BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Department of Electrical and Electronic Engineering

EEE 460 (Optoelectronics Laboratory)

Project title: Experimental setup to measure spectral characteristics of a LED or LASER

Submitted By: Group 04

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Section: G1

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Introduction

Spectroscopy studies how matter interacts with electromagnetic radiation at different wavelengths or frequencies. To perform this, a device known as a spectrometer is used to generate spectral lines and determine their wavelength and intensity. The primary goal of this project is to build a spectrometer that can analyze the spectrum of visible light from a variety of sources. This spectrometer, which is inexpensive and widely available, can give a better knowledge of light sources such as LEDs, tungsten, and fluorescent lighting.

Theory

A diffraction grating is an optical component with a periodic structure that diffracts light into multiple beams traveling in different directions. This means it separates light into its constituent wavelengths, creating a spectrum similar to a rainbow. The most basic sort of diffraction grating is made up of several parallel, equally spaced slots. As light passes through the grating, its various components are diffracted at angles specified by the angle at which the wave of light strikes the grating, the distance between the diffracting elements on the grating, and the light's wavelength. This makes the grating a dispersive element. Therefore, spectrometers frequently employ diffraction gratings.

Assuming a diffraction grating made up of a set of slits of spacing d, a plane wave of monochromatic light of wavelength   is normally incident on a grating. Each slit in the grating acts as a quasi-point wave source from which light propagates in all directions.

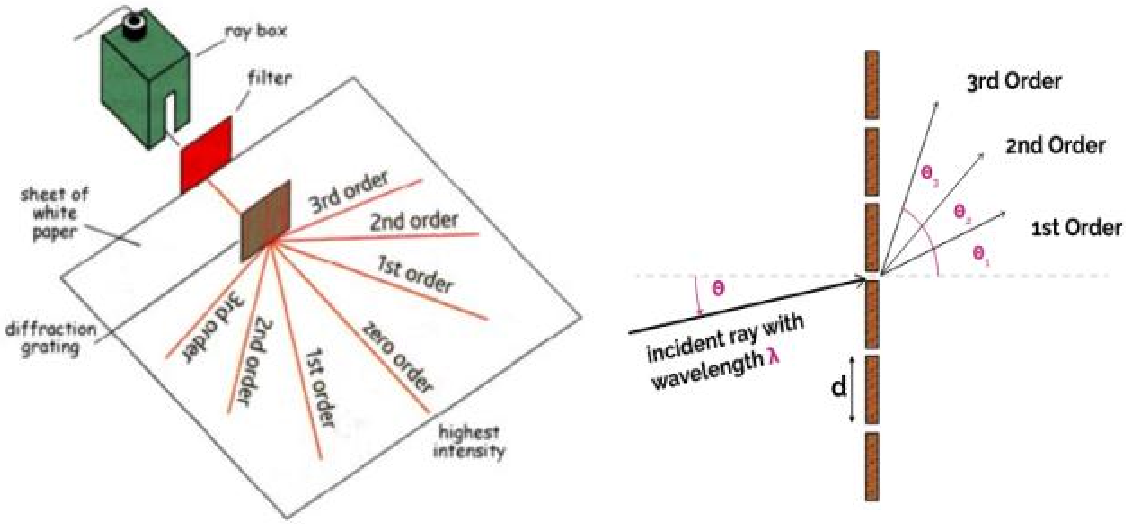


Fig 1: diffraction grating mechanism

- When a plane light wave is normally incident on the grating, the diffracted light has maxima at diffraction angles θ given by the diffraction equation as : d sinθ= mλ

Here, m is the order of diffraction. If the plane wave is incident at any arbitrary angle θi to the grating normal, the grating equation becomes:

d (sinθi-sinθ)= mλ

- Because diffraction happens in radiant waves, a series of spectra may be observed in the middle of the zero order spectrum.

- When many gratings are utilized, the multicolored spectrum becomes less visible with each higher order, but the center zero order stays white as predicted. If one of the primary colors (red, green, or blue) is pointed at a diffraction grating, the diffracted wave creates an angle according to its wavelength, and the primary color appears on the screen. If a color composed of primary colors is employed, the diffraction grating will split it into fundamental colors and provide a spectrum based on their relative wavelengths. For instance, if a yellow wave is used, it will produce a spectrum of red and green waves on the screen.

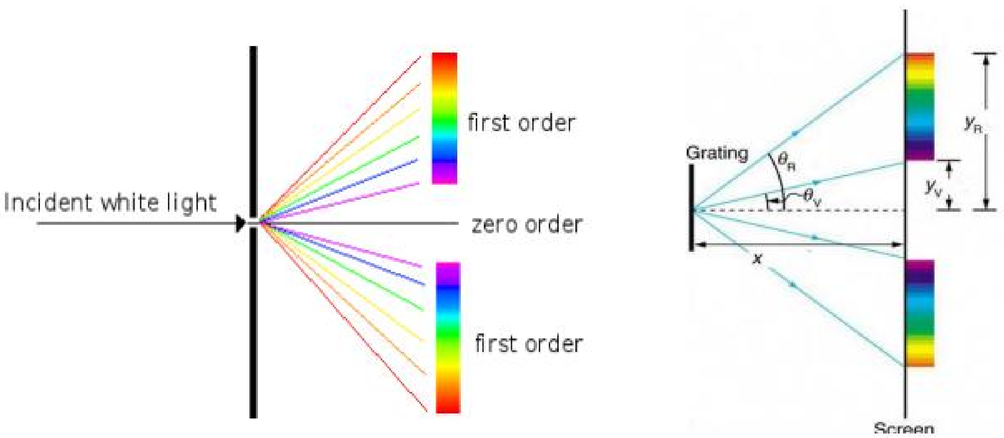


Fig 2: diffraction of white light through a single slit

Reasons for Using a Black Box:

Light Control:

Stray Light Reduction: The primary reason is to minimize stray light. Light entering the spectrometer from outside its intended path can distort readings and compromise accuracy. A black box absorbs stray light, creating a controlled environment for light traveling through the intended optical components.

