BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 460 (January 2024)

Optoelectronics Laboratory

Final Project Report

Section: G2 Group: 02

Webcam based Spectrometer

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Signature of Instructor: ______________________________

Academic Honesty Statement:

IMPORTANT! Please carefully read and sign the Academic Honesty Statement, below. <u>Type the student ID and name, and put your signature</u>. ***You will not receive credit for this project experiment unless this statement is signed in the presence of your lab instructor.***

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

Signature: ____________ **Full Name: Dipika Rani Nath** **Student ID: 1906092**	**Signature:** ____________ **Full Name: Zahin Ikbal Zeal** **Student ID: 1906101**
Signature: ____________ **Full Name: Jannatul Ferdous** **Student ID: 1906103**	**Signature:** ____________ **Full Name: Fahim Ahmed** **Student ID: 1906110**

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1 Abstract

This project introduces the design and implementation of a spectrometer based on a webcam, featuring a compact and affordable setup. A diffraction grating, derived from a compact disc (CD), was used to separate incoming light into its spectral components. A standard webcam captured the dispersed light, and the resulting image was sent to a computer for analysis. By applying image processing techniques and manual calibration, the spectral profile of the incident light was successfully plotted. This spectral profile gives us an idea regarding the intensity of various wavelength components of our LED sources and helps us analyze the composition of white light.

2 Introduction

Spectroscopy is a fundamental technique in optics that involves the study of how light interacts with matter by analyzing its spectral components. It works by dispersing light into its constituent wavelengths, enabling the investigation of properties such as absorption, emission, and reflection. In optics, spectroscopy plays a crucial role in understanding the behavior of light and its interaction with various materials, helping to determine their optical properties, such as refractive index, transparency, and composition. This technique is widely used in designing optical devices, studying light-matter interactions, and advancing fields like photonics, fiber optics, and optical engineering. Some of the essential parameters in terms of spectroscopy include peak wavelength which is the wavelength at which the LED's spectrum has maximum intensity. Depending on the color of the LED there can be more than one peak in the curve. Besides there is the spectral distribution which is the distribution curve of the relative intensity shows power of each power against its wavelength. From this spectral power distribution curve main wavelengths of the LED can be estimated.

3 Design

3.1 Problem Formulation (PO(b))

The spectral analysis of LEDs usually relies on spectroscopes or other professional-grade optical instruments to examine the emitted light. In this project, however, the objective is to develop a low-cost setup using a standard webcam to capture the light source's image and analyze it to determine its spectral properties. This method presents several challenges that need to be overcome to ensure accurate and dependable results.

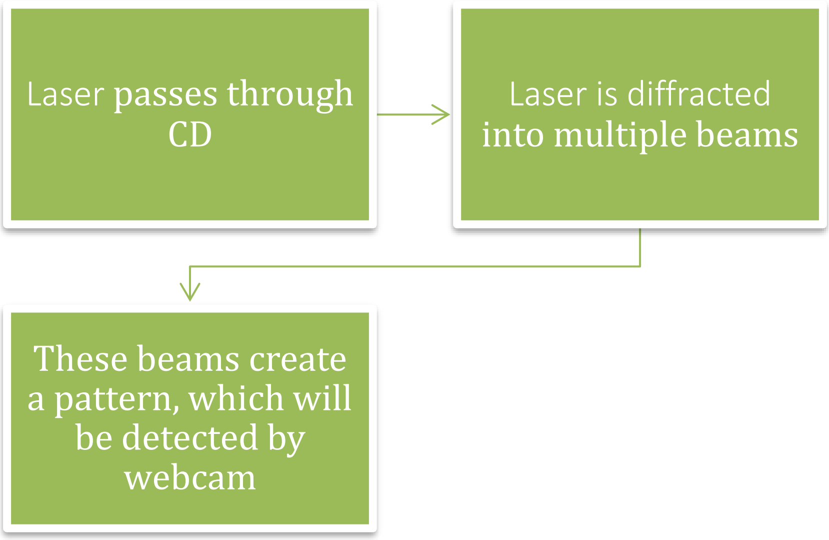
Analyzing the problem formulation gives us an idea regarding the steps we needed to follow to get this project working. The webcam that was used for analyzing light took in raw data, which are not suitable for spectral analysis as light of various wavelengths for the sources are blended, and for us to analyze it, we needed to sperate in its spectral components. For this, analyzers such as prisms are needed which provide high precision, but is cost extensive, and for that matter we had to compromise for a less efficient dvd grooves.

