Homemade Spectrometer and Spectroscopy Experimental Analysis

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1 Design And How It Works

Figure 1: External view of the spectrometer

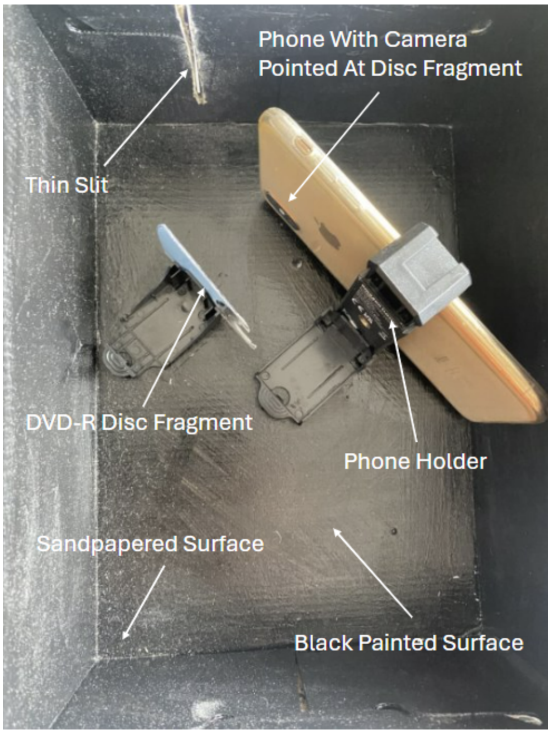

Figure 2: Internal view of the spectrometer

The spectrometer is contained within a black-painted shoe box, sanded down to reduce reflections and block external light. The thin slit restricts incoming light, improving spectral resolution, while a plastic bag over it diffuses light to reduce glare. The DVD-R fragment acts as a diffraction grating (1350 lines/mm [1]), splitting light into its components. This is then captured by my phone, connected to my computer via the Camo application [2] for a live feed and manual control over exposure and ISO, allowing relative intensity comparisons. Theremino Spectrometer [3] calculates intensity from image brightness. All emission spectra generated are an average of hundreds of repeat readings to minimise anomalies.

2 Calibration

As Theremino Spectrometer only provides position-based intensity, wavelength calibration is necessary. For calibration, I have used a CFL [4] which produces sharp, distinct peaks at specific wavelengths due to mercury fluorescence within the bulb. Matching two known peaks (436 nm and 546 nm) calibrates the software.

