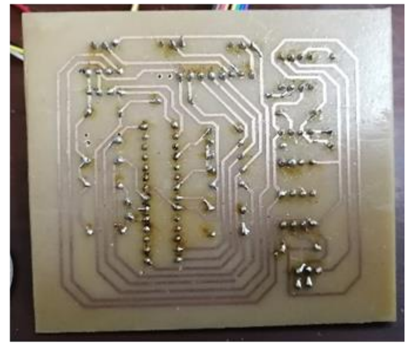


Figure 11: Breadboard implementation

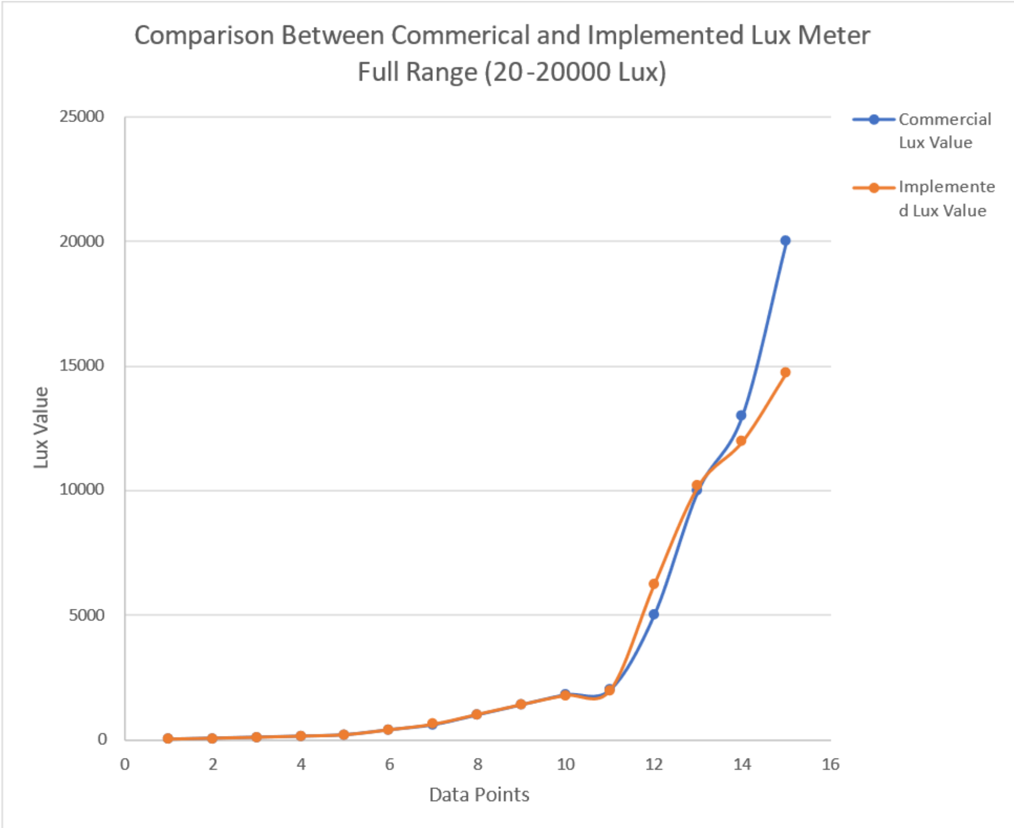




Figures 12, 13: Soldered PCB front and back

4. **RESULTS**

- As mentioned before our lux meter needs to be switched into the corresponding range by the user. So, the user needs to have an understanding of the range he wants to take the measurements in. Our lux meter is calibrated using a commercial lux meter. The graph given below showcases the comparison between the commercial lux meter and our implemented lux meter.



From this we can see that our lux meter works exceptionally in 0 – 200 lx mode and moderately in 0 – 2000 lx mode and it works with a slight variation in 0 – 20000 lx mode.

5. DISCUSSION

5.1.Scarcity of components

- During the COVID19 pandemic and the economic crisis situation of the country the scarcity of components was a major issue that we had to overcome. Importing components and outsourcing PCB printing to foreign countries were not an option due to high taxes and extreme delays in shipping. Due to this reason, checking availability was one of the main factors we needed to consider when designing the circuit. We had to redesign and recalibrate the circuit several times due to the local unavailability of materials used in the circuit. In terms of designing the PCB from a local manufacturer, we had to face some limitations in terms of the minimum path width and path gap as well.