Improved Sensitivity: By minimizing stray light, the signal-to-noise ratio improves, leading to better sensitivity and detection of weaker signals. This is crucial for analyzing faint light sources or measuring small spectral features.

Calibration and Stability:

Controlled Environment: A black box can provide a stable and controlled environment for the spectrometer's internal components. This helps maintain calibration and reduces drifts in readings due to external factors like temperature changes or ambient light fluctuations.

Preventing Contamination: If the spectrometer deals with sensitive materials or requires specific environmental conditions, a black box can prevent contamination or exposure to unwanted elements.

Ease of Construction:

Modular Design: Some home-built spectrometers utilize pre-built modules or kits housed in black boxes. This simplifies construction and reduces the need for complex mechanical or optical skills.

Protection: A black box can protect delicate components from dust, moisture, or accidental damage during construction and use.

A ***spectrometer*** is a scientific instrument used to measure and analyze light across different wavelengths. It essentially works by separating light into its individual colors, like a rainbow, and then measuring the intensity of each color. This information, plotted as a graph, creates a spectrum, which acts like a fingerprint for the light source or the material it interacted with.

Here's a breakdown of its role and key components:

Function:

- Identify materials: By analyzing the unique spectral fingerprint, scientists can identify the elements or molecules present in a sample.

Different materials absorb or emit light at specific wavelengths, leaving their signature on the spectrum.
- Study properties: Spectrometers can also be used to study various properties of materials, such as their chemical composition, structure, and even temperature.

Components:
- Light source: Emits light, either white (like a lamp) or specific wavelengths (like a laser).
- Collimator: Focuses the light into a parallel beam for accurate analysis.
- Monochromator: Separates the light into its individual wavelengths using a prism, grating, or interferometer.
- Sample: The material whose light interaction is being analyzed.
- Detector: Measures the intensity of light at each wavelength.
- Readout: Displays the spectrum, typically a graph showing intensity vs. wavelength.

Types:
There are various types of spectrometers, each suited for specific applications:
- Optical spectrometers: Analyze light in the visible, ultraviolet, or infrared range.
- Mass spectrometers: Analyze the mass-to-charge ratio of ions, identifying different atoms or molecules.
- Raman spectrometers: Analyze vibrational modes of molecules, providing information on their structure and composition.

Applications:
Spectrometers play a vital role in diverse fields:
Astronomy: Studying the composition of stars, planets, and other celestial objects.
Chemistry: Identifying and analyzing the elements and molecules in various samples.
Biology: Understanding the structure and function of proteins, DNA, and other biomolecules.
Materials science: Characterizing the composition and properties of materials like metals, ceramics, and polymers.
Environmental science: Monitoring air and water quality by analyzing their composition.

Medicine: Diagnosing diseases and monitoring treatments by analyzing blood, tissue samples, etc.

