An LED and Spectroscopy System for Detecting Aflatoxin in Corn

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Abstract

This project is about designing a reproducible LED and spectroscopy system. The goal is to enable users to change the setting for the LEDs and spectrometer to detect the type and amount of aflatoxins on corn kernels. The data can be recorded in the computer with spectrometer. We are guided by John Hart to follow and modify the original prototype in Bioprocess Laboratory on campus. The beginning part of this paper introduces aflatoxins and how different LEDs help in detecting its presence. Then, we move onto discussing the details of design for each module and its verification result. Lastly, we conclude our report with what have been accomplished and suggestions for future work.

Contents

1. Introduction

1.1 Objective

Aflatoxins is a toxic component produced by fungi, such as Aspergillus flavus and Aspergillus parasiticus, which grow in agricultural crops such as corn, peanuts, and tree nuts [1]. It can be detected based on its special physical property under LEDs, whereby it emits bright greenish-yellow fluorescence (BGYF) under ultraviolet light [2]. For instance, the B-group aflatoxins exhibit blue fluorescence; the G-group aflatoxins exhibits yellow-green fluorescence under ultraviolet (UV) light [3]. The paper [2] also mentions that near infrared reflectance spectroscopy (550 nm to 1700 nm) is used to evaluate the internal quality of grains and nuts. Our project is about creating a low-cost Light Emitting Diodes (LEDs) spectroscopy system to let researchers from other places participate in this aflatoxin research. Therefore, ultraviolet, visible and infrared light needs to be used in our project.

1.2 Purpose

The goal of our project is to balance the five groups of LEDs for the spectroscopy system and collect data from the spectrometer to detect if the corn kernel is toxic. The brightness of each group of LEDs should be able to controlled by a microcontroller. The five groups of LEDs include ultraviolet light LED, visible light LED, and infrared light LED (three different wavelengths). As the maximum current each pin of the microcontroller can support is low, we decided to use transistors to balance the LEDs. All LEDs were mounted onto a light tube made with PCL. Two sensors are mounted at the top and the bottom of the light tube. The user should be able to change the brightness of the LEDs to a specific value before the experiments. Then upload the command onto the microcontroller. When a kernel is dropped into the light tube, the sensor can send the signal to the controller; and the controller can switch on LEDs and trigger the spectrometer in 10ms. When the kernel gets to the bottom of the light tube, another sensor should be able to send signal to the controller; and the controller can switch off all LEDs and stop collecting data from the spectrometer. A graphical user interface is also built to monitor the light sensor and the brightness level. In this way, the researchers can change the setting of the experiment based on their specific requirement.

<u>Requirement:</u>

1) The controller must be able to control the brightness of each individual groups of LED diodes via pulse width modulation with high operating frequency
2) The voltage regulator module must be able to output 6A current at maximum with 5V rating.
3) Signal from the light sensor should be detected by the controller and the spectrometer

should be able to be triggered by the controller.
4) The GUI can control the brightness of the LEDs.

1.3 Block Diagram

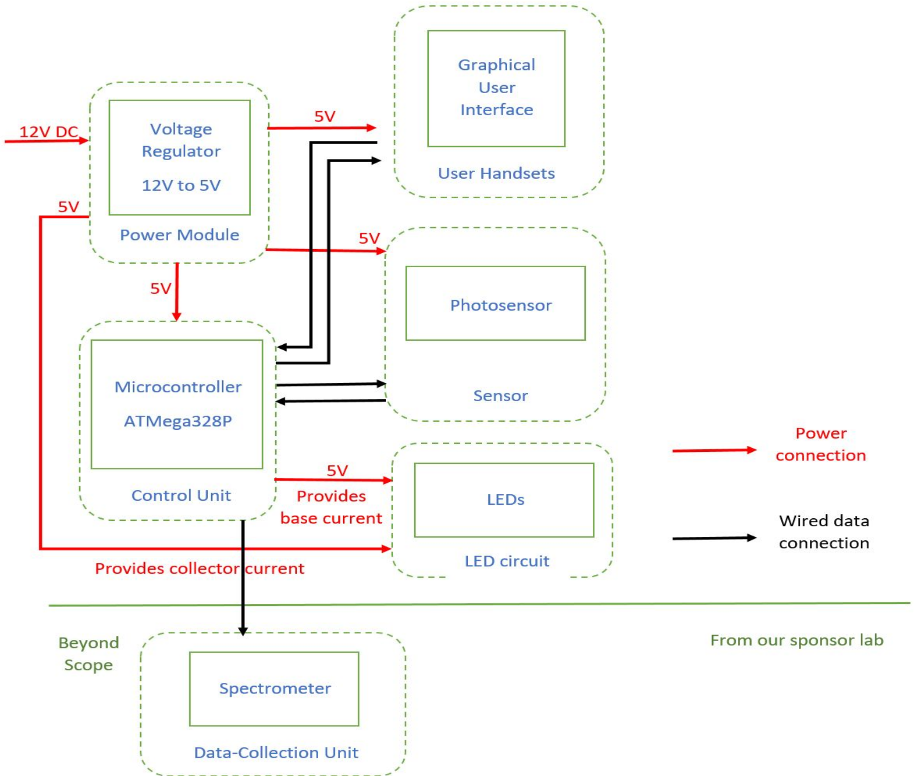

Figure 1: Block Diagram for our project

2. Design and Block Description

2.1 Power Module

2.1.1 Power Supply

12V and 5A power adapter is used in our project. A power adapter with datasheet is chosen to ensure its safety and reliability. It is able to supply 12V and 5A at maximum.

2.1.2 Voltage Regulator

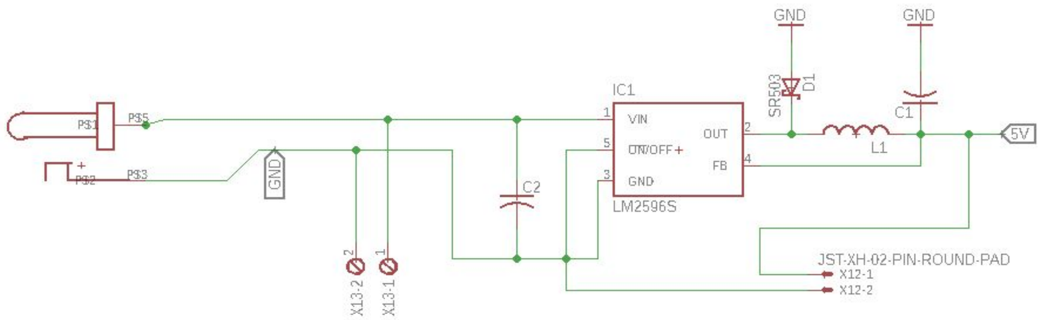

Figure 2: Circuit Diagram from LM2596-5.0 datasheet

LM2596-5.0 is used for this project. The design of the circuit is based on the one shown on the first page of its datasheet [4]. The capacitor connected at the input and output is to reduce the noise, which helps to stabilize the input and output current. The Schottky diode is to

2.2 Control Module

2.2.1 Microcontroller

As for the core of the processing unit, we choose an ATMega328P [5] as the processor unit which our project will rely on. It was being chosen not only because its low cost, user-friendly, and also the low power consumption. Meanwhile, we clocked it at 16 MHz, which is sufficient for processing the signals for controlling on-board components. Our original design included a Wi-Fi module and SD card on the controller board. However the Wi-Fi module needs to be connected with TX and RX pin FT232RL[6] chip, which may cause some issues when transmitting signal from FT232RL to ATMega328P. So we removed the Wi-Fi chip from the controller board. Another issue we met when we tried to upload code on the microcontroller was the ATMega328P hadn't been burned bootloader. In that case, I borrowed a UNO from Professor John to burn bootloader onto the chip. The circuit is shown below [7]. However, when we tried to upload code, it still kept showing the error: avrdude: stk500_getsync(): not in sync: resp=0x00. After searching online, and trying different solutions, we found the problem was that only one of RTS pin and DTR pin on FT232RL can be connected to RST pin on ATMega328P. Otherwise the controller cannot reset properly. So we removed the connection between RTS pin of FT232RL and RST pin of ATMega328P, which made the controller work well.

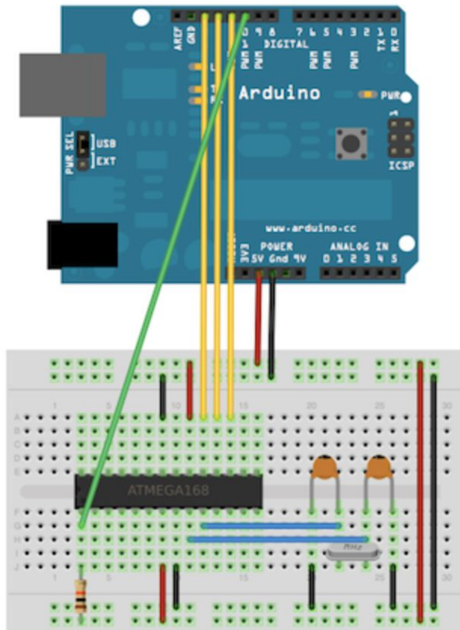

Figure: 3 Circuit of Burning Bootloader

2.2.2 Operation Status LED

A LED was added to the microcontroller module. It provides the indication whether the controller is under operation or sleeping mode. At the beginning, we decided to connect the operation status LED at reset pin, so that it can be switched on when the controller is connected with power, be switched off when we upload code onto the board. However, it will affect reset function of the signal. The LED on the RST pin would takes a lot voltage. So in our final design, we moved the operation status LED to pin 13. And connected it with a 100 ohm resistor in series. When we connect the controller to laptop, it will flash for several times. And when we upload the code, it will flash for several times. Otherwise, it is in sleeping status.

2.3 LED Module

2.3.1 LED Balancing Circuit

Six of the same type of LEDs (5 types in total) were connected in parallel. We were following the design shown on page 3 in the document by STMicroelectronics [8]. The microcontroller ATmega328P has 6 outputs pins (pin 5, pin 11, pin 12, pin 15, pin 16 and pin 17) and which can be used with pulse width modulated output. They are the six PWM channels [6]. The microcontroller will generate pulse width modulated (PWM) signal to pulse the LEDs for 10ms.

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The duty cycle of the PWM signal can be adjusted to control the brightness of the LEDs, due to the change in average current into the base of the transistor. We were also referring to some resources from website, such as Circuit Digest [9], Reuk [10] and Ermicro blog [11] which helps in the circuit design.