5.2. Upper range resolution issue

- According to the datasheet, the TEMT6000 phototransistor is most sensitive in the 10 to 1000 lux range, but as per the requirement of the project, our lux meter should be able to measure up to an intensity of 20 000 lux. Therefore, we need to enclose the lux meter in a diffuser lens with a semitransparent sheet that linearly scales the intensity at the sensor compared to the intensity of the surrounding. Using this technique and several calibrations rounds we were able to increase the accuracy in the 1000 to 10 000 range quite effectively, however the 10 000 to 20 000 range was impractical to calibrate even using the brightest light source we could obtain in the laboratory which was a 60 W incandescent bulb. Also, by using the diffusing and reducing the intensity of light that falls into the sensor, the first range we chose (0 - 200 lux range) suffered a slight loss in resolution due to the whole range being within a millivolt range (0 - 530 mV).

5.3. Choice of a manual range switching to increase resolution

- In the lux meter circuit, we decided to go with a rotary switch to switch the range from 200, 2000 and 20 000 lux ranges. This allowed us to utilize the inbuilt 8-bit ADC of the ATMega328P in a very efficient way without over complicating the circuit.

6. REFERENCES

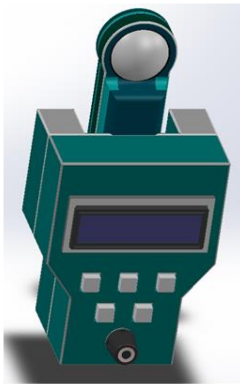
1. https://www.electronics-lab.com/project/lux-meter-module/
2. https://en.wikipedia.org/wiki/Lux
3. https://www.newark.com/vishay/temt6200fx01/transistor-photo-npn-550nm-0805/dp/31M2935
4. https://forum.allaboutcircuits.com/threads/designing-a-lux-meter-with-a-phototransistor.162014/

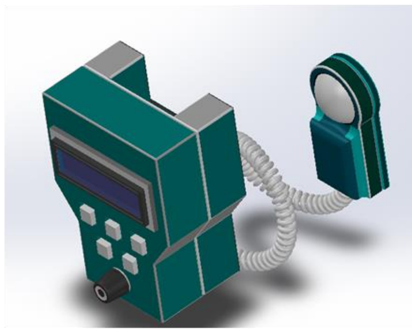
7. ACKNOWLEDGEMENT

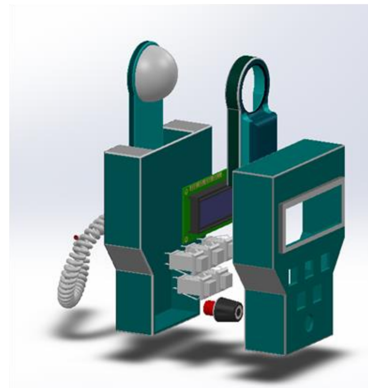
We would like to extend our gratitude to all those who contributed to making this project a success. A special mention to Ms. Dinithi Hemakumara, the supervisor of our project for the advice and support throughout. The laboratory staff, workshop staff and department administration showed immense support even keeping the labs open during off hours and holidays for us to get our projects completed on time. Final extent of thanks to the helpful batchmates who synergized with each other to complete our projects the best way possible.