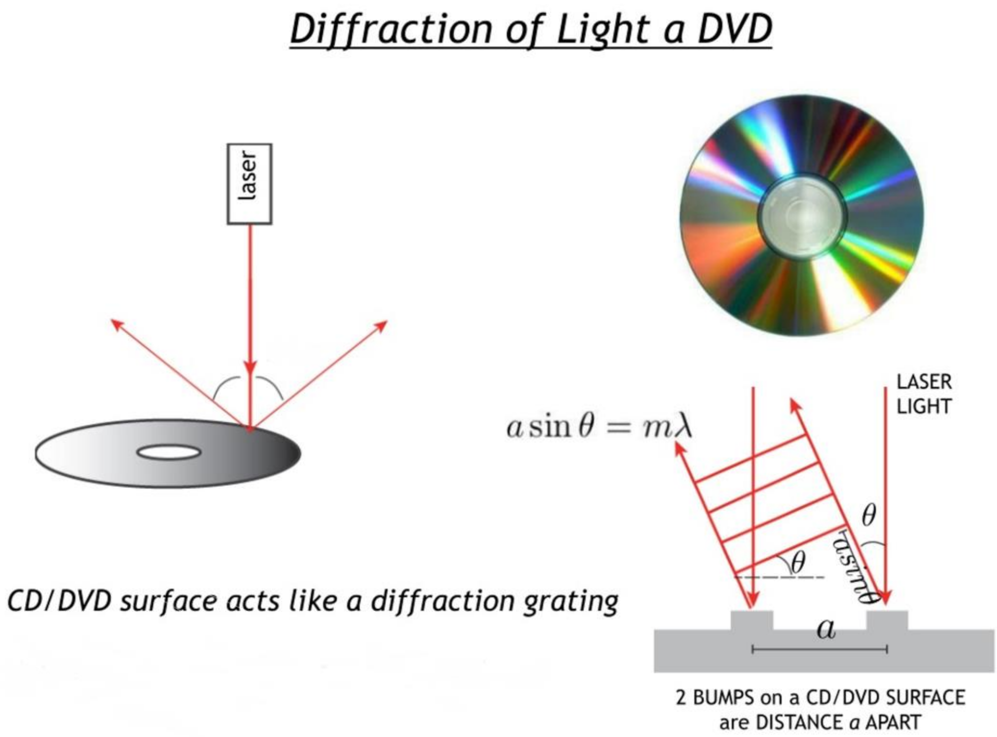
Again there are the surrounding factors such as external light which hinders the accuracy of the experiment, by interfering with the source lighting. This in turn would inhibit the accuracy. For that matter, the setup was designed in such a way as to reduce the external issues as much as possible.

Addressing these challenges requires innovative problem-solving and the development of a practical, low-cost system for spectral analysis, suitable for applications in resource-constrained environments.

3.1.1 Identification of Scope

Process of Grating:





3.1.2 Analysis

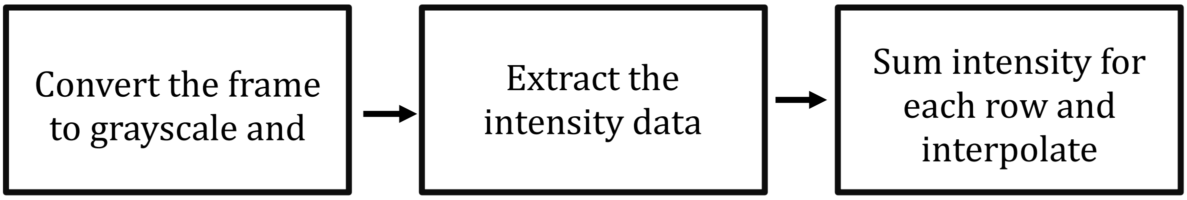
As light sources, we primarily used LEDs, the LED light after passing through the slit of the casing falls onto the grooves of dvd surface, and undergoes diffraction. Relating with the figure above,

Process of grating

- a*sin(theta)=m*lambda
- a is the spacing between the grooves on the CD
- m is the ortder of the diffraction grating
- Theta is the angle of diffraction

When laser passes through CD, it is diffracted into multiple beams. These beams create a pattern, which will be detected by webcam.

3.2Simulation Model



3.3Hardware Design

Components

WEBCAM (MICROPACK MWB-16)

LED & LASERS

BOX

CD

3.4 Full Source Code of Firmware

[7]:
```
import cv2
import numpy as np
import matplotlib
print(matplotlib.get_backend())  # Check current backend
matplotlib.use('TkAgg')  # Example: Set to TkAgg if not already

import matplotlib.pyplot as plt
```

```
TkAgg
```