Calculation: (to find the values of R_b , R_c for the five types of LEDs)

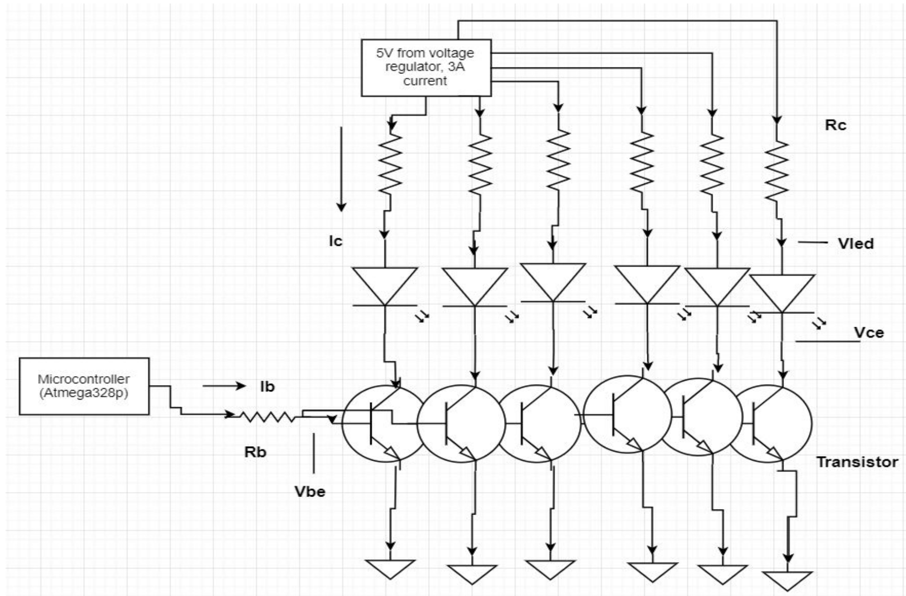

Figure 4: Circuit diagram for LEDs and microcontroller

Based on the design the LED balancing circuit, we need to calculate the resistance of R_C and R_B. Here is some data we know from the datasheet: The output voltage from an I/O pin on ATmega328P [6] is around 5V; The maximum DC current can be supported by the I/O pin on ATmega328P [6] is 40.0mA; the DC current gain depends on the current flowing through the collector Based on the datasheet of PN2222A NPN transistor [12]. To calculate the value of R_C, we need to this equation:

$$R_c = \frac{V_{cc} - V_{led} - V_{CE}}{I_c} \quad (2.3.1)$$

where V_{CC} is output voltage of voltage regulator, V_{LED} is the forward voltage of LED, V_{CE} is collector-emitter current in saturation, and I_C is forward current of LED.

To calculate the current at the base of the transistor I_B, we will use this equation:

$$I_B = \frac{I_c}{h_{FE}} \quad (2.3.2)$$

where I_C is the current at the collector of the transistor, and h_{FE} is the DC current gain of the transistor.

To calculate the value of R_B, we need to this equation:

$$R_B = \frac{V_{pin} - V_{BE}}{I_B}$$

(2.3.3)

where V_{pin} is output voltage of ATmega328P, V_{BE} is the base-emitter current in saturation, and I_B is the current at the base of the transistor.

1) **For C513A-MSN-CV0Y0132:**
   (forward current is 30mA; forward voltage is 3.2V.) [13]

Let I_c = 30mA, V_{fwd} = 3.2V, $V_{ce,\ saturation}$ = 0.30 V [12],

$$R_c = \frac{V_{cc} - V_{led} - V_{CE}}{I_c} = \frac{5.0V - 3.2V - 0.3V}{30mA} = \frac{1.5V}{30mA} = 50\ \Omega \quad (2.3.4)$$

Since the approximate value of h_{FE} = 35 [12], The current into each base of transistor is

$$I_b = \frac{I_c}{h_{FE}} = \frac{30mA}{35} = 0.857\ mA \quad (2.3.5)$$

V_{BE}(sat) ≈ 0.6V [12] , Resistor connected to each base of transistor is

$$R_b = \frac{V_{pin} - V_{BE(SAT)}}{I_{base}} = \frac{5V - 0.6V}{0.857mA} = 5134(\Omega) \quad (2.3.6)$$

2) **For MTE3650L2-UV-HP**

(Forward current is 300mA; forward voltage is 3.5V) [14]

Let I_c = 300 mA, $V_{fwd,}$ = 3.5V, $V_{ce,\ saturation}$ = 0.30 V [12]

$$R_c = \frac{V_{cc} - V_{led} - V_{ce}}{I_c} = \frac{5.0V - 3.5V - 0.3V}{300mA} = \frac{1.2V}{250mA} = 4\ \Omega \quad (2.3.7)$$

Since the approximate value of h_{FE} = 50 [12], the current needed for each base is

$$I_b = \frac{I_c}{h_{FE}} = \frac{300mA}{50} = 6\ mA \quad (2.3.8)$$

V_{BE}(sat) ≈ 1.0 V [12], Resistor connected to each base of transistor is

$$R_b = \frac{V_{pin} - V_{BE(SAT)}}{I_{base}} = \frac{5.00 - 1.00}{6\ mA} = 667\ \Omega \quad (2.3.9)$$

3) **For MTE5010-095-IR:**

(Forward current is 100mA; forward voltage is 1.25V.) [15]

Let I_c = 100 mA, V_{fwd} = 1.25 V, $V_{ce,\ saturation}$ = 0.30 V [12]

$$R_c = \frac{V_{cc} - V_{led} - V_{ce}}{I_c} = \frac{5.0V - 1.25V - 0.3V}{100mA} = \frac{3.45V}{100mA} = 34.5\ \Omega$$

(2.3.10)

Since the approximate value of h_{FE} ≈ 50 [12], the current needed for each base is

$$I_b = \frac{I_c}{h_{FE}} = \frac{100mA}{50} = 2mA \quad (2.3.11)$$

V_{BE}(sat) ≈ 0.6 V [12], Resistor connected to each base of transistor is

$$R_b = \frac{V_{pin} - V_{BE(SAT)}}{I_{base}} = \frac{5V - 0.6V}{2mA} = 2200\ \Omega \quad (2.3.12)$$

4) **For TSHA5200:**

(Forward current is 100mA; forward voltage is 1.5V) [16]

Let I_c = 100 mA, $V_{fwd,\ max}$ = 1.5V, $V_{ce,\ saturation}$ = 0.30 V [12]

$$R_c = \frac{V_{cc} - V_{led} - V_{ce}}{I_c} = \frac{5V - 1.5V - 0.3V}{100mA} = \frac{3.2V}{100mA} = 32\ \Omega \quad (2.3.13)$$

Since the approximate value of h_{FE} ≈ 50 [12], the current needed for each base is

$$I_b = \frac{I_c}{h_{FE}} = \frac{100mA}{50} = 2mA$$

(2.3.14)

V_{BE}(sat) ≈ 0.6 V [12], resistor connected to each base of transistor is

$$R_b = \frac{V_{pin} - V_{BE(SAT)}}{I_{base}} = \frac{5V - 0.6V}{2mA} = 2200\ \Omega \quad (2.3.15)$$

5) **For TSUS5400:**
(Forward current is 150mA, forward voltage is 1.3V) [17]
Let I_c = 150 mA, V_{fwd} = 1.3V, $V_{ce,\ saturation}$ = 0.30 V [12]

$$R_c = \frac{V_{cc} - V_{led} - V_{ce}}{I_c} = \frac{5V - 1.3V - 0.3V}{150mA} = \frac{3.4V}{150mA} = 22.7\ \Omega \quad (2.3.16)$$

Since the approximate value of h_{FE} ≈ 50 [12], the current needed for each base is

$$I_b = \frac{I_c}{h_{FE}} = \frac{150mA}{50} = 3mA \quad (2.3.17)$$

V_{BE}(sat) ≈ 0.6 V [12], resistor connected to each base of transistor is

$$R_b = \frac{V_{pin} - V_{BE(SAT)}}{I_{base}} = \frac{5V - 0.6V}{3mA} = 1467\ \Omega \quad (2.3.18)$$

After making sure these LEDs can get to the maximum brightness, we need to use Pulse Width Modulation (PWM) to change the duty cycle of the output voltage of the pin of ATMega328P. When the duty cycle is changed, the average output voltage will be changed as well. As long as the blinking frequency is high enough, we won't see the blink, but the decreasement of the brightness.

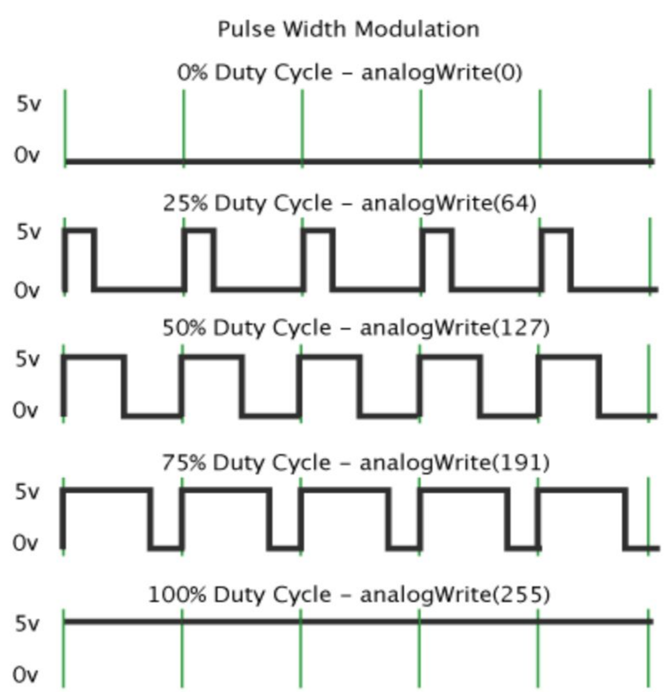

Figure 5: Pulse Width Modulation [18]

As the graph shown above, when the duty cycle is 0%, the average voltage is 0V; when the duty cycle is 25%, the average voltage is 1.25V; when the duty cycle is 50%, the average voltage is 2.5V; when the duty cycle is 75%, the average voltage is 3.75V; when the duty cycle is 100%, the average voltage is 5V. The resistance at bas is fixed, the voltage across the base resistor is decreasing, then the current through the base resistor will decrease too. At the same time, the current at the collector will decrease as well.

2.4 Sensor Module

2.4.1 770 nm LED

Two 770 nm LEDs were put at the top and bottom of the light tube. The LED chosen has a narrow beam which concentrates on the sensor. When we select the LED, we considered the wavelength of the LED. The LEDs used in the experiment are TSUS5400 (950nm), TSHA5200 (870nm), MTE5010 (1050nm), MTE3650 (365nm), C513A (450nm, 600nm). Looking at the spectrum below, we can find there is a gap around 770 nm. So in order to reduce the effect to the experiment result, we need to avoid the overlap. 770 nm LED is a good choice here. The forward voltage of this LED is 1.55V and the forward current is 50mA from the datasheet [19]. The supply voltage is 5V. We connected the 770 nm LED with a 68 ohm resistor in series so that it can get to the maximum brightness.