Experimental Setup

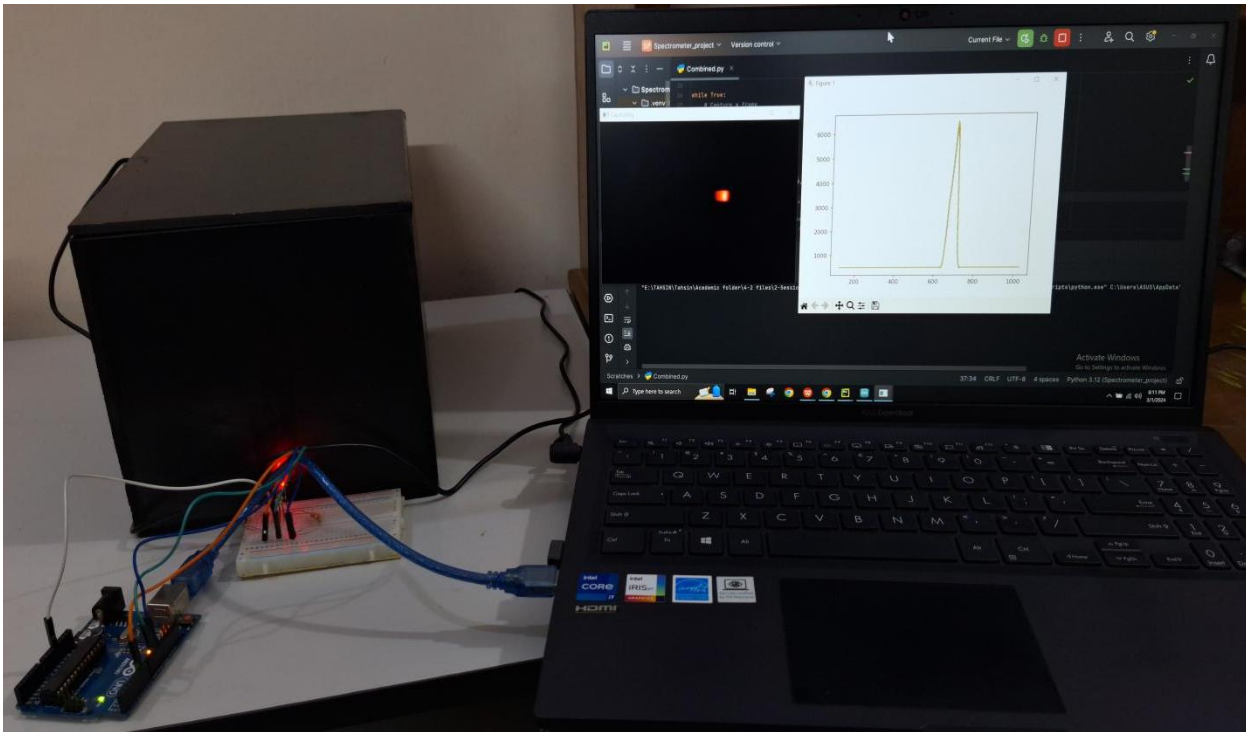


Fig: Overall Setup

Fig:Webcam Setup inside the black box

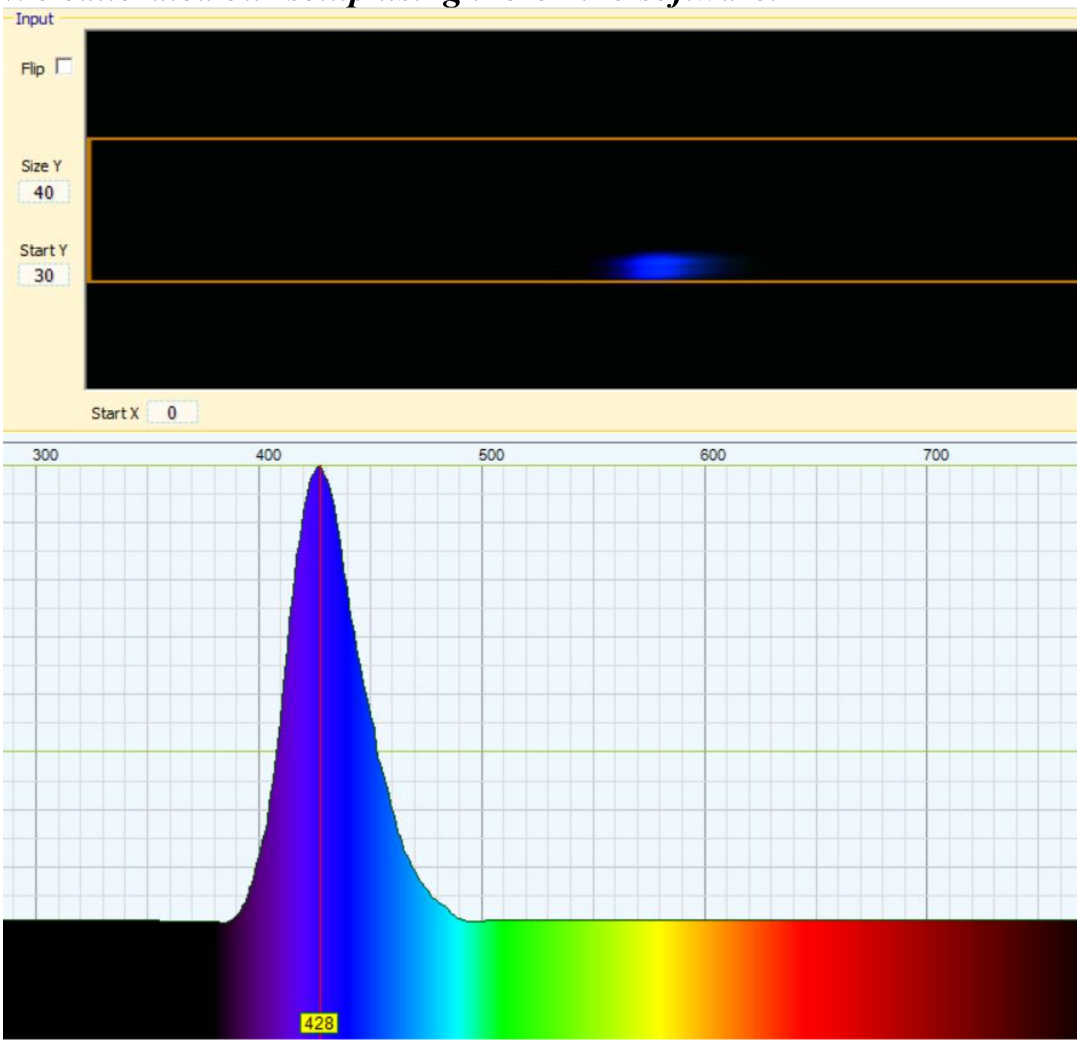
Experimental procedure:

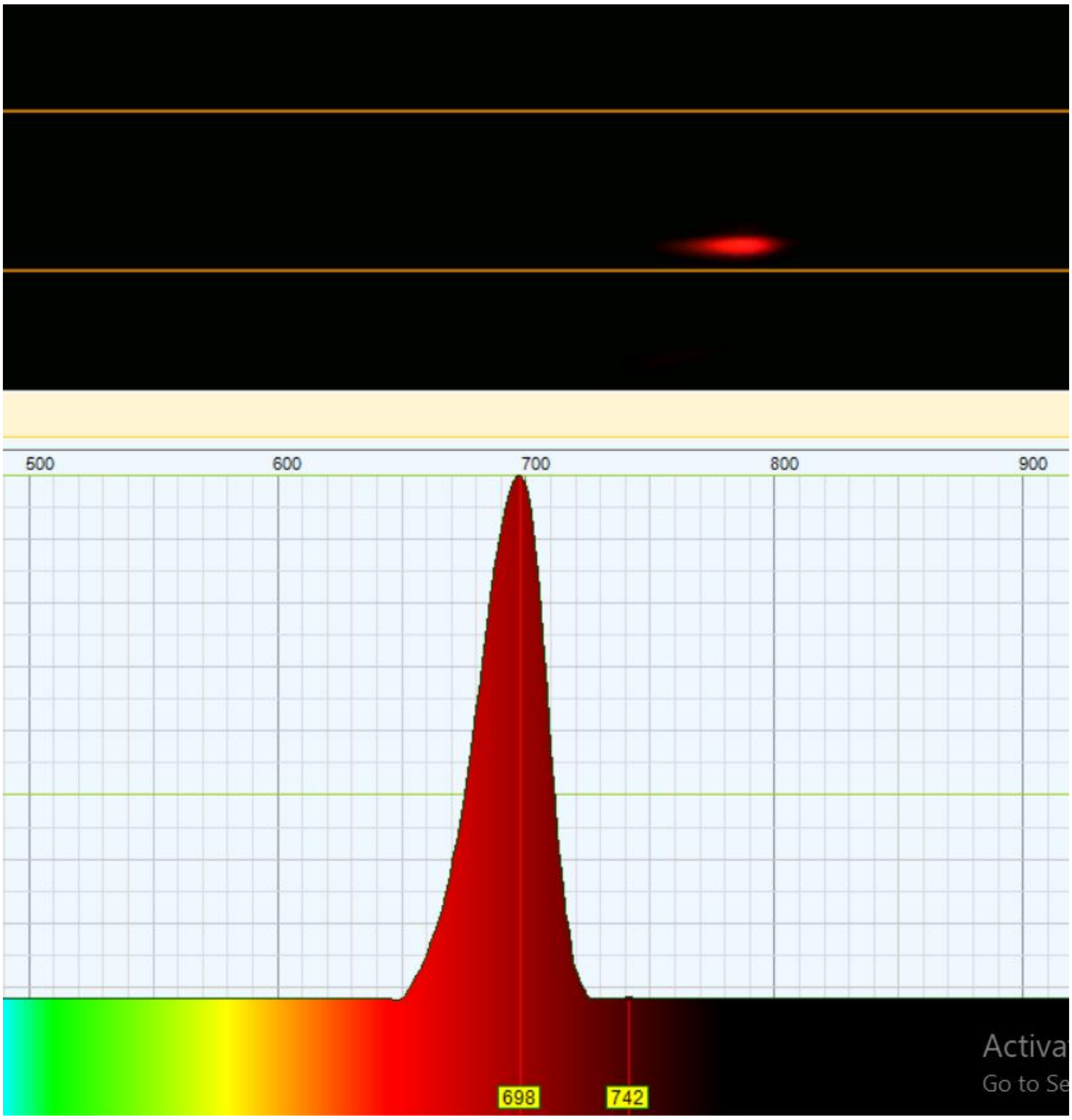
1. We have used Logi C270 HD WebCam for light capturing.
2. We have used DVD for diffraction grating .A diffraction grating is able to disperse a beam of various wavelengths into a spectrum of associated lines because of the principle of diffraction: in any particular direction, only those waves of a given wavelength will be conserved, all the rest being destroyed because of interference with one another. DVDs have diffraction grating under the silver layer, that's why we used a DVD. The grating is attached in front of a camera which is then placed inside a housing.
3. We also used a pair of blades to reduce the dimension of the slit to reduce further diffraction of light through the slit.
4. We have used a total black box as the housing for camera because housing of any other color would have otherwise been reflected from side walls and interfere with our analysis.
5. We also used Theremino software for calibration purpose. After comparing with Theremino software, we set calibration value=**23** for our spectrometer code for maximum accuracy.
6. For spectral analysis,all the codings were performed using Python in PyCharm platform. We plotted relative intensity vs wavelength in nm obtained after some image processings using Python commands.

7. Various colors of LEDs as well as lasers were tested in our project and we have provided detailed information about peak intensity,peak wavelength, line width etc which can be used to determine the quality of a light source very easily using this low cost device.

Calibration :

We calibrated our setup using theremino software.





500
600
700
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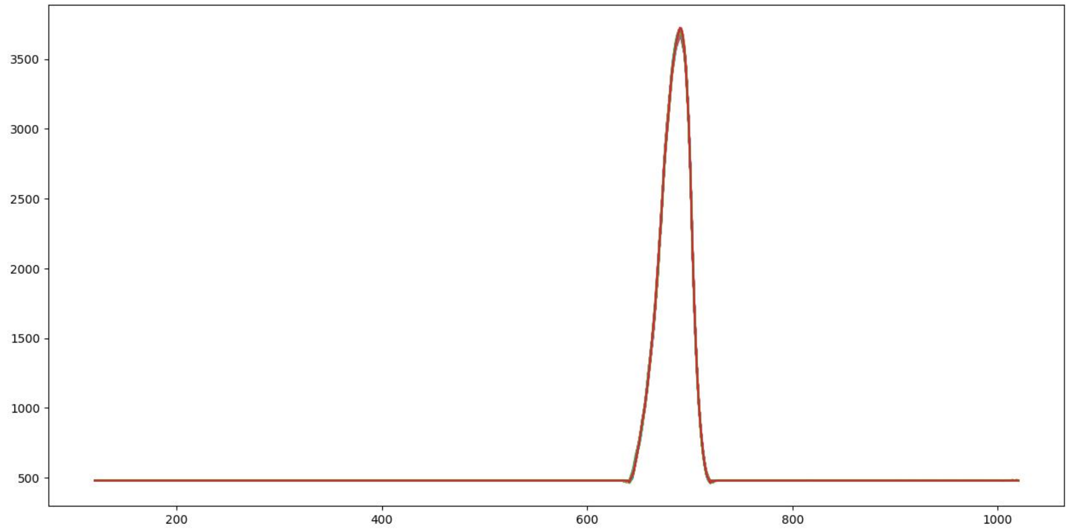
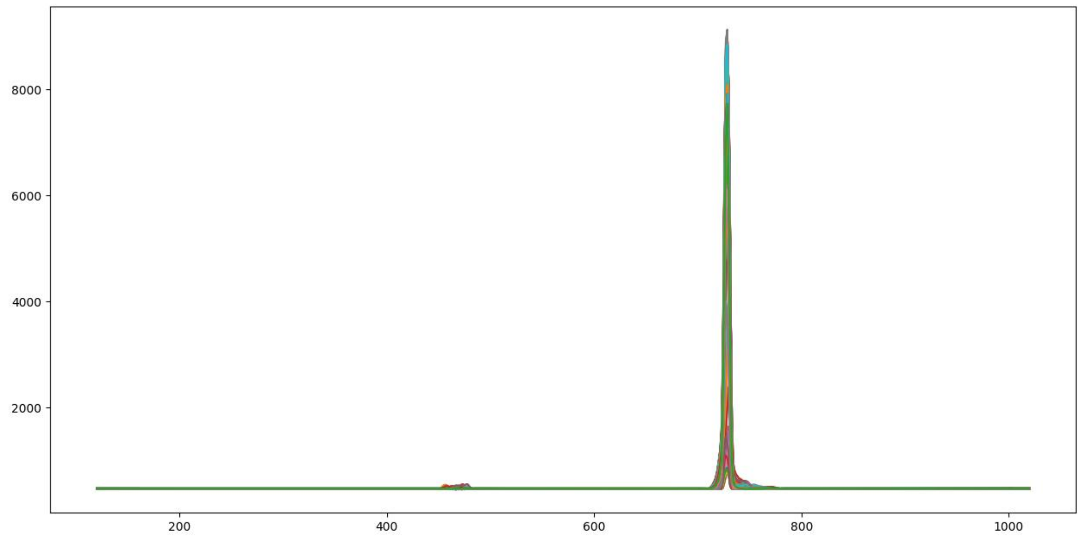
698
742
Activa
Go to Se