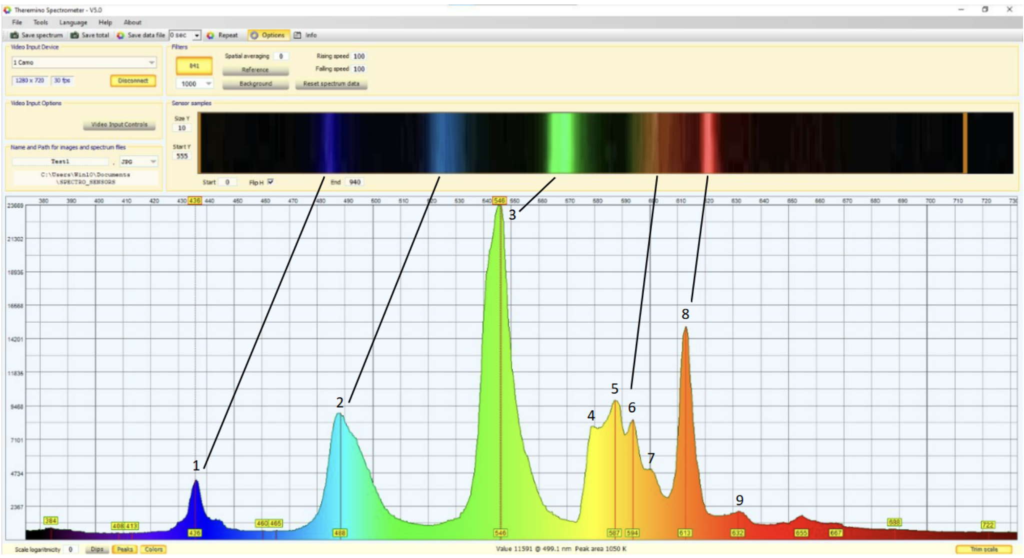

Figure 3: Calibration of the spectrometer using the emission spectrum of the CFL

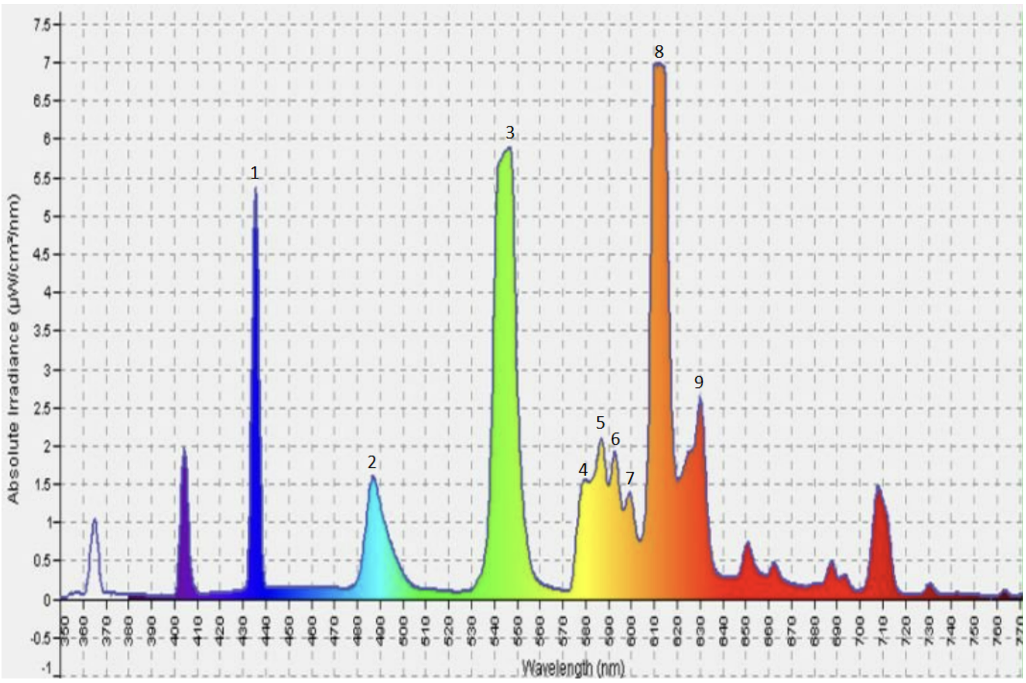

Figure 4: Emission spectrum of a CFL taken from the internet [5]

Figure 3 shows the camera view and corresponding emission spectrum below. As shown, the 9 peaks clearly visible in the spectrum match perfectly with ones online, indicating that calibration has been successful. However, relative intensities did not match, which I believe is due to the Bayer-filtered sensor [6] inside my phone, which senses some colours more strongly than others.

3 Emission Spectrum of The Sun

Pointing the spectrometer outside, we can generate an emission spectrum of the Sun.