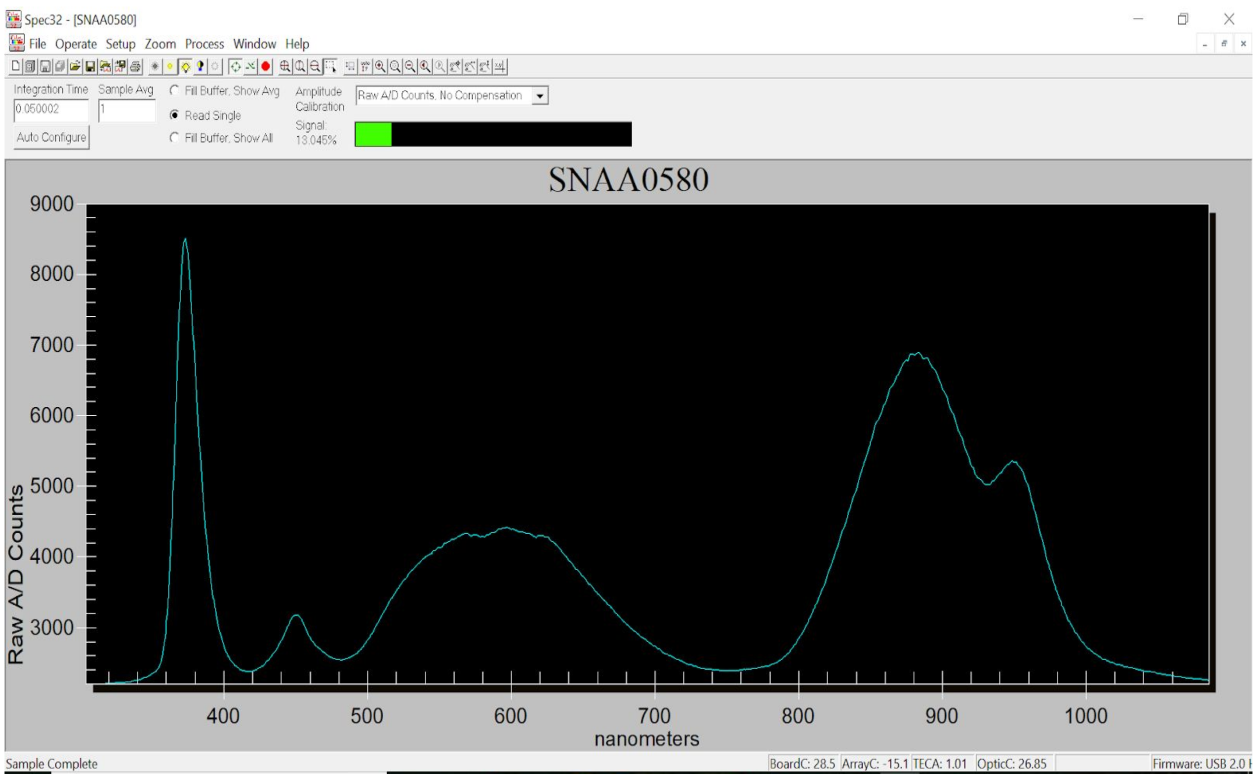

Figure 6: Spectrum of LEDs used in experiment

2.4.2 Sensor

The light sensor can detect the presence of kernel as it blocks the red light when sliding down the glass tube. The sensor can then send signal to the microcontroller to trigger the spectrometer to collect the data. We chose SD5600 honeywell sensor here to detect the light. This sensor has three pins, VCC, OUTPUT, and GND. As long as connect the output pin to an input pin of ATMega328P, the microcontroller can read the data. The SD5600 sensor can detect the light with wavelength around 850nm [20], by checking the datasheet of SD5600, we found that the relative sensitivity at 770 nm is about 0.9, which is good enough for our project.

2.5 Graphical User Interface (Matlab)

A simple interface can be created in Matlab, as shown here:

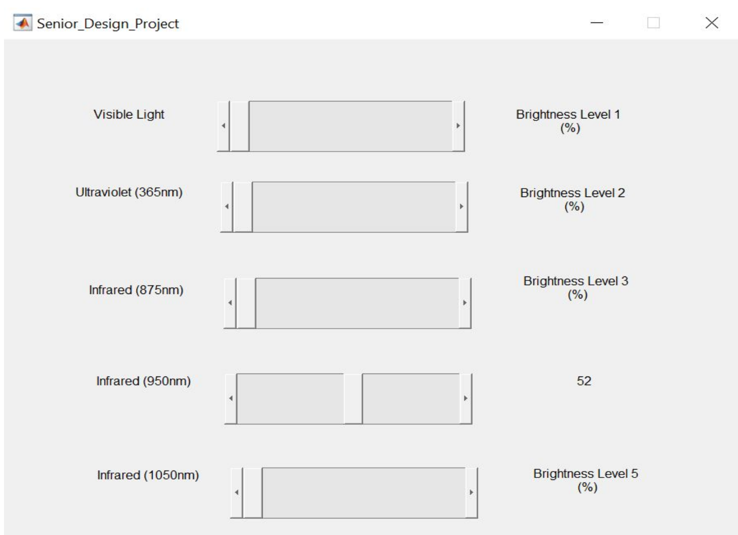

Figure 7: GUI Screen

The static text boxes on the right side are coded to show the percentage of the brightness level. The value of brightness level is calculated from the fraction from the slider bar, which has a maximum value of around 255. For each slider, we need to type code at its Callback function. At the output function at the beginning, we configure the serial connection to the specific port and "Arduino".

3. Design Verification

3.1 Power Module

3.1.1 Power Supply

Requirement: The output of the power supply is 11.6V-12.4V.

Testing Procedure and Results: Use an oscilloscope to measure the output voltage at barrel

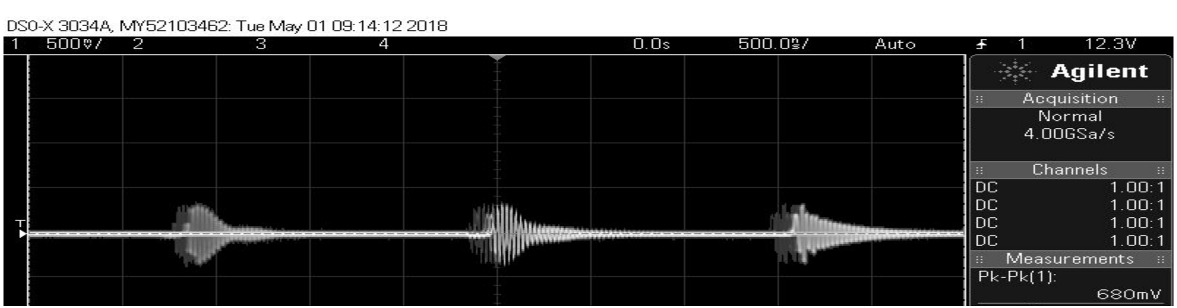

Figure 8: Capture of the power output from the oscilloscope

connector. The average value shown on the oscilloscope is 12.31V, which is within the range.

3.1.2 Voltage Regulator

Requirement: The voltage regulator is able to output 4.8V-5.2V.

Testing Procedure and Results: Use cable to connect the output from the voltage regulator to the oscilloscope. The average reading of both voltage regulators is around 4.97V and 4.96V, which are within the range stated.

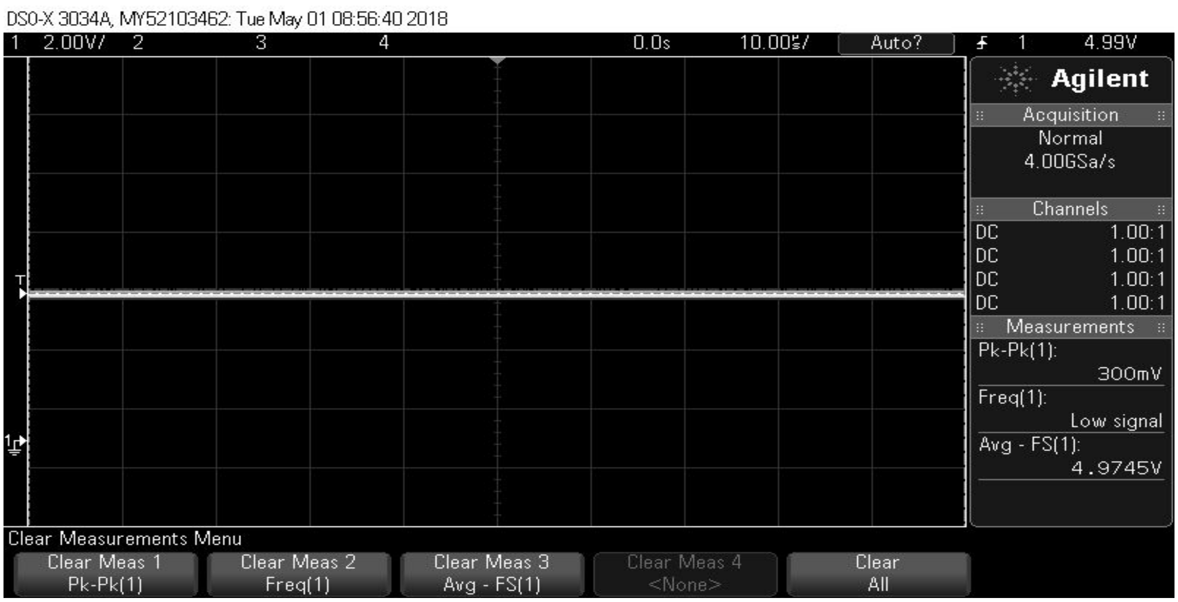

Figure 9 : Output of the first voltage regulator (on the board where power supply is connected)

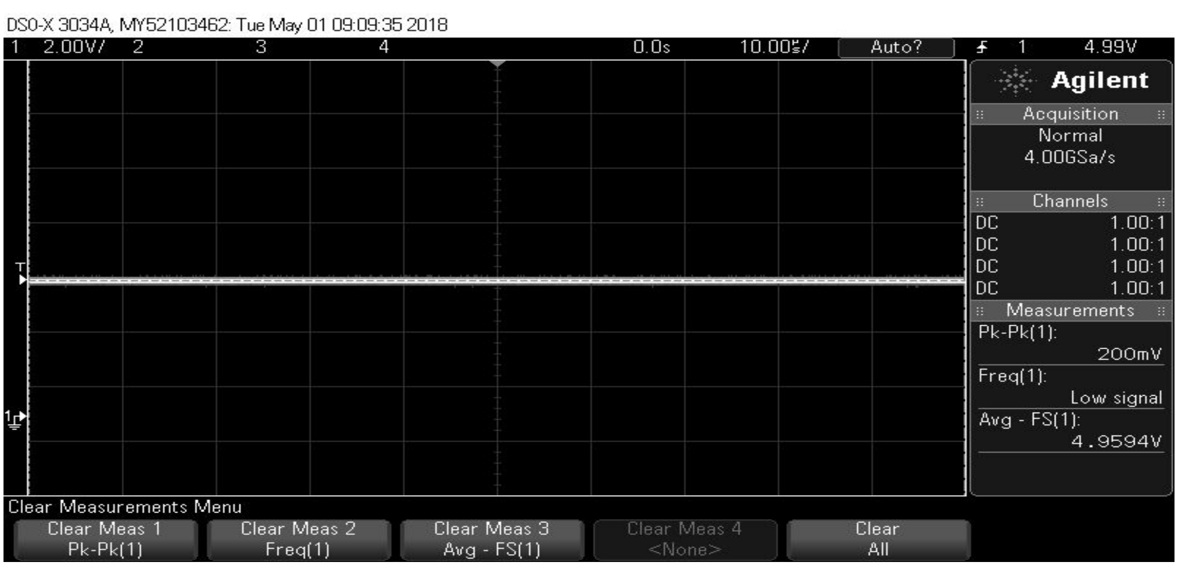

Figure 10: Output of the second voltage regulator (on the board where UV and TSHA5200 LEDs

are connected)

3.2 Control Module

3.2.1 Microcontroller

Requirement: It can transmit and receive signal via serial connection over RX/TX PIN to Arduino program. An operation status LED is placed between the FT232RL chip and ground.