[8]:
```
#===Camera Setup===
camera_index = 1     # Index 0 for laptop cam, 1 for external cam
# Create video capture object
cap = cv2.VideoCapture(camera_index)
# Set video capture parameters
cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)  # Adjust resolution if needed
cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)

if not cap.isOpened():
    print("Error: Camera not accessible.")
    exit()
```

```python
calib = 25# Calibration offset

# Set up plot
plt.ion()  # Turn on interactive mode
fig, ax = plt.subplots()
ax.set_xlabel('Wavelength (nm)')
ax.set_ylabel('Intensity')

# Initialize intensity array and wavelength vector
#intensity_array = []

# Placeholder for intensity data
wavelength = np.linspace( 100+ calib, 1000 + calib,640)[::-1]
initial_intensity=np.zeros_like(wavelength)  # Start with zeros

#Plot the initial data
line, = ax.plot(wavelength, initial_intensity, 'r-')  # Red line

ax.set_xlim([100 + calib, 1000 + calib])
ax.set_ylim([0, 255 * 480 * 1.1])  # Example: Max grayscale sum

frame_count = 0  # Debugging counter for frames
```

```python
while True:
    ret, frame = cap.read()
    if not ret:
        print("Error: Failed to capture frame.")
        break

    frame_count += 1
    print(f"Frame {frame_count}: Captured successfully.")  # Debug frame capture

    # Convert to grayscale
    gray_image = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
    cv2.imshow("Live Video Feed (Grayscale)", gray_image)  # Show grayscale feed

    # Calculate intensity (sum of each column)
    intensity = np.sum(gray_image, axis=0)
    print(f"Frame {frame_count}: Intensity max = {np.max(intensity)}, min = {np.min(intensity)}")  # Debug intensity

    # Update plot data dynamically
    line.set_ydata(intensity)  # Update y-data (intensity)
    ax.set_ylim(0, np.max(intensity) * 1.1)  # Adjust y-axis dynamically

    plt.draw()  # Refresh the plot
    plt.pause(0.01)  # Allow time for the plot to update

    # Break the loop if 'q' is pressed
    if cv2.waitKey(1) & 0xFF == ord('q'):
        print("Exiting loop.")
        break
```

```python
[6]: # Release resources
     cap.release()
     cv2.destroyAllWindows()
     plt.ioff()  # Turn off interactive mode
     plt.show()
```

Table: Source Code for the main program

4 Implementation

Fig: Hardware setup

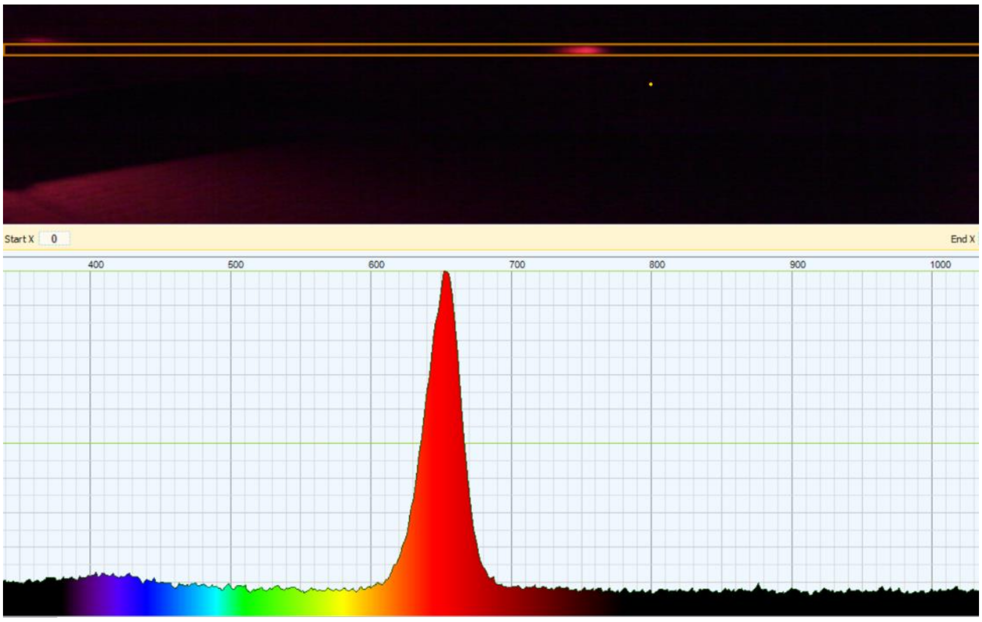
4.1 Description

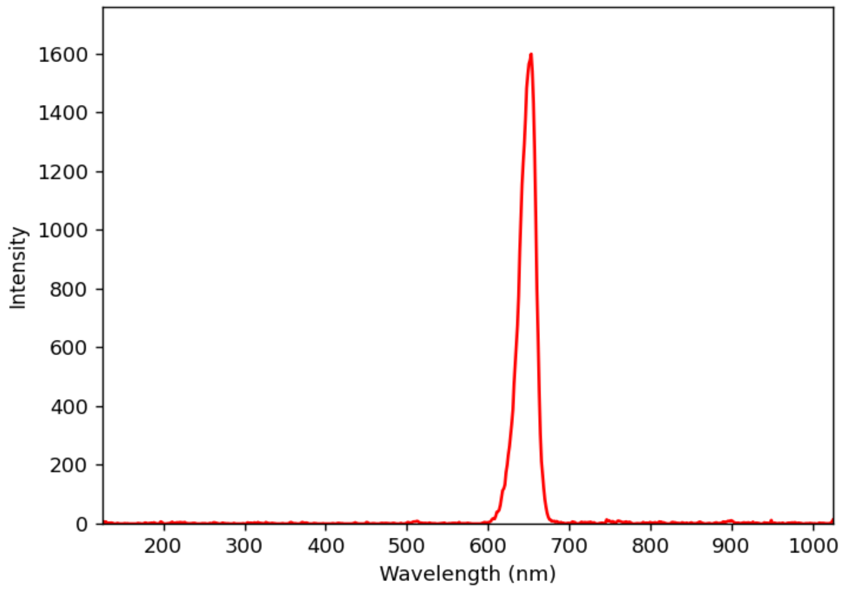
The purpose of this project was to design a system to analyze the spectral charavteristics of LED, using a webcam. The hardware housing was designed in such a way to reduce the descripancies as much as possible, by limiting the interference of external light sources. The LEDs were powered by a 9V battery, the intensity was controlled by a potentiometer.