Results :Intensity vs wavelength for different lights from LEDs and Lasers

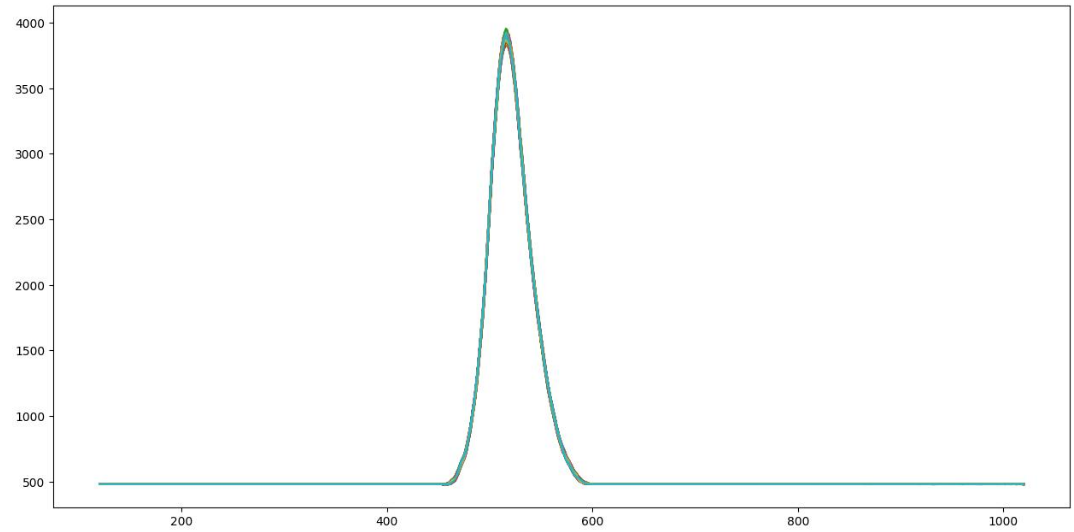
For red led:



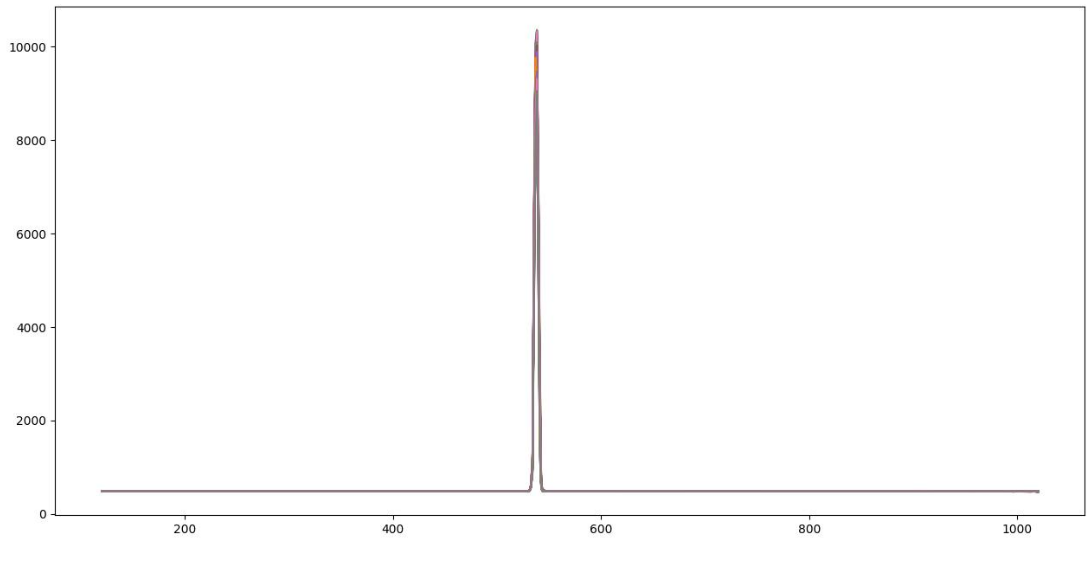
For red laser:



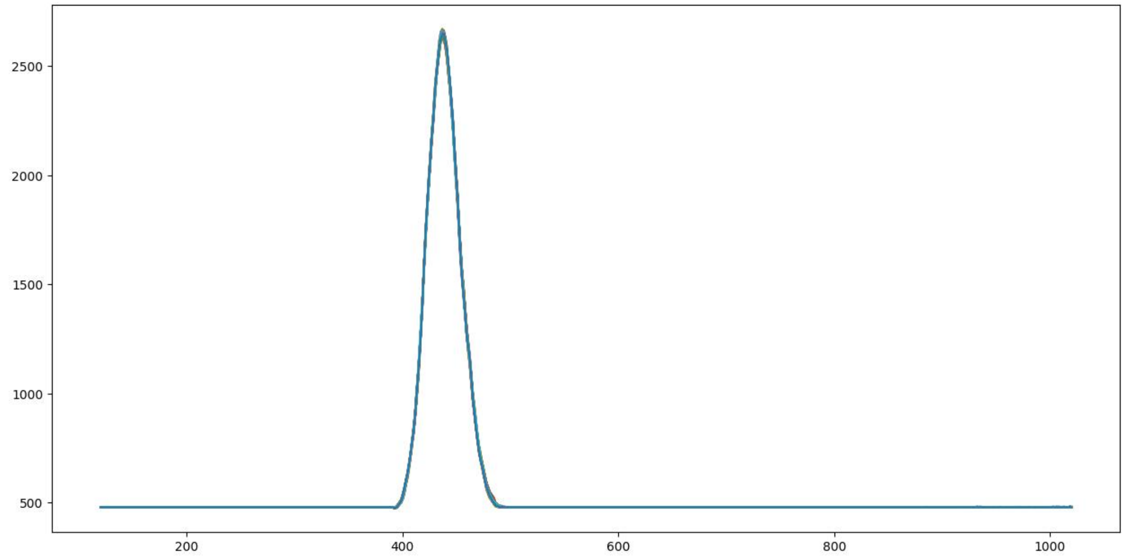
For green led:



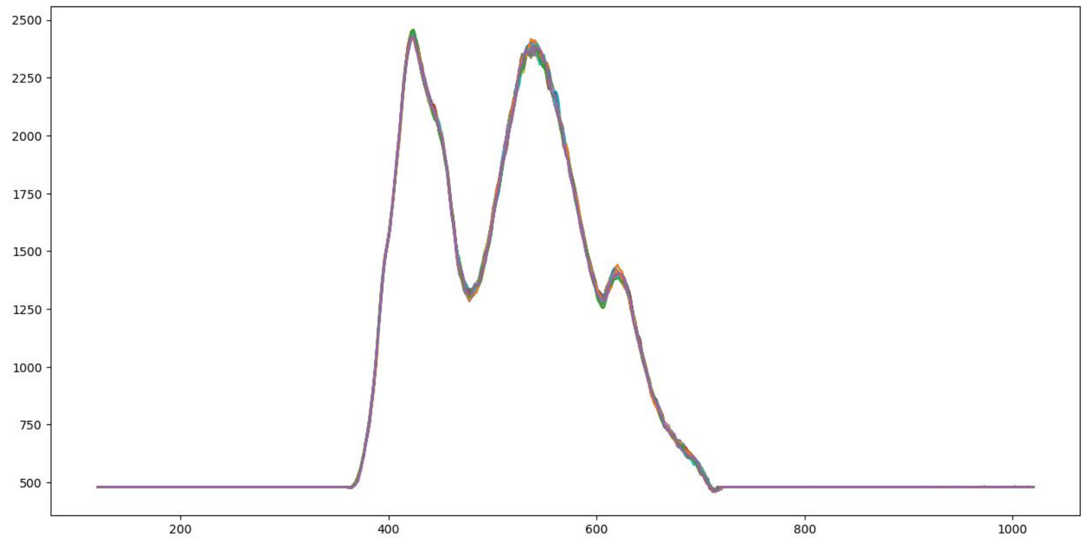
For green laser:



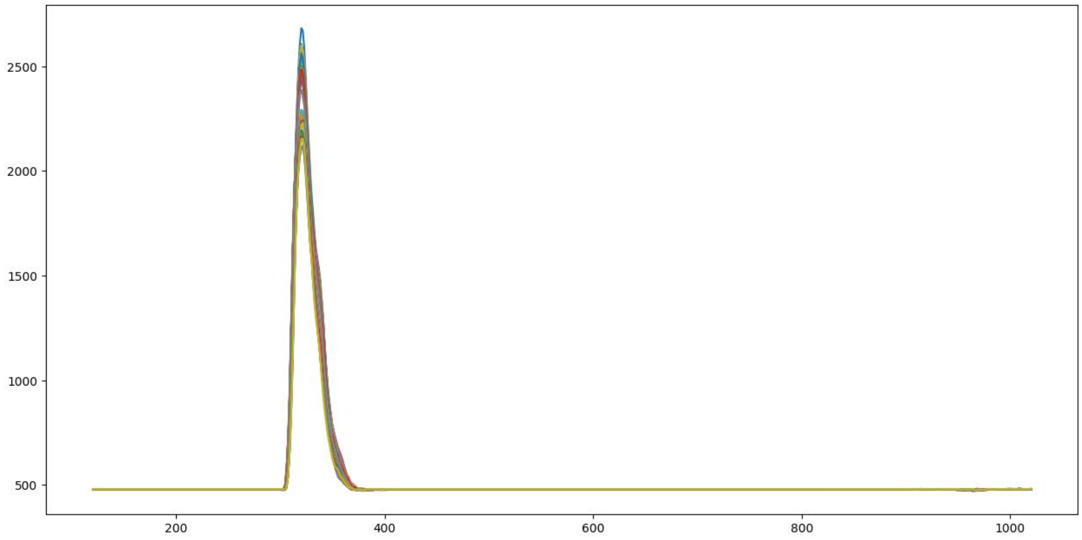
For blue led:



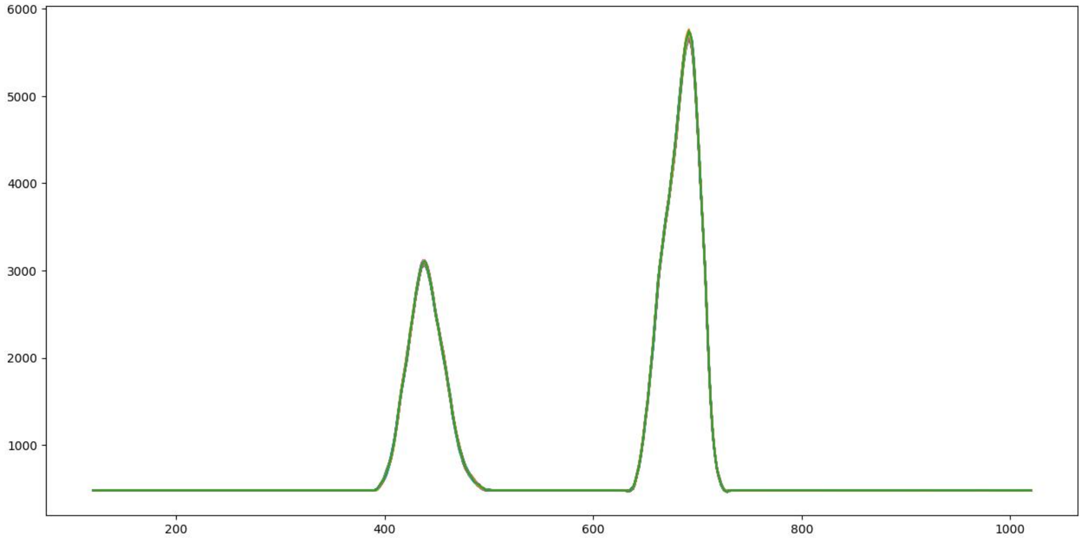
For white led:



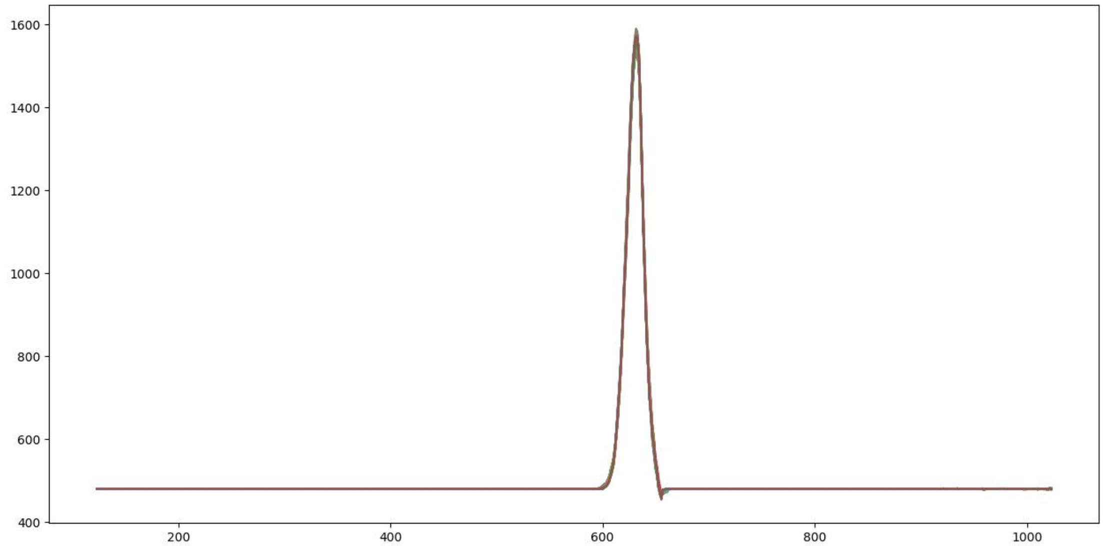
For UV ray:



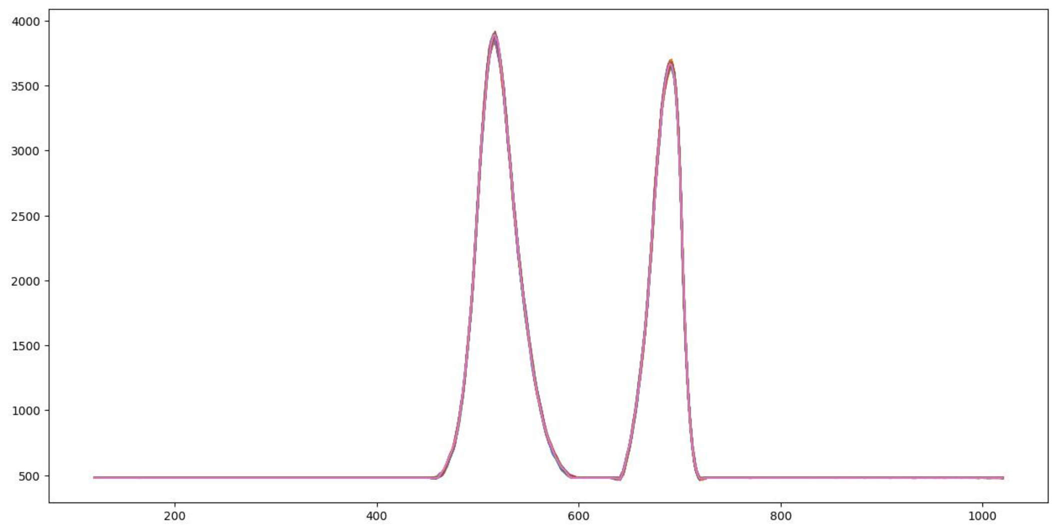
For magenta :



For orange color:

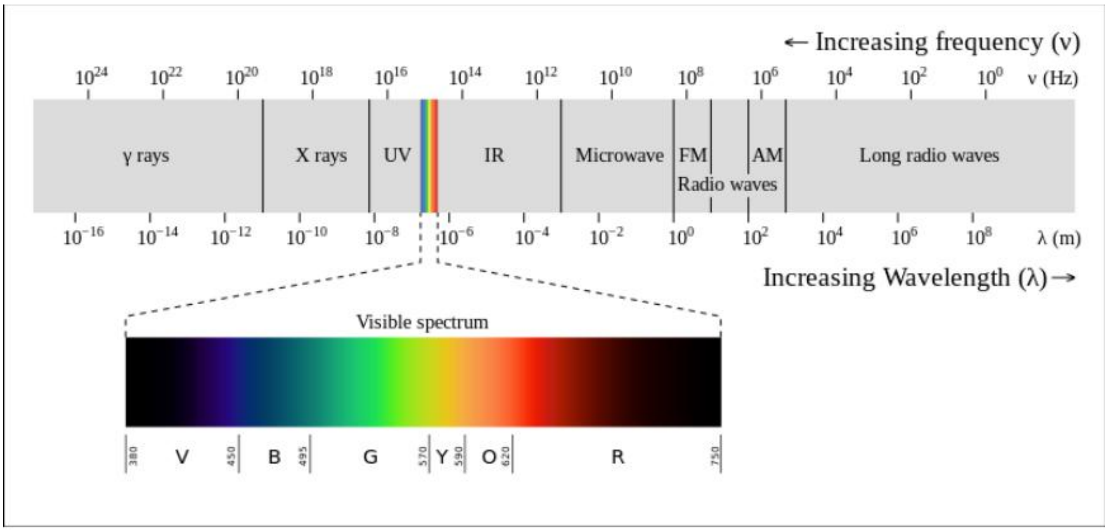


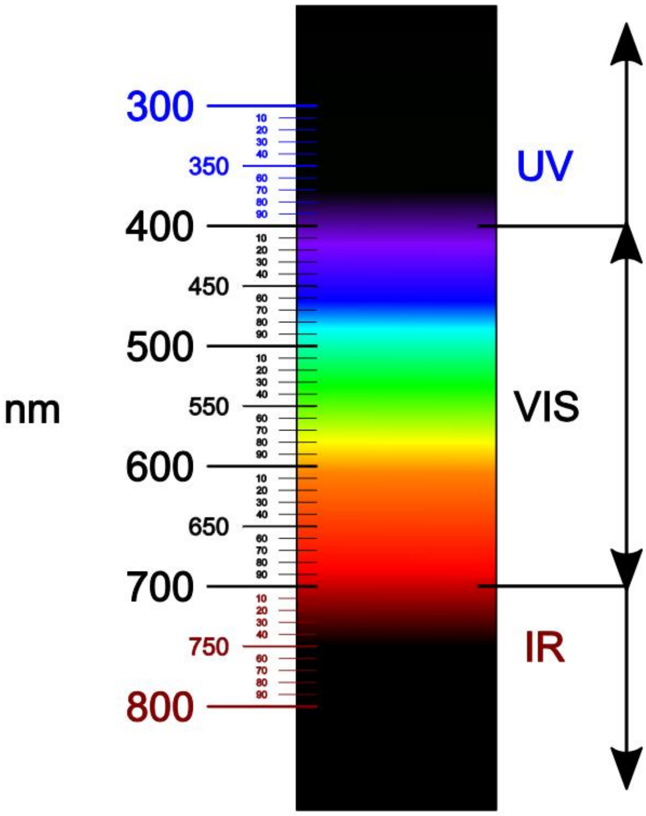
For yellow led :



Data table:

Source Type	Peak Intensity	Peak Wavelength(s) in nm	Line width in nm
Red LED	3752	688	703-664=39
Green LED	3932	511	542.7-492.8=49.9
Blue LED	2666	436	457.6-417=40.6
Orange LED	1597	631.5	641.5-617.6=23.9
Yellow LED	3912 & 3678	514 & 689.8	544-492.8=51.2 & 701.1-666.5=34.6
White LED	2456 & 2410	425 & 538.1	Not measurable at half width
Red Laser	9130	722	725-720=5
Green Laser	10360	538.7	538-536=2
UV LED	2684	310	335-307=28
Magenta LED	3143 & 5900	436.3 & 639.8	463-415=48 & 705-663=42





Here are the 7 from shortest to longest wavelength.
Violet - shortest wavelength, around 380-450 nanometers with highest frequency. They carry the most energy.
-Indigo - 420 - 440 nm
-Blue - 450 - 495 nm
-Green - 495 - 570 nm
-Yellow - 570 - 590 nm
-Orange - 590 - 620 nm
-Red - longest wavelength, at around 620 - 750 nanometers with lowest frequency

source: https://www.thoughtco.com/understand-the-visible-spectrum-608329

Arduino code for generating different colors using RGB LED:

```
int redPin= 6;
int greenPin = 10;
int bluePin = 11;

void setup() {
```

```
  pinMode(redPin, OUTPUT);
  pinMode(greenPin, OUTPUT);
  pinMode(bluePin, OUTPUT);
}

//code for rgb controller

void loop() {
  setColor(255,0,255); // variable Color
  delay(1000000000);

}

void setColor(int redValue, int greenValue, int blueValue) {
  analogWrite(redPin, 255-redValue);
  analogWrite(greenPin, 255-greenValue);
  analogWrite(bluePin, 255-blueValue);
}
```

Python Code for our spectrometer output :

```
import cv2
import numpy as np
import matplotlib.pyplot as plt

# index 0 for laptop cam,1 for external cam
camera_index = 1

# 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)

calib = 23

# Set up plot
plt.figure()
plt.xlabel('Wavelength (nm)')
plt.ylabel('Intensity')
plt.xlim([100, 1000])

# Initialize intensity array and wavelength vector
intensity_array = []

while True:
```

```
    # Capture a frame
    ret, frame = cap.read()

    if not ret:
        break

    # Convert to grayscale
    gray_image = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)

    cv2.imshow("Capturing", frame)  # to see the video in separate window

    # Calculate intensity (sum of each row)
    intensity = np.sum(gray_image, axis=0)

    wavelength = np.linspace(100 + calib, 1000 + calib, len(intensity))

    # Update intensity array and plot: adding current intensity values to array
    intensity_array.append(intensity)

    plt.plot(wavelength, intensity)
    plt.draw()

    plt.pause(0.001)  # Adjust delay as needed

# Release resources
cap.release()
plt.show()
```

Cost analysis:

Component/software	Amount in Taka
Webcam	1900
Housing for webcam	800
Additional costs(DVD)	100
Total	2800

As for the software part,we have used ***Python*** which is a free, open-source programming language that is available for everyone to use. It also has a huge and growing ecosystem with a variety of open-source packages and libraries.

Conclusion:

In this project, we built a low-cost spectrometer and analyzed the spectrum outputs using image processing in Python. The effects of diffraction gratings on light waves have been studied. The results were not ideal owing to the limits of utilizing widely accessible equipment, but they offered a solid picture of how the light spectrum behaved after passing through a grating, including wavelengths, fundamental color components, and intensities. In the future, stronger technology and sources will be available to provide even better spectra and more exact observations. Furthermore, the performance may be increased by analyzing many orders of outputs and determining the core components and spectrum of higher levels.

Demonstration link:

https://youtu.be/EYErckcUiVw?feature=shared