Testing Procedure and Results: The microcontroller board was connected to the computer with a USB cable. We connected a red visible light LED with a 100 ohm resistor in series at pin12 of ATMega328P. We used the example blink code from Arduino IDE to test if the controller can transmit and receive the signal. The only change in the example code is we need to define that the LED is at pin 12. The LED at pin 12 blinked after done uploading message was displayed on the screen.

3.2.2 Operation Status LED

Requirement: Able to shine visible light when the circuit is working properly with 5V DC supply with a maximum current put through of 25mA.

Testing Procedure and Results: When we plugged the controller board into the laptop, the laptop can provide 5V voltage for the controller, and the operation status LED blinked for several times. Then it was off. When we uploaded code onto the controller, the operation status LED blinked for several times. After uploading is done, the LED were switched off.

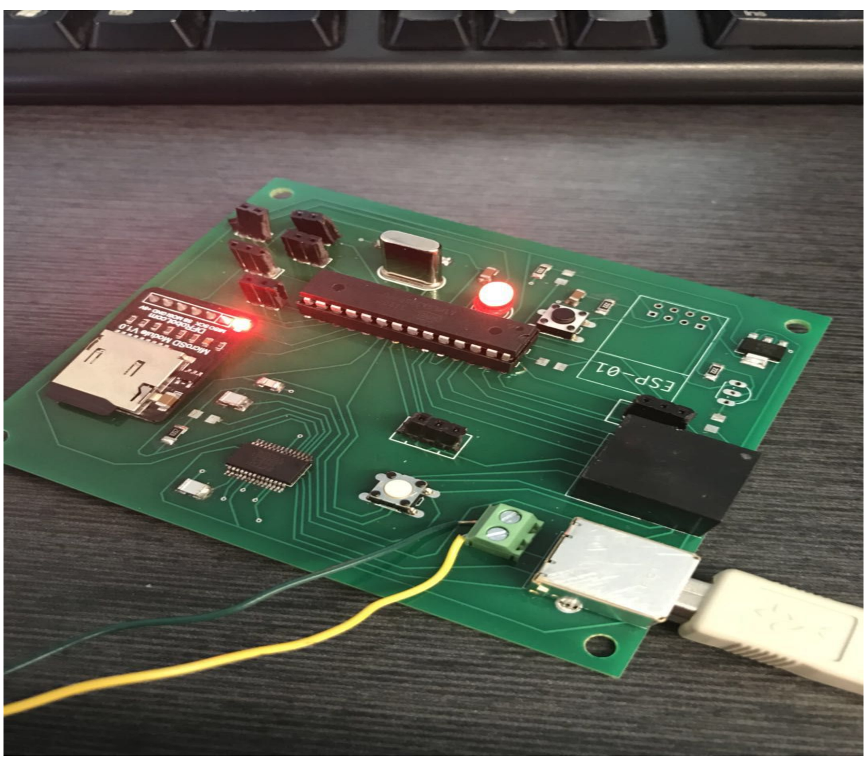

Figure 11: Microcontroller Board

3.3 LED Module (LED Balancing Circuit)

Requirement: The brightness of the same group of LEDs needs to be almost the same, whereby the forward voltage across the same type of LEDs are almost the same.

Testing Procedure and Results: Multimeter was used to measure the forward voltage across each LEDs on the circuit board. The data was collected and tabulated as below:

LED Part Number	Forward Voltage from datasheet (V)	Actual Voltage across LED (V)					
TSUS5400	1.3	1.385	1.365	1.394	1.428	1.358	1.585
TSHA5200	1.5	1.401	1.411	1.387	1.386	1.398	1.385
MTE5010	1.2	1.236	1.230	1.237	1.228	1.229	1.226
MTE3650	3.5	3.352	3.389	3.360	3.389	3.344	3.348
C513A (visible)	3.2	3.124	3.092	4.850	3.036	3.080	3.082

Table 1: Voltage Measured across Each LED

The actual forward voltage across LED are close to each other. The forward voltage in the table is the typical value, So it is normal that the actual voltage may be slightly different. Another reason for why some groups of LED has lower voltage compared with the forward voltage is that we chose higher resistance at the collector of the transistor. In order to find surface mount resistors with low price, small tolerance, and appropriate size, sometimes we chose slightly higher resistance to protect the circuit. There is only one exception among the data collected from C513A. After we made sure it's not the soldering issue, we assume it's because of the quality of that transistor.

After changing the duty cycle of the output voltage, we observed the amplitude change in spectrum. The amplitude decreased from 2800 to 2100. The spectrum are below.

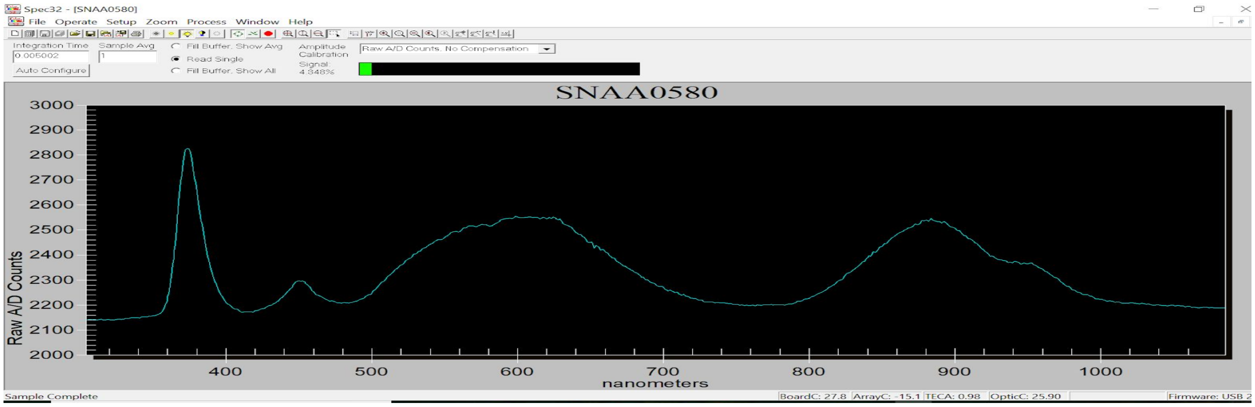

Figure 12: Spectrum at 100% Duty Cycle

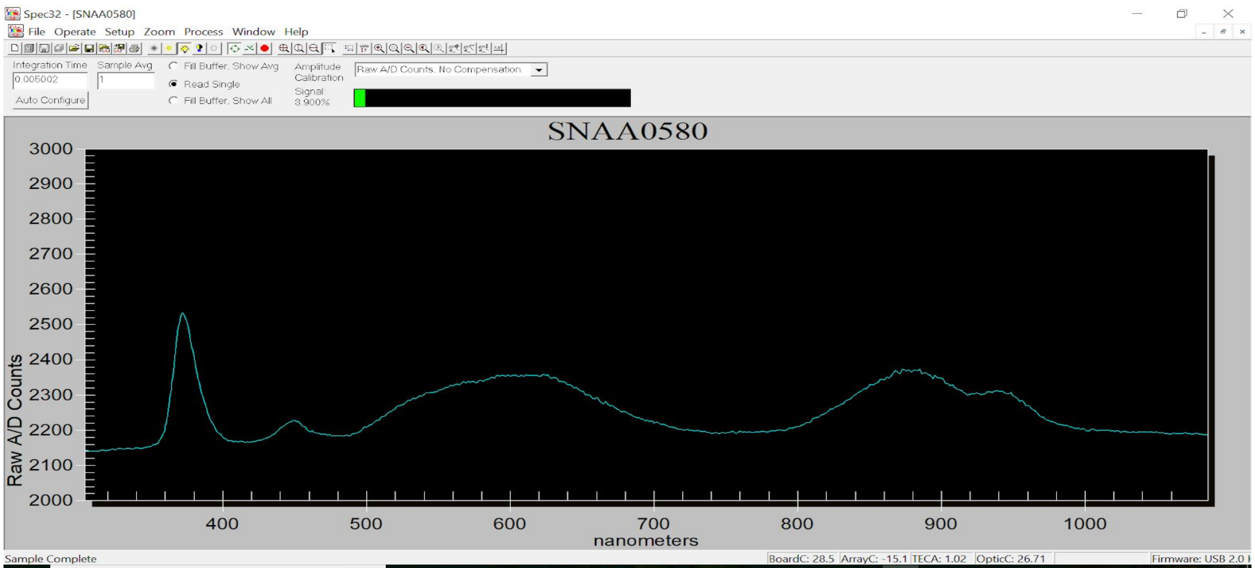

Figure 13: Spectrum at 50% Duty Cycle

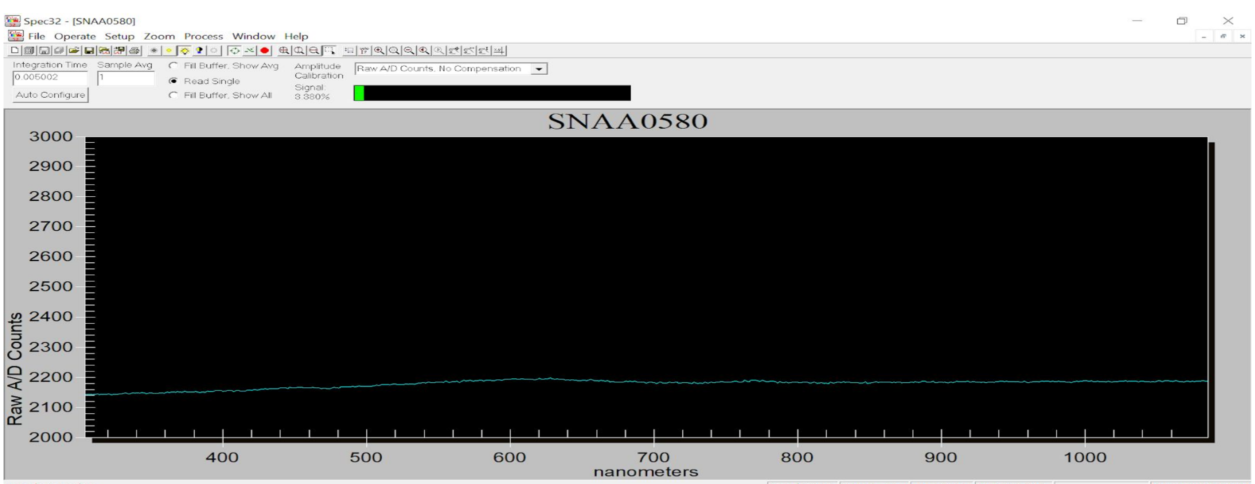

Figure 14: Spectrum at 0% Duty Cycle

3.4 Sensor Module

3.4.1 770 nm LED

Requirement: The two LEDs can light up and get to the maximum brightness.