4.2 Experiment and Data Collection

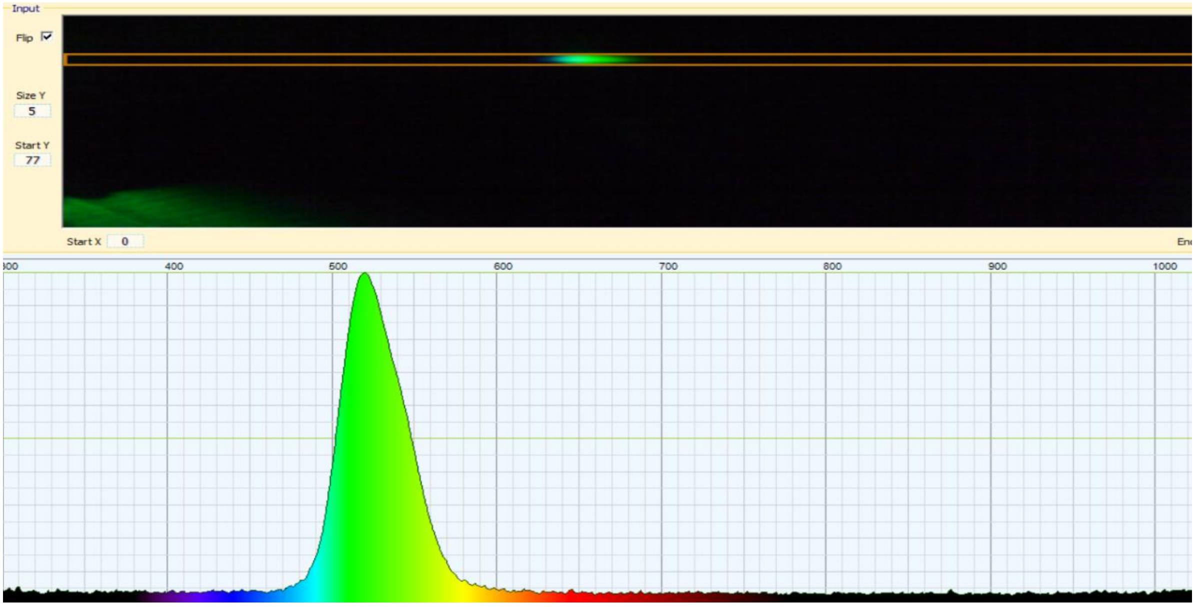
Data collection was performed in two stages. Firsty the spectrum from theremino software was analyzed. For the same LED, the spectrum was observed for our hand written code.