8. <u>APPENDIX</u>

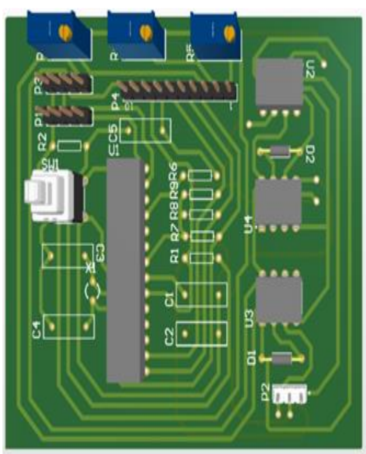
8.1. <u>Enclosure Design</u>

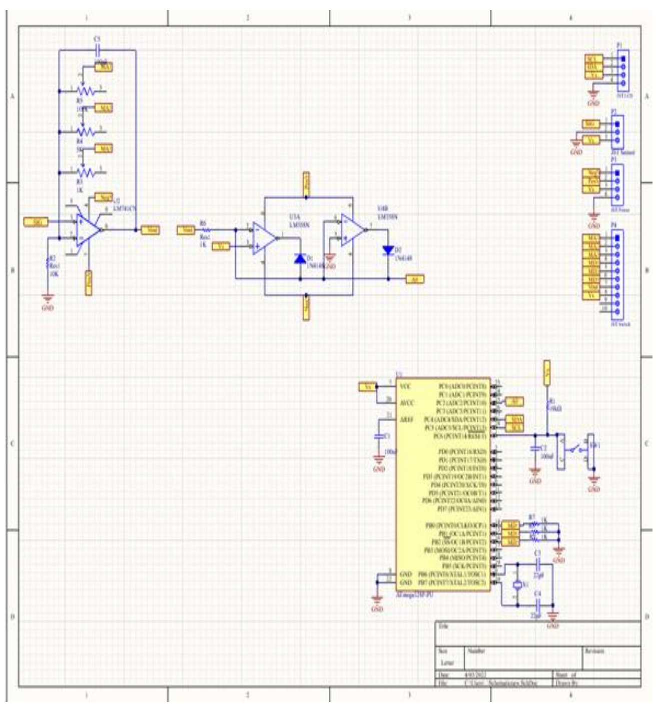






8.2. <u>PCB Design</u>





8.3. Microcontroller circuit code

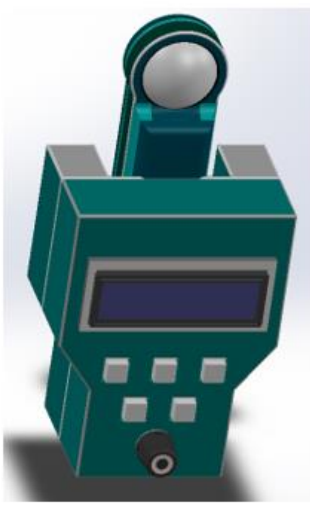
```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>//code used for i2c

LiquidCrystal_I2C lcd(0x27,20,4);

#define v_in A0
int buttonPin1 = 8;
int buttonPin2 = 9;
int buttonPin3 = 10;

int buttonState1 = 0;
int buttonState2 = 0;
int buttonState3 = 0;

int Value=0;
void setup() {
     Serial.begin(9600);
     lcd.init();                       // initialize the lcd
     lcd.init();
  // Print a message to the LCD.
     lcd.backlight();
     pinMode(v_in,INPUT);
     pinMode(buttonPin1, INPUT);
     pinMode(buttonPin2, INPUT);
     pinMode(buttonPin3, INPUT);


     lcd.print("Lux-Meter");
     delay(1000);
     lcd.setCursor(0, 0);
     lcd.print("Select Mode:");
     delay(1000);
     lcd.setCursor(0, 1);
     lcd.print("M1   M2   M3");
     delay(1000);
     lcd.clear();

}
void loop() {
     int luxvalue =analogRead(v_in);
     buttonState1 = digitalRead(buttonPin1);
     buttonState2 = digitalRead(buttonPin2);
     buttonState3 = digitalRead(buttonPin3);

     lcd.setCursor(0, 0);

     Serial.println(luxvalue);
     float v =(luxvalue*5.00/1024);
     if (buttonState1 == HIGH) {
        lcd.print("Mode 1");
        Value = (6.9598*pow(v,2)) + (8.4298*v) + 2.6393;

     } else if (buttonState2 == HIGH) {
        lcd.print("Mode 2");
        Value = (13.521*pow(v,2)) + (326.02*v) - 17.211;

     } else if (buttonState3 == HIGH) {
        lcd.print("Mode 3");
        Value = 49.924*exp(1.0562*v);

     }  else {
        lcd.print("Select Mode");
     }
     delay(500);
     lcd.clear();
     lcd.setCursor(4, 0);
     lcd.print("Lux Value");
     delay(500);
     lcd.setCursor(5, 1);
     lcd.print(Value);
     lcd.print(" Lux");
     delay(500);
     lcd.clear();
}
```

CONTRIBUTIONS

Name	Index Number	Contribution
Fonseka K.A.S	190183U	General design and implementation of circuit.
Gajaanan S.	190185D	PCB design, Solidworks design, Coding, General design and implementation of circuit.
Gajoshan V.	190186G	Component choice and gathering, Testing and calibration, General design and implementation of circuit.

Gunasekara M.S.K	190202F	PCB implementation, testing and calibration, General design and implementation of circuit.
Hettihewa D.P.G	190231R	PCB implementation, testing and calibration calibration, General design and implementation of circuit.

Datasheet



- Operating range=>20-20000lux (3 Ranges)
- Accuracy=>above 90% (In the range of 20-2000lux)
- Photoelectric element=>TEMT6000 Photo Transistor
- Power supply=> Use 3.7v Li-ion rechargeable batteries
- Dimension=>9cm x 12cm x 6cm
- User interface
  - Display=>liquid Crystal Display
  - Rotary Switch=>3 Mode Selection
  - Light sensor can hold separately from main component
- Precise and easy readout, wide range
- High accuracy in measuring
- LCD Display provides low power consumption
- Compact and light weight

Range	Resolution
20-200 lux	1lux
200-2000 lux	10 lux
2000-20000 lux	100 lux

Relative Spectral Response