Testing Procedure and Results: We observed that we can see the light from 1 meter away. We also used the multimeter to measure the voltage across the LED. The typical forward voltage from the datasheet is 1.55V. The voltage measured are 1.666V, and 1.680V. So these two 770 nm LEDs are in maximum brightness.

3.4.2 Sensor

Requirement: It can detect the light from the 770 nm LED, and send the analog signal to microcontroller.

Testing Procedure and Results: We connected the sensor on the controller board, used analogread to read the data from output pin of the sensor, then observed the value displayed on the monitor. When the light is blocked, the reading is around 1000, and when the light is detected, the reading is around 0. The data we collected is below.

Figure 14: sensor output when the light is blocked

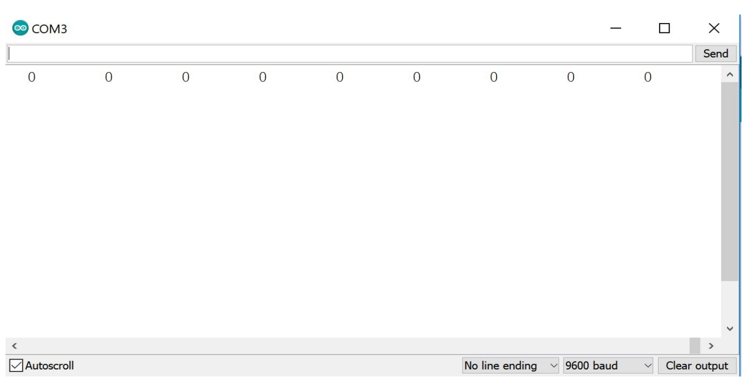

Figure 15: Sensor Reading When the Light is Detected

3.5 Graphical User Interface (Matlab)

Requirement: The interface consists of 5 check boxes and sliders for each type of LEDs, which let users to select which LEDs to switch on and adjust the brightness level.

Testing Procedure and Results: We ran and uploaded the code in Matlab. The GUI is adjustable for users. However, there is error to open a serial connection to our controller board. Generally, Matlab GUI is only able to interact with Arduino. Our board is not an actual Arduino.

4. Costs

4.1 Component List

Description	**Manufacturer Name**	**Retail Cost ($)**	**Quantity**	**Actual Cost ($)**
Standard LEDs - Through Hole Warm White Round	Cree, Inc.	0.25	6	1.50
EMITTER UV 365NM 300MA TO-39	Marktech Optoelectronics	21.50	6	129.00
SWIR EMITTER 1050NM TO-46 FLAT	Marktech Optoelectronics	45.01	6	270.06
Infrared Emitters 5V 22mW 875nm 12 Deg	Vishay Semiconductors	0.56	6	3.36
Infrared Emitters 22 Degree 210mW	Vishay Semiconductors	0.50	6	3.00
SGA60U12-P1J	MEAN WELL	19.13	1	19.13
350 TB FXD 180 TMT	Amphenol Anytek	0.35	13	4.57
LM2596S-5.0/NOPB	Texas Instruments	5.71	2	11.42
IC MCU 8BIT 32KB FLASH 28DIP	Microchip Technology	2.01	1	2.01
Multilayer Ceramic Capacitors MLCC - SMD/SMT 0805 35V 15uF X5R 20% T: 1.25mm	TDK	0.81	2	1.62
Tantalum Capacitors - Polymer SMD 10volts 220uF ESR 40mohm	Panasonic	1.92	2	3.84
Schottky Diodes & Rectifiers 4.0 Amp 30 Volt	Vishay-Semiconductor	0.99	2	1.98
Fixed Inductors SER2915H AEC-Q200 33 uH 10 % 30 A	Coilcraft	4.87	2	9.74
Thick Film Resistors - SMD 1206 3.09Kohms	Panasonic Industrial	0.10	2	0.20

1% AEC-Q200	Devices			
Thick Film Resistors - SMD	Yageo	0.22	2	0.44
Multilayer Ceramic Capacitors MLCC - SMD/SMT 1206 1200pF 25volts C0G 2%	Vishay / Vitramon	0.40	2	0.80
FT232RL-REEL	FTDI, Future Technology Devices International Ltd	4.50	4.50	4.50
EMITTER VISIBLE 770NM 50MA RAD	Marktech Optoelectronics	2.73	2	5.46
DETECTR OPTOSCHMITT TO-46	Honeywell Sensing and Productivity Solutions	10.63	2	21.26
CRYSTAL 16.0000MHZ 20PF T/H	ECS Inc.	0.60	2	1.20
ANALOG UV SENSOR BREAKOUT	Adafruit Industries LLC	6.50	1	6.50
RES SMD 22 OHM 1% 1W 2512	Yageo	0.33	12	3.92
RES SMD 1.4K OHM 1% 1/4W 1206	Yageo	0.03	12	0.40
RES SMD 47 OHM 0.1% 1/4W 1206	Panasonic Electronic Components	0.47	10	4.74
RES SMD 5.1K OHM 0.1% 1/4W 1210	Panasonic Electronic Components	0.50	10	5.01
RES SMD 4.7 OHM 1% 3/4W 1206	Vishay Dale	0.36	10	3.59
RES SMD 68 OHM 1% 1/4W 1206	Rohm Semiconductor	0.10	2	0.20
CAP CER 10UF 16V X5R 1206	Taiyo Yuden	0.34	3	1.02
RES SMD 2.2K OHM 0.1% 1/4W 1206	Panasonic Electronic Components	0.66	3	1.98
RES SMD 6.8K OHM 0.1% 1/4W 1206	Panasonic Electronic Components	0.66	3	1.98
RES SMD 100 OHM 0.5% 1W 1206	Susumu	0.97	3	2.91
RES SMD 10K OHM 0.1% 1/4W 1206	Yageo	0.55	3	1.65
RES SMD 20K OHM 0.1% 1/4W 1206	Panasonic Electronic Components	0.66	3	1.98

CONN RCPT USB TYPE B R/A PCB	Amphenol FCI	0.92	2	1.84
	Total			532.81

4.2 Labor

Team member	Hourly Rate	Total Hours	Total Costs (Rate*Hours*2.5)
Jiahui Chen	$40	100	$10,000
Foong Yee Wong	$40	100	$10,000
Team Total	$40	200	$20,000

4.3 Total Cost

Components	Labor	Total
$532.81	$20,000	$20532.81

5.Conclusion

5.1 Accomplishments

The code in the Arduino is able to communicate with our designed controller board to control the brightness of the LEDs and to trigger the spectrometer. The brightness of the LEDs are also balanced, whereby the forward voltage of the same type of LEDs are almost the same. Spectrum can also be collected and displayed on a computer or laptop. The spectrum then helps us to determine which group of LEDs has the highest intensity.

5.2 Uncertainties

The uncertainty in this project is the thermal issue. It is challenging for us to exact the heat dissipation and hence the temperature rise. We can check the temperature by using an infrared thermometer. The solution for this issue is to perform simulation with the WEBENCH Power Designer suggested in the datasheet [4]. The online simulation can show us the temperature of the whole board, therefore we can get an idea on how to choose parts which can make the circuit safer.

5.3 Ethical considerations

The purpose of our project is to design a device which can help to detect Aflatoxin in grains. This project is related to solving the issue of food safety. This is an implementation of IEEE ethics code #1 -- holding paramount the health of the public [21]. The device we design will be used by the department of Food Science and Human Nutrition research team so that they can further study aflatoxin in grains. Their research results will help the public to improve the understanding of the emerging technologies for the detection of toxins in food. This is also the IEEE ethics code #5 required [21]. At the same time, contributing to society and human well-being is also the requirement in ACM code of ethics [22].

During the testing of our project, some data is not as we expected. For example, the voltage across one of the visible light LED is 4.85V, which should be around 3.5V. We didn't ignore the error or write a fake data in our report. Instead, we admitted this error and tried to find the reason why we got this error. It's required in IEEE ethic code #3 -- to be honest and realistic in stating claims or estimates based on available data and #7 -- to seek and accept honest criticism of technical work, to acknowledge and correct errors [21].

There are several potential safety hazards with our project. In our project, we used 30 LEDs, including some UV LEDs. UV radiation may harm human's eyes. Exposure to ultraviolet (UV) radiation have acute harmful effects and chronic harmful effects. The acute harmful effects is short-lived and reversible. Sunburn (or erythema) and tanning (or pigment darkening) are examples of this. UV-A and UV-B may cause acute harmful effects. Besides acute effects, chronic effects are more serious. Premature aging of the skin, suppression of the immune system, damage to the eyes, and skin cancer are all possible chronic harmful effects of exposure to UV. So sometimes it's life threatening [23].

5.4 Future work

The hardware can be improved by increasing the thickness of the board and trace so the current can have more space to flow. Additional, a box can be made for the light tube and the PCB stack. The lab environment which our product will be placed at requires Biology Safety Level 2. It is essential for the researchers at the facilities to be able to perform maintenance easily for our design. Therefore, we need to have proper way to isolate the circuit from the chemical compounds used to decontaminate the system, such that there won't be any toxic or chemical reaction which may take place with our product.

The software can be improved as well. First, we should be able to store the data collected from the spectrometer, and do the comparison with the standard value to filter out good kernels and bad kernels. Second, we may continue improvement on programming method, by using another method for the GUI for our controller board. Python could be a more suitable option for this project.