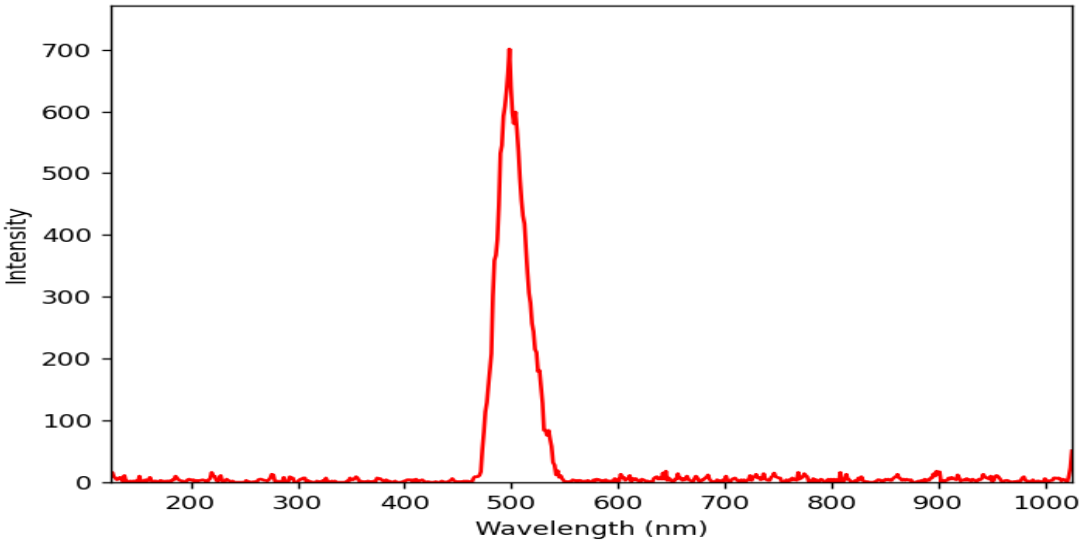
For RED LED



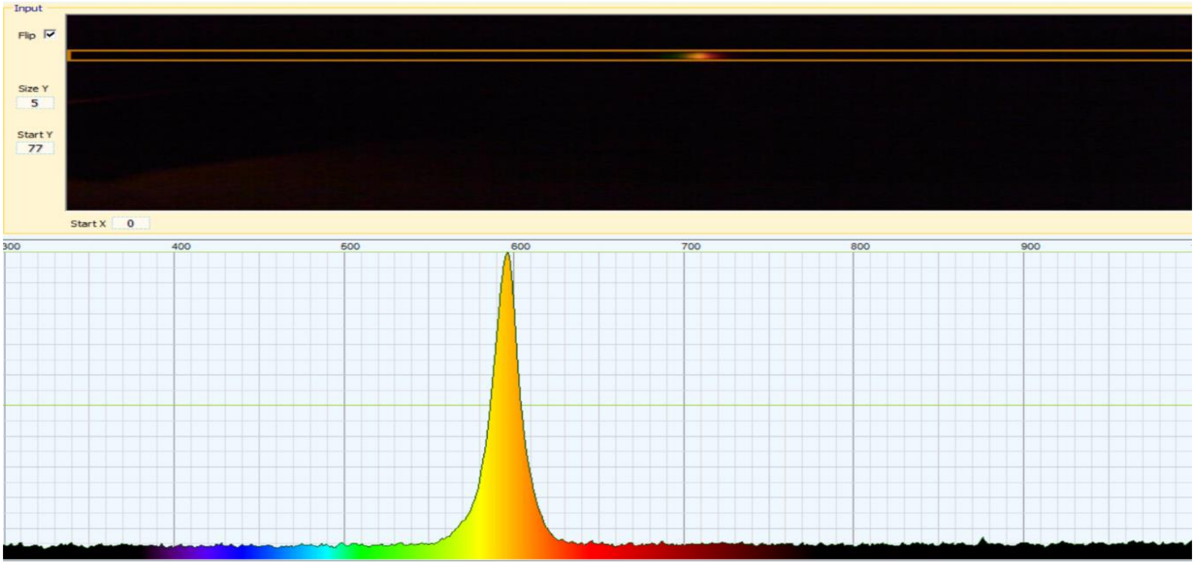


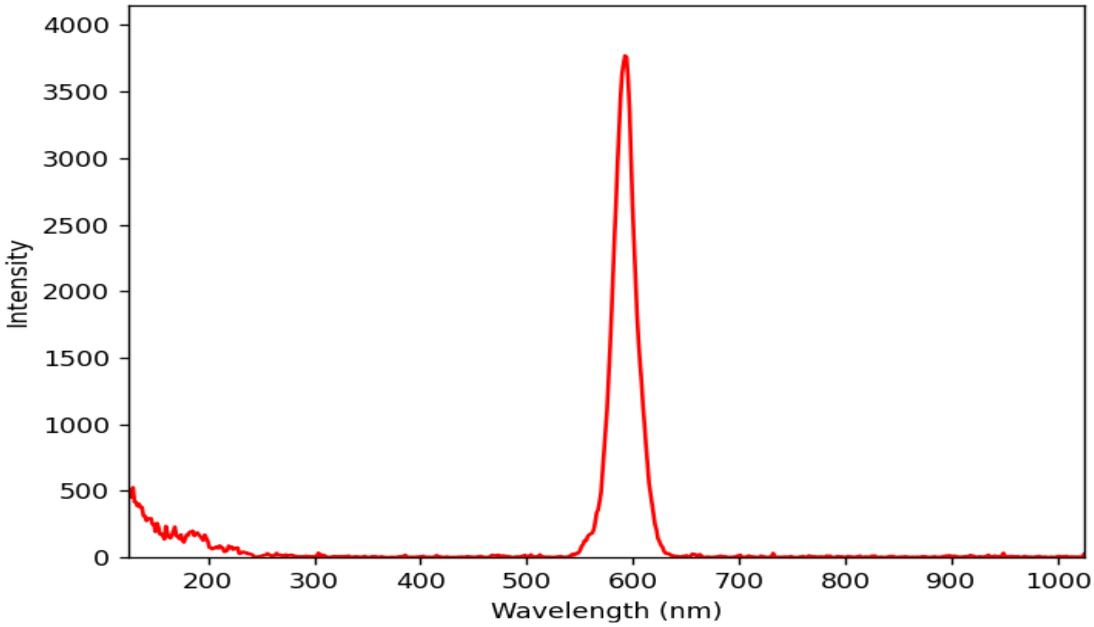
For Green LED



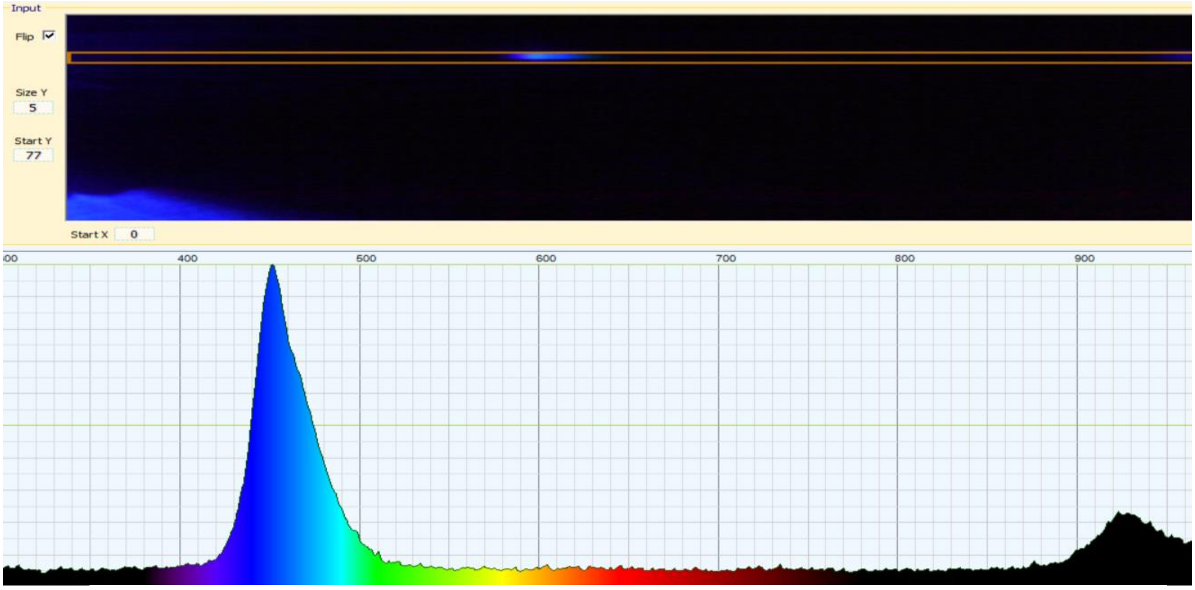


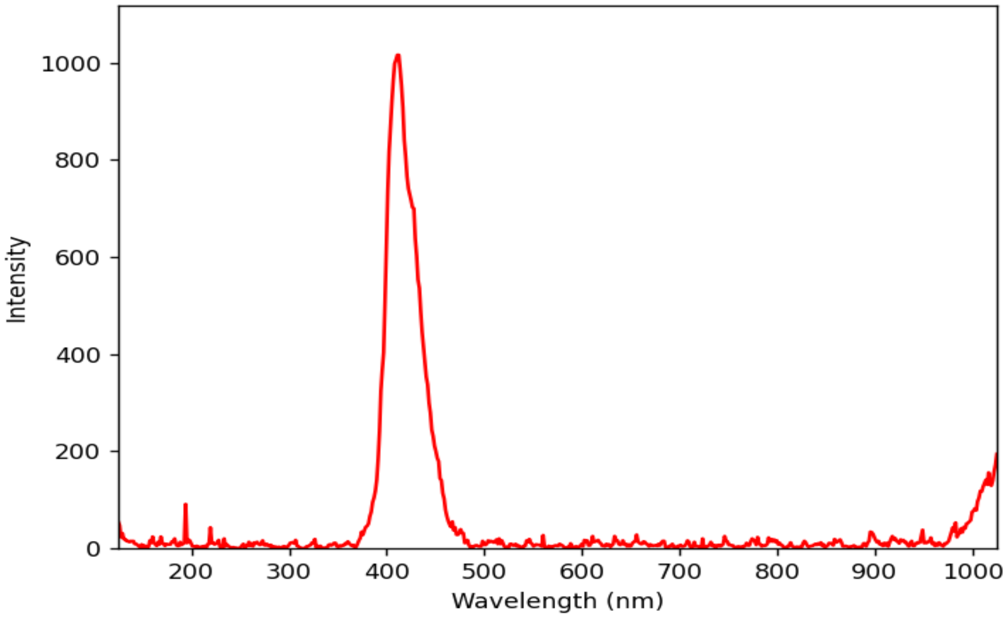
For Yellow LED



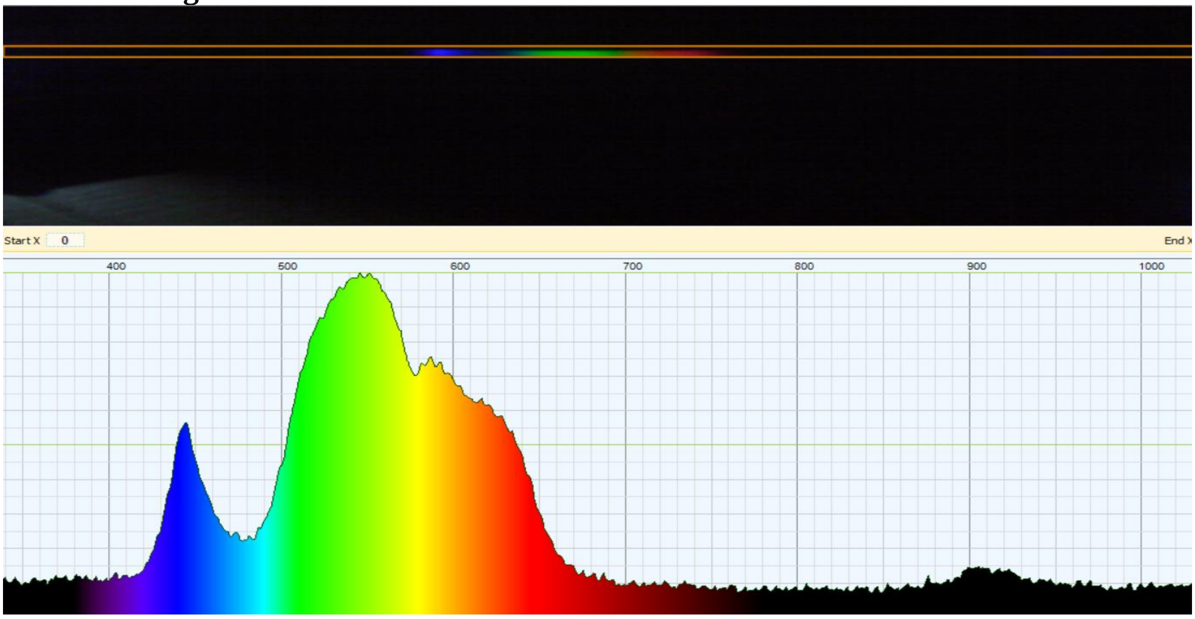


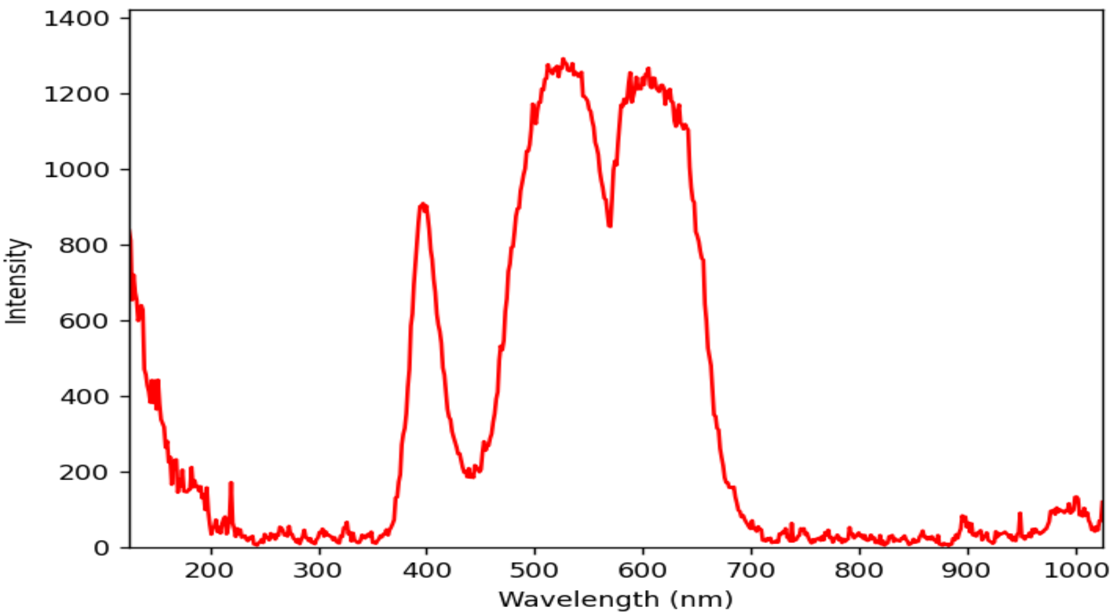
For Blue LED


Input
Flip
Size Y
5
Start Y
77
Start X
0
400
500
600
700
800
900


Intensity
Wavelength (nm)
1000
800
600
400
200
0
200
300
400
500
600
700
800
900
1000

For White Light





4.3 Data Analysis

The collected data were processed using both Theremino software and the custom Python code. Here we tried to find out the corresponding peaks for each LED in each cases. Using the results of the theremino software as base, we basically tried to recreate the same result for our python code. For that purpose proper calibration had to be done, which was an iterative process.

4.4 Results

The experimental results demonstrated successful spectral characterization of LEDs with notable findings:

Spectral Peaks and Wavelengths:
Red LED: Observed peak at approximately 650 nm in theremino software, and our code result shows around 620 nm which is consistent with red light emission.

Green LED: Observed peak at approximately 520 nm in theremino software, and our code result shows around 500 nm which is consistent with green light emission.