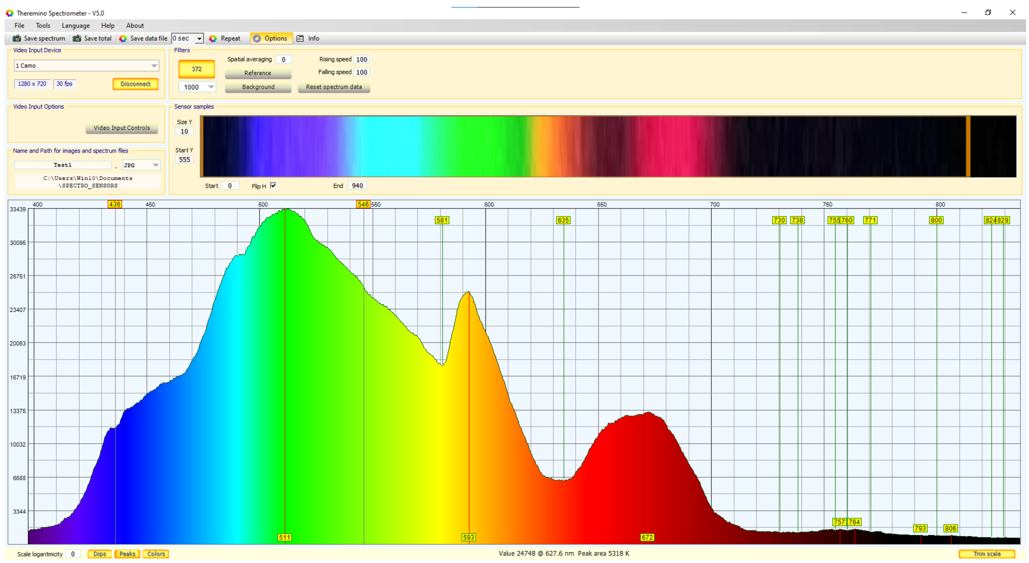

Figure 5: Generated emission spectrum of the Sun

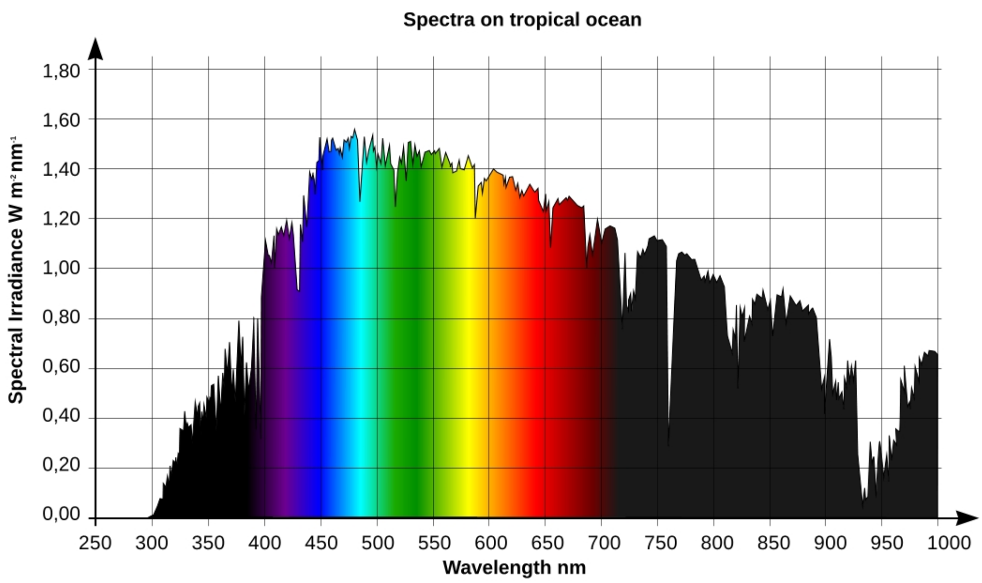

Figure 6: Emission Spectrum of the Sun at sea level taken from the internet [7]

The peak wavelength is roughly correct, however there is a false peak at 593 nm and a false dip at 635 nm - again potentially due to the Bayer filter. The Sun's spectrum contains over 570 dips called Fraunhofer lines [8], absorption lines from elements in the Sun's atmosphere corresponding to their excited states. Bunsen and Kirchhoff [9] famously used these lines to identify the elements in the Sun. However, my generated emission spectrum has no noticeable dips, indicating low spectral resolution.

4 Emission Spectrum of Filament Bulb

To further test this Bayer filter hypothesis, I have generated the emission spectrum of a filament bulb which produces incandescent light, similar to the Sun.