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Appendix A: Requirement and Verification Table

Requirement and Verification Table

Power module

Requirement	Verification	Verification Status
The output of the power supply is 11.6V-12.4V.	Use a digital multimeter to measure the output voltage and current at the 2 pins of barrel connector (at the bottom of the circuit board) and check whether it is around 12V.	Y

Voltage Regulator module

Requirement	Verification	Result
The voltage regulator is able to output 4.8V-5.2V.	1. Solder all components on the voltage regulator PCB. 2. Connect two wires (output and ground) on the PCB, and insert them on to the breadboard. 3. Use power supply to generate 12V DC input voltage. Connect ground of the power supply and the PCB on the breadboard. 4. Use the oscilloscope to measure the average voltage, peak-to-peak value, and amplitude value, across the resistors.	Y

Microcontroller Board

Requirement	Verification	Result
1) Can transmit and receive signal via serial connection over RX/TX PIN to Matlab Graphical User Interface. 2) An operation status LED is placed between the FT232RL chip and ground. 3) Can send trigger signal to the spectrometer after receiving signal change from light sensor. 4) Can control the brightness of different groups of LEDs.	1. Connect the microcontroller board to the computer by using a USB cable. 2. Check whether the operation status LED lights up. 3. Set up program to monitor the correct COM port and check whether data can be transferred 1. Check the computer (connected to spectrometer) to see whether data is collected, when the trigger signal is sent.	Y

Matlab Graphical User Interface

Requirement	Verification	Result
1) The interface consists of 5 check boxes and sliders for each type of LEDs. 2) They enable users to select which LEDs to switch on and adjust the brightness level. .	1) After running the code, check whether the selected LEDs are switched on. 2) Their brightness level is checked for some trials to make sure that the slider is working when the slider is changed.	N

Sensing Module (Two sets of 770nm LEDs and light sensor)

Requirement	Verification	Result
The LEDs can light up.	Observe whether there is light emitting from the two LEDs.	Y
The light sensors are connected to the microcontroller and is able to transfer signal change due to the change in brightness.	1. Align each light sensor with the emitting diode and check if the microcontroller receives signal. 2. Block the light in front of the sensor and check if there is change in the data collected in the serial monitor.	Y

LED Balancing Circuit

Requirement	Verification	Result

LEDs can reach the maximum brightness when the duty cycle is set to 99.9% on the function generator.	A. Connect the circuit on the breadboard. Use the 5V power supply at the collector of the transistor, and function generator at the base of the transistor. B. Set the input signal shape to be square; peak-to-peak value to be 5V; offset to be 2.5V, frequency to be 1000 Hz, and duty cycle to be 99.9% (maximum). C. Measure the current and voltage across the LED, read the data from the sensor or observe the brightness. a) For the visible LEDs (C513A-MSN-CW0Z0232), observe the light emitted to make sure they are working well. The current through it should be 25-30mA, the voltage across it should be 3.0V - 4.0V. b) For the infrared (IR) LEDs (MTE5010-095-IR, TSHA5200 and TSUS5400), use SI1145 sensor breakout board to get the data of IR index. Cover the IR LEDs with a box when they light up. Check the reading to make sure that they are above 300. The voltage across them should be 1.0V -1.4V, 1.2V-1.8V, 1.0-1.7V. The current through them should be 85mA-110mA, 95mA-115mA, 120mA-160mA.	Y

	c) For the ultraviolet (UV) LEDs (MTE3650L2-UV-HP), use GUVA-S12SD to collect the index data to make sure that the LEDs are working normally. Cover the UV LEDs with a box when they light up. Wear goggles for further protection. The current through it should be 220-300mA, the voltage across it should be 3.0V-4.0V.	
The brightness of the LEDs can be changed by changing the duty cycle (average output voltage)	A. Connect the LED circuit on the breadboard. Use the 5V power supply at the collector of the transistor, and function generator at the base of the transistor. B. Set the input signal shape to be square; peak-to-peak value to be 5V; offset to be 2.5V, frequency to be 1000 Hz. C. Change the duty cycle from 99.9% to 1%. Observe the decrease of brightness of the visible LEDs. For IR and UV LEDs, use sensor breakout board to collect the index data. The frequency of the occurrence of high value should decrease. Compare the current and voltage data with the data we got from maximum brightness test to see if there is brightness change.	Y