Blue LED: Observed peak at approximately 450 nm in theremino software, and our code result shows around 410 nm which is consistent with blue light emission.

Yellow LED: Observed peak at approximately 590 nm in theremino software, and our code result shows around 585 nm which is consistent with yellow light emission.

White LED: for this particular case we bserved peaks at approximately 450 nm, 550 nm and 570 nm in theremino software, and our code result shows around 400 nm, 520 nm, and 600nm which is consistent with white light emission. It consisted of contributions from blue, mostly green and yellow light.

Intensity Observations:
The yellow LED showed the highest intensity among all measured LEDs, suggesting stronger emission efficiency.
The red LED exhibited moderate intensity, with a well-defined peak.
The blue LED had a lower intensity but a sharper peak, indicative of focused emission.
The Green LED had the worst efficacy, and hence the least intensity was obtained.

5 Design Analysis and Evaluation

5.1 Novelty

The novelty of the project was the hand written code that we wrote, and the simple yet effective hardware design that was able to serve our purpose.

5.2 Design Considerations (PO(c))

The development of the cost-effective spectroscopy setup involved several key considerations to ensure accurate and reliable spectral analysis. Each design element was carefully addressed to overcome challenges related to environmental factors, optical limitations, and the use of non-specialized components.

1. **Lighting Insulation**: External light sources were effectively blocked to minimize interference, ensuring that only the target light source was analyzed. This step was essential for preserving the accuracy and integrity of the spectral data.
2. **Light Diffusion**: A piece of tape was strategically positioned in front of the slit to diffuse the incoming light. This diffusion helped create a uniform beam, enhancing the precision of spectral separation and analysis.
3. **Grating Preparation**: The top opaque layer of a compact disc (CD) was carefully removed to reveal a clean diffraction grating pattern. This process required precision to maintain the grating's integrity, as its quality directly affected the resolution of the spectral lines.
4. **Image Processing**: The images captured by the webcam were meticulously cropped and calibrated during analysis. Calibration was performed using reference wavelengths to ensure the spectral data accurately matched the true wavelengths of the light source.

5.2.1 Considerations to public health and safety

Safe Materials and Assembly: The hardware components were selected with safety in mind, avoiding hazardous materials. The re-usage of material (show box) indicates a environment friendly measure, minimizing waste.

5.2.2 Considerations to environment

Efficient Resource Usage: Hardware components were chosen to minimize environmental impact, for that matter, the casing was done by an already available showbox, thus not using cardboard or wooden planks which are detrimental to the environment.

Energy Efficiency: The light sources are small LEDs which are not power hungry, thus minimizing waste.

Sustainability: The modular design allows components to be reused or repurposed for future projects, promoting sustainable practices.

5.3 Limitations of Tools (PO(e))

While the cost-effective spectroscopy setup successfully demonstrated the capability to analyze the spectral characteristics of light sources, it faced several limitations due to the tools and methods used. These constraints primarily impacted the accuracy, range, and overall quality of the spectral analysis.

1. **Spectral Range**: The setup was designed for the visible spectrum and did not support infrared (IR) wavelength analysis. Extending its functionality to the IR region would require removing the webcam's infrared filter and performing additional calibration. However, this step would increase the setup's complexity and could introduce further calibration difficulties.
2. **Lack of a Collimating Lens**: The absence of a collimating lens to focus the incident light posed challenges in achieving a uniform beam profile, which is essential for an accurate diffraction pattern. Additionally, when the light intensity exceeded a certain threshold, the diffraction pattern became distorted, reducing the reliability of the spectral data.
3. **Webcam Resolution**: The limited resolution of the webcam used in the setup was a major drawback. The low image quality resulted in grainy diffraction patterns, making it difficult to clearly resolve and analyze closely spaced spectral lines. This reduced the precision and accuracy of the spectral analysis.

5.4Log Book of Project Implementation

Date	**Milestone achieved**	**Individual Role**	**Team Role**	**Comments**
25/10/2024	Writing the python code and initial testing	1906110		Successful
01/11/2024	Collecting Materials and Hardware setup	1906101		Successful
08/11/2024	Primary data collection from setup	1906103,1906101		Successful
18/11/2024	Calibration of theremino and code	1906092		Successful
24/11/2024	Final data collection	Whole team		Successful

6 Project Management and Cost Analysis PO(k)

Equipment	Approximate Cost (bdt)
Webcam	2000
CD	100
Wooden plank	300
Cardboard box (Alternative to plank)	200
Light sources (multiple)	300
Total	2700/ 2600

9 References

1. https://www.theremino.com/en/applications
2. https://www.scribd.com/document/596041972/Theremino-Spectrometer-Help-ENG
3. *https://www.waveformlighting.com/tech/calculate-color-temperature-cct-from-cie-1931-xy-coordinates*
4. *https://insights.regencysupply.com/what-is-correlated-color-temperature-cct-and-how-do-you-choose-it-for-your-lighting*