Appendix B: PCB Design

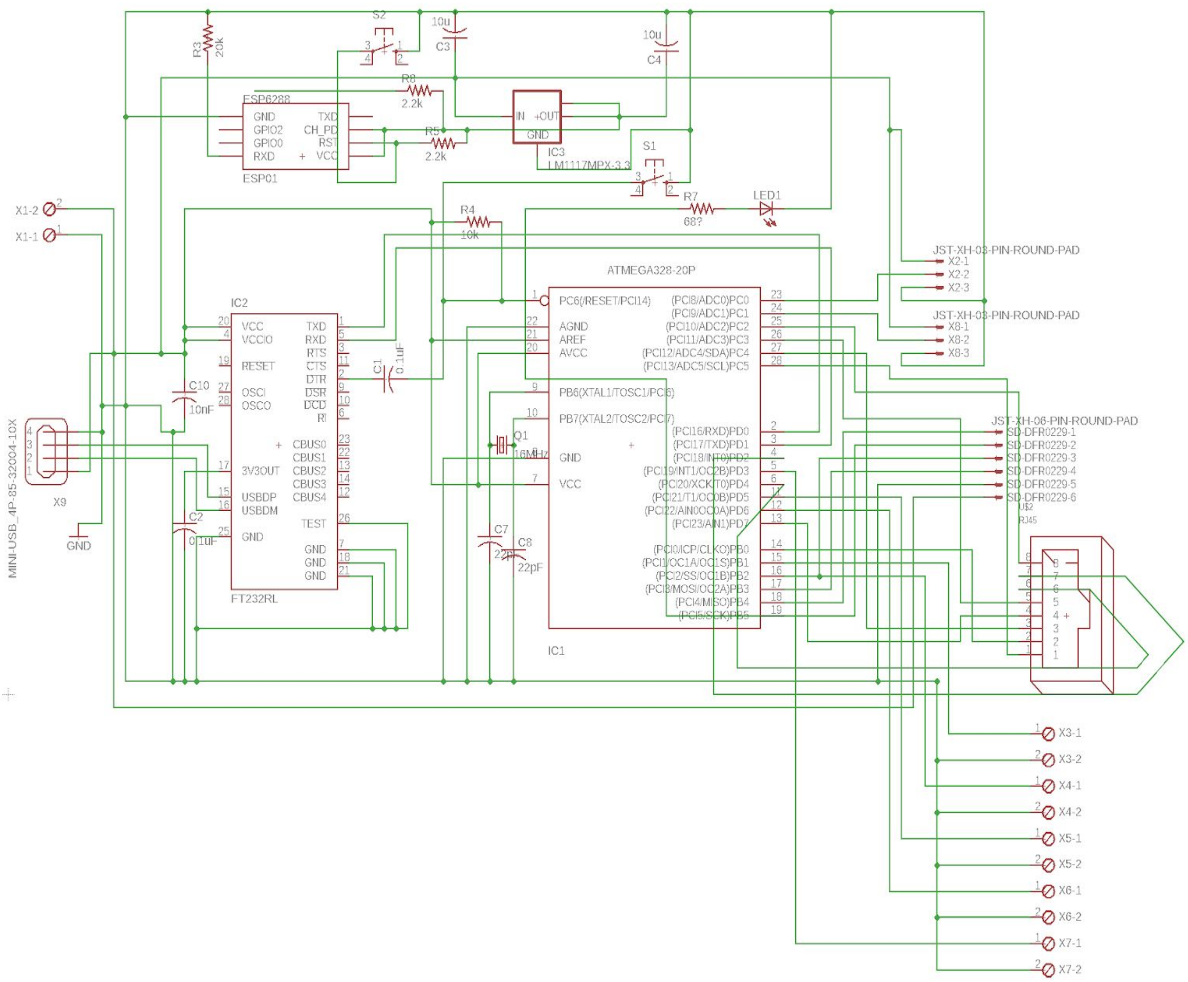

Figure 16: Controller Schematic

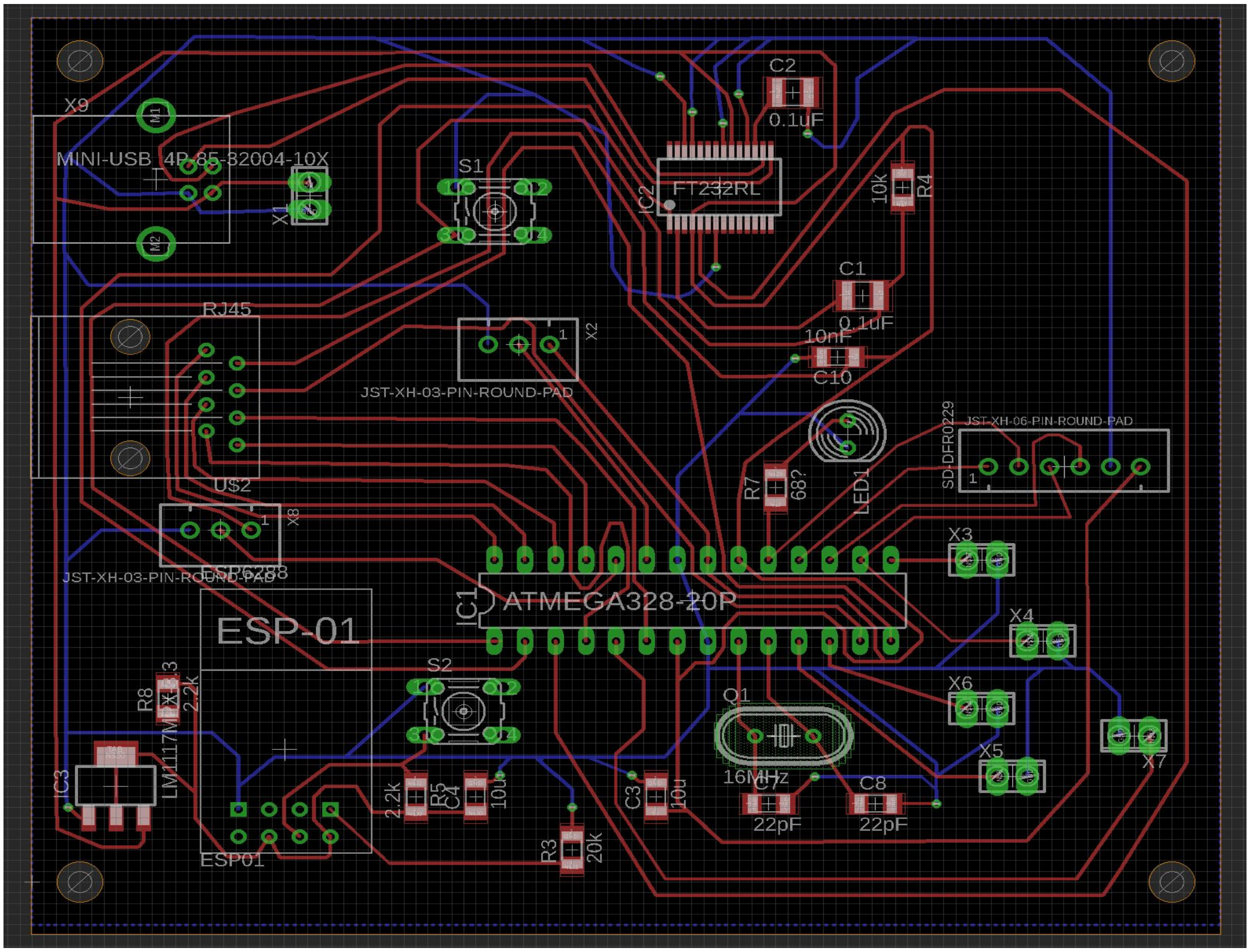

Figure 17: Controller PCB Design

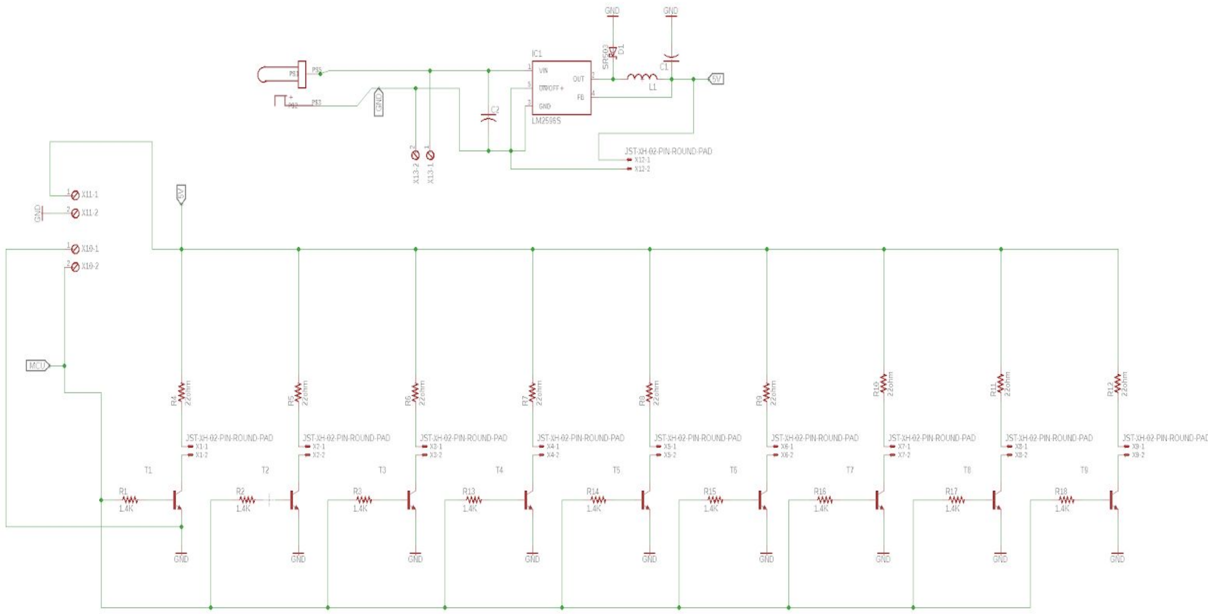

Figure 18: TSUS 5400 LED Schematic

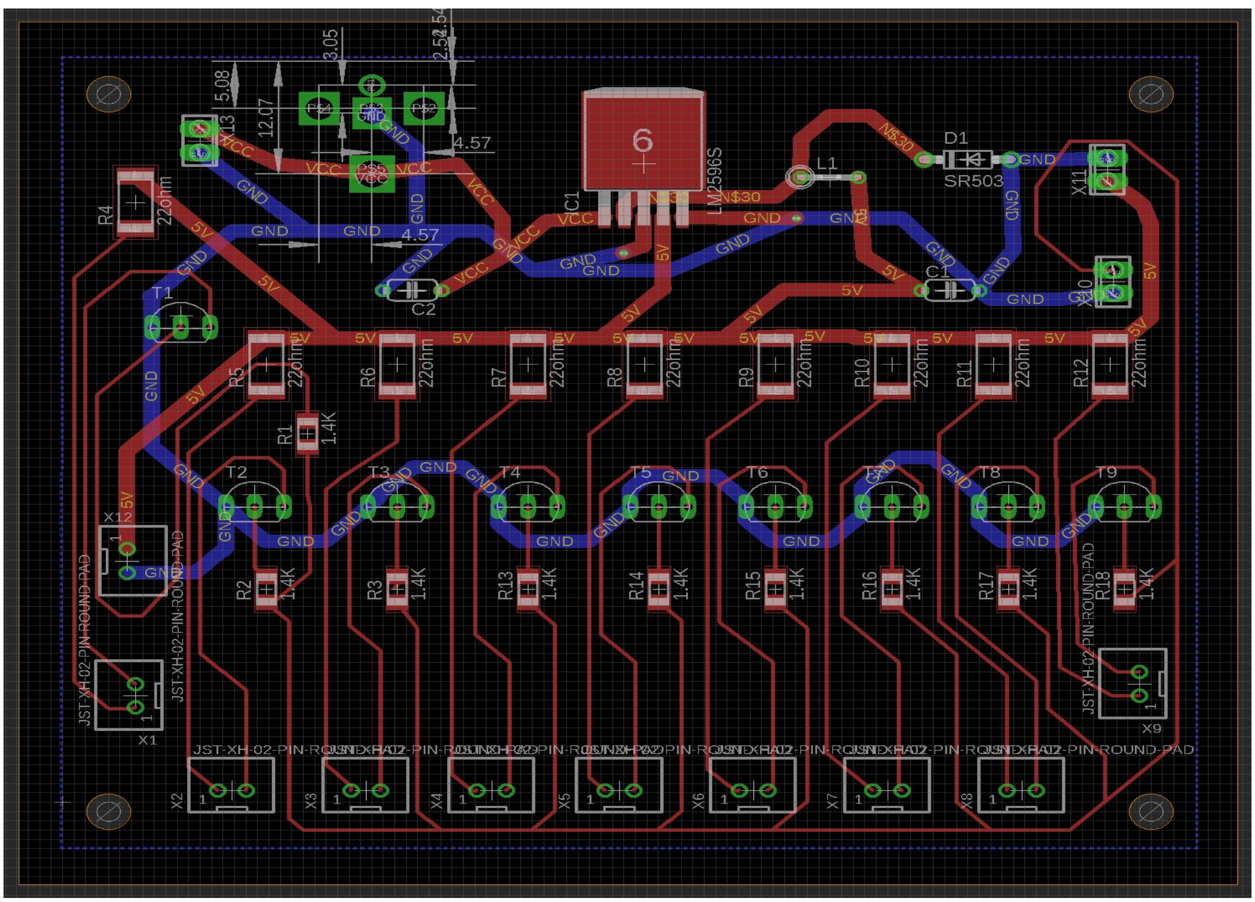

Figure 19: TSUS 5400 LED PCB Design

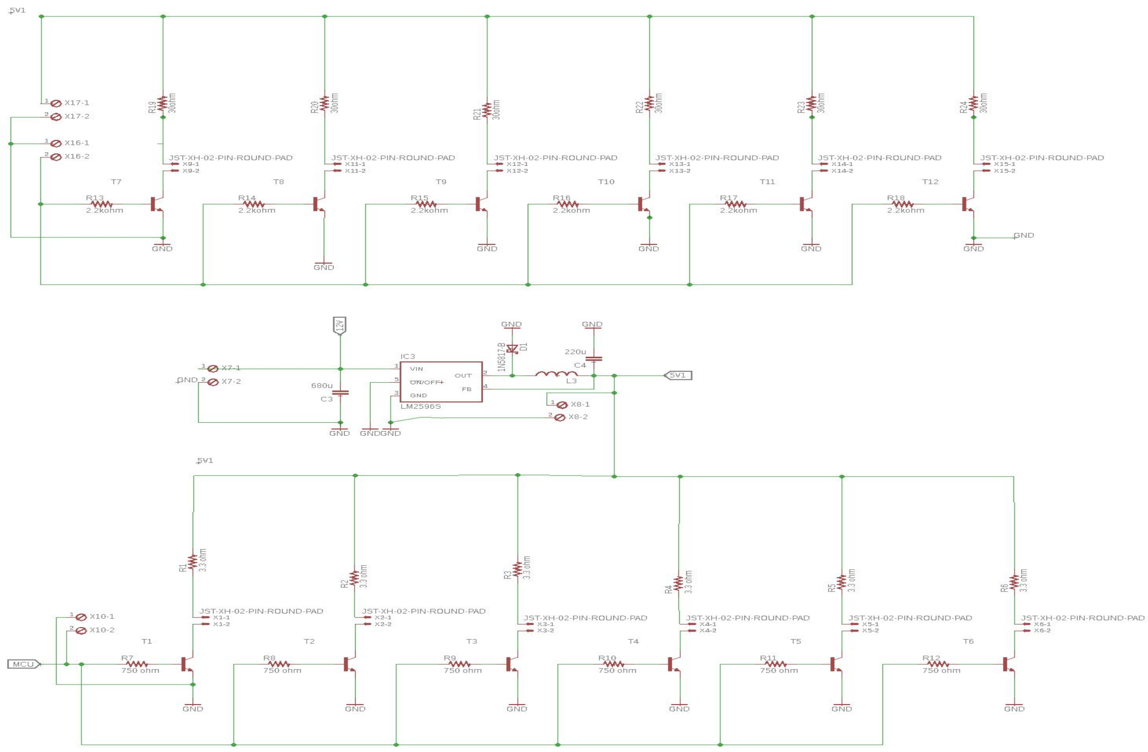

Figure 20: IR and UV LED Schematic

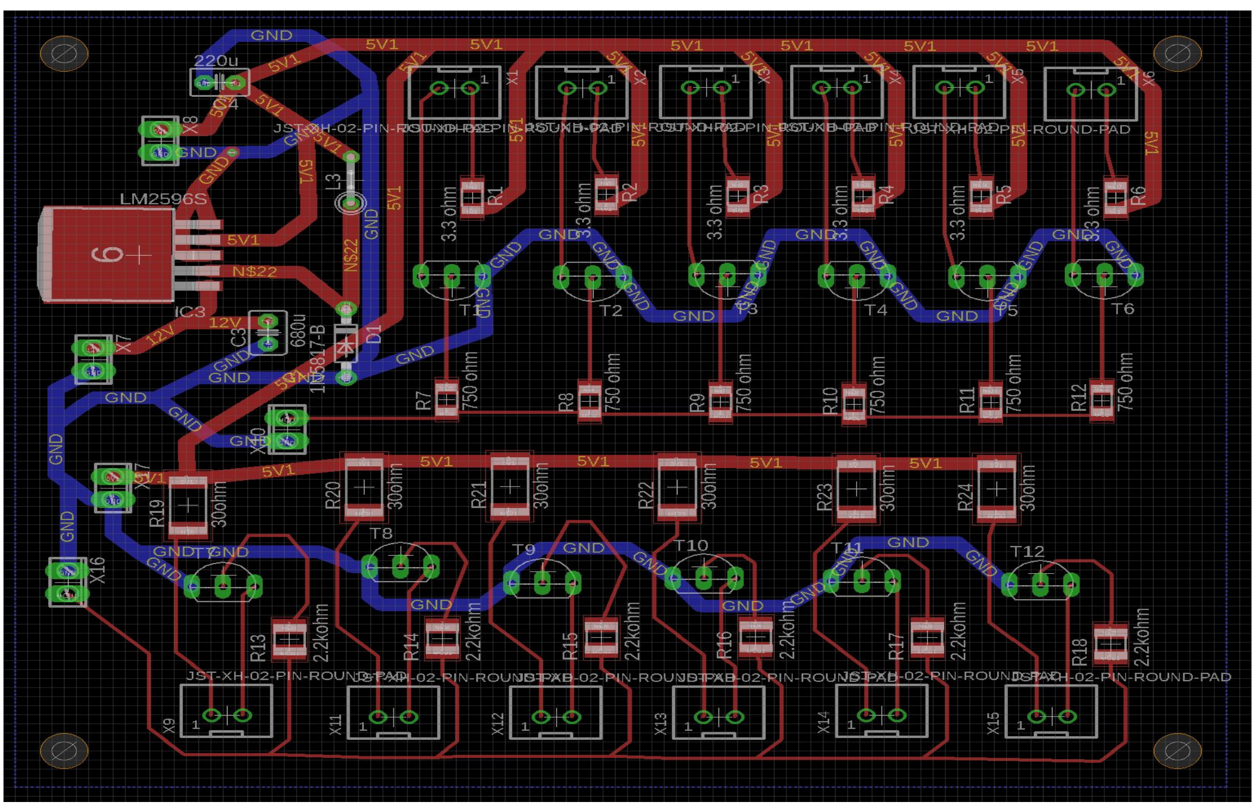

Figure 21: IR and UV LED PCB Design

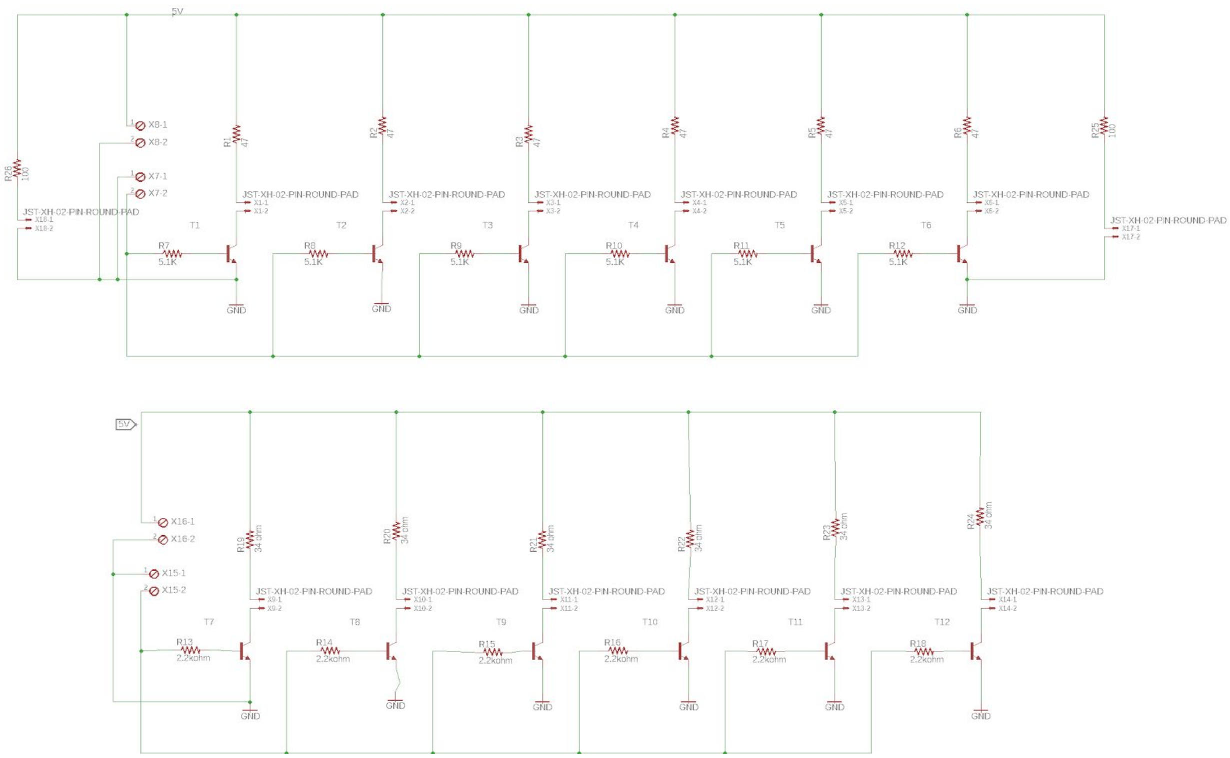

Figure 22: IR and Visible LED Schematic

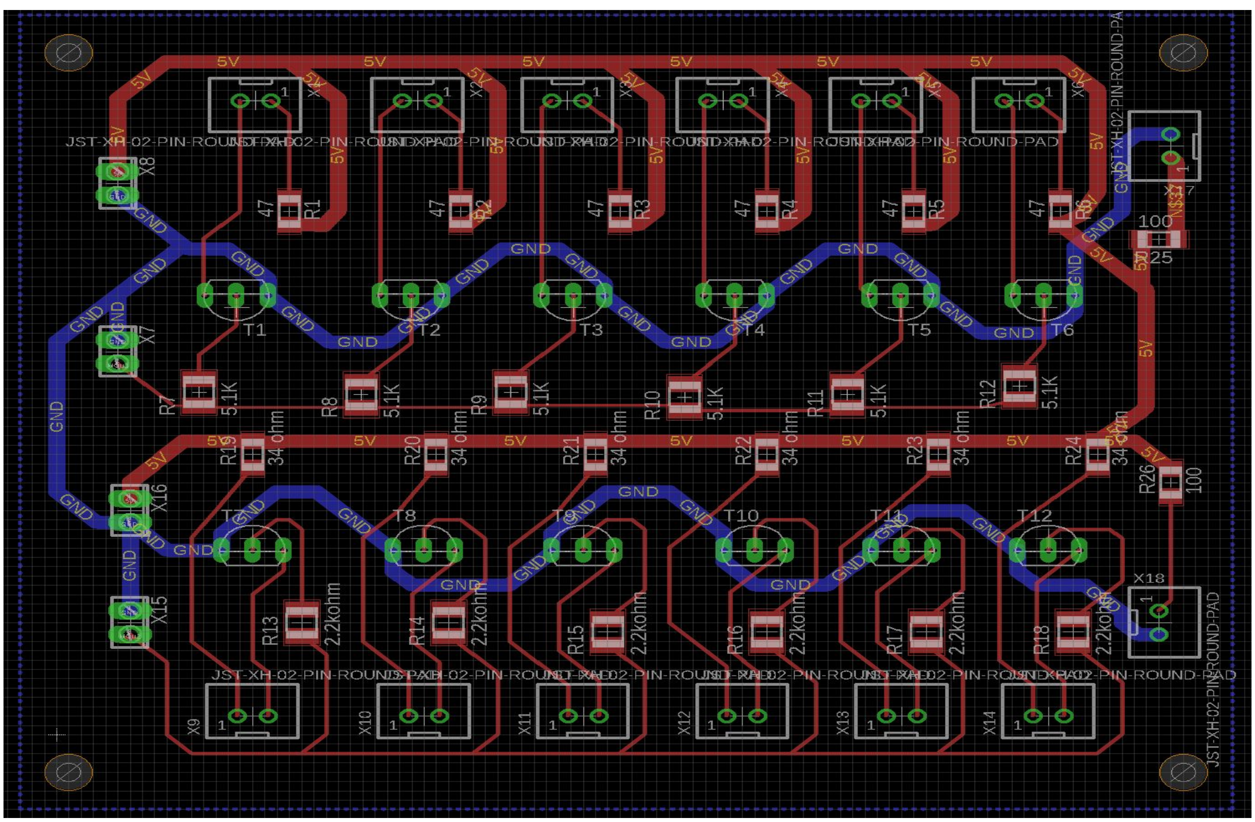

Figure 23: IR and Visible LED PCB Desig

Appendix C: Final Implementation of Physical Design

Figure 24: Close-up View for the Power Adapter

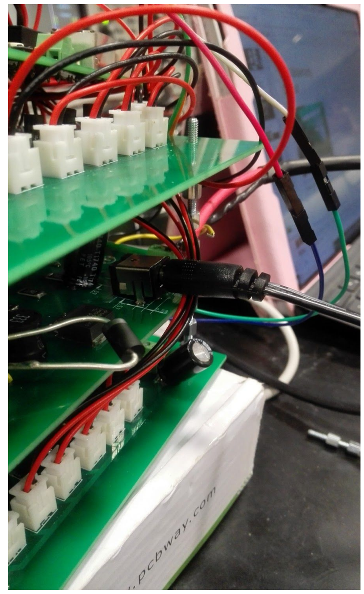

Figure 25: Close-up view at the barrel jack and barrel connector

Figure 26: Close-up view at the spectrometer

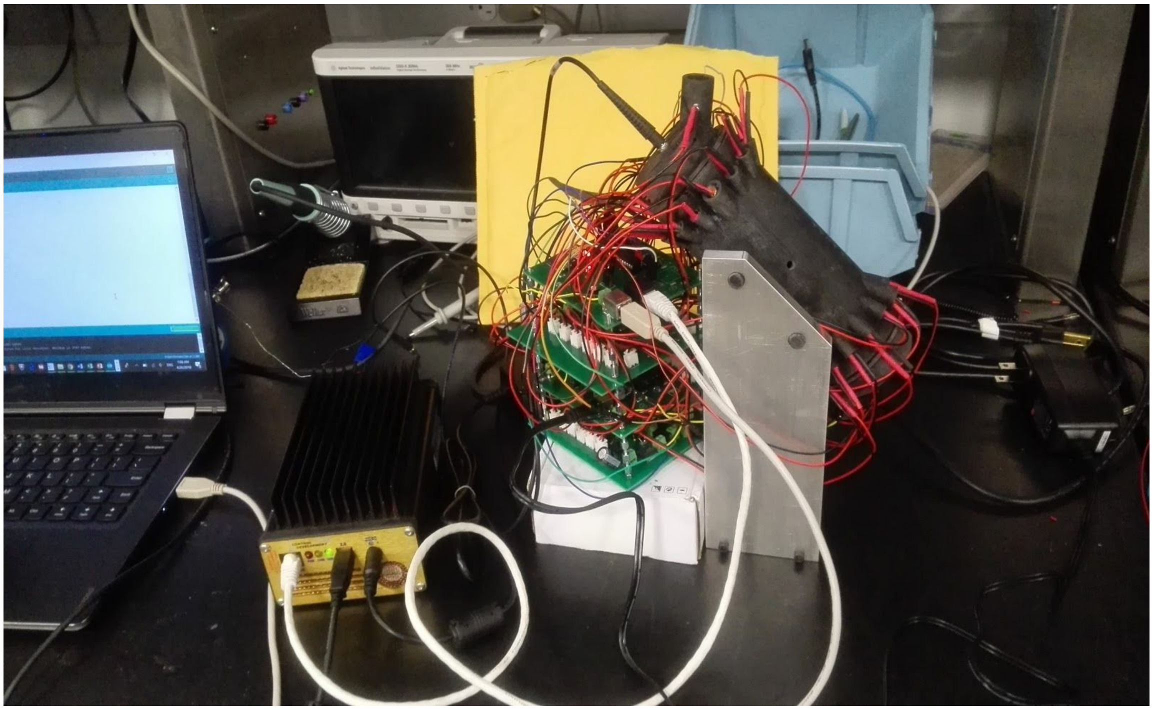

Figure 27: Set-up of the Project