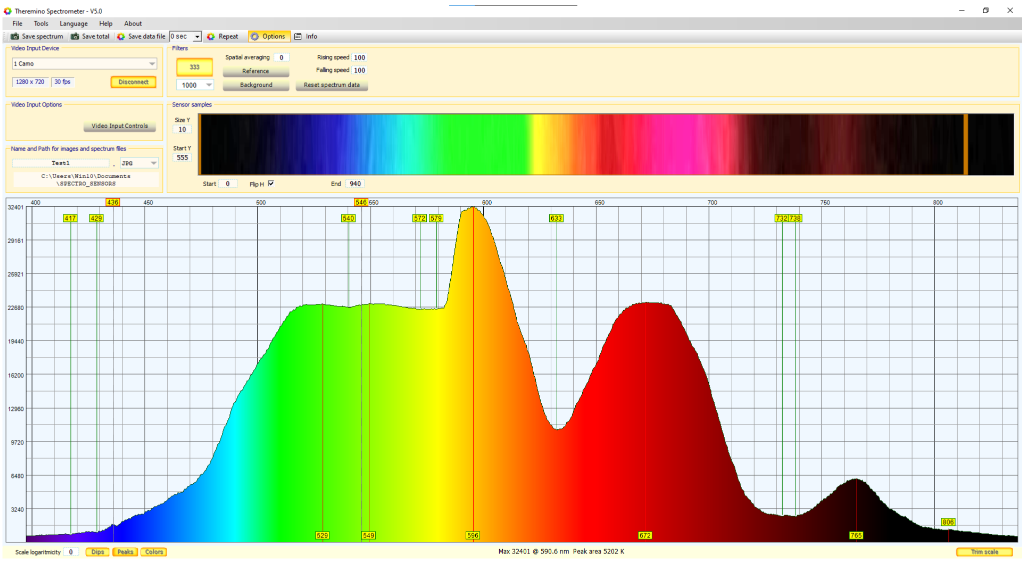

Figure 7: Generated emission spectrum of a filament bulb

A false peak at 596 nm and false dip at 633 nm have again been identified, providing strong evidence in support of my theory.

5 Calculating Concentration

I then tested the spectrometer's precision in a primary application of spectroscopy - calculating concentrations of solutes in solution. Using 0.01 M Iodine solution and assuming linear negative correlation, I created a calibration curve between intensity of transmitted light and concentration with two samples of known concentration. This allows me to find the concentration of any subsequent sample using only intensity.

Intensity (AU)	Concentration (M)
18430	0.01
11036	0.005

Figure 8: Table of data in Excel collected from known concentrations of iodine where peak intensity was measured

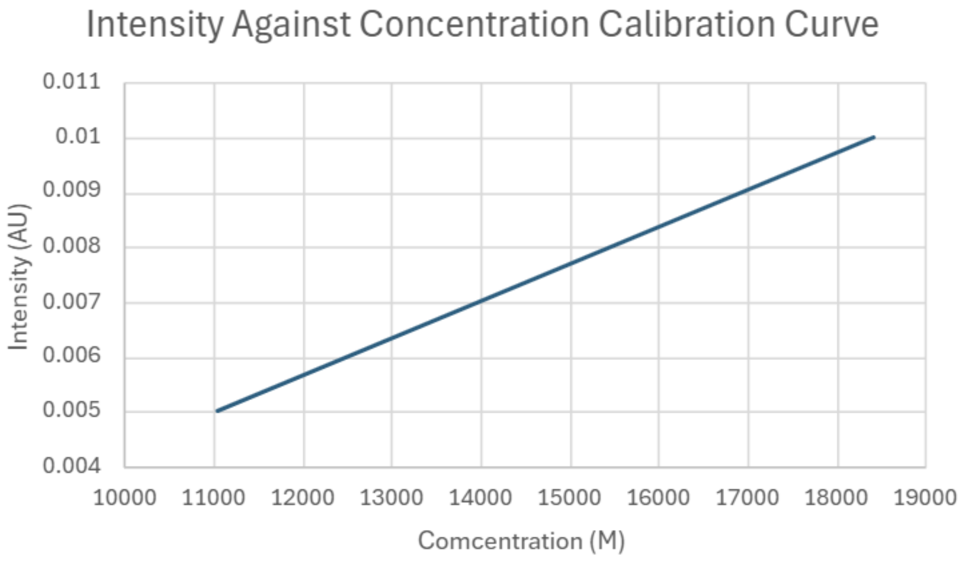

Figure 9: Calibration curve from the table in Excel

Generating the emission spectrum of a third sample of 0.0075 M iodine gave a peak intensity of 14275 AU. Comparing this result to the expected result of 14733 AU gives a 3.11% difference. Therefore, the spectrometer can calculate concentration to around 3% accuracy.

6 Conclusion

It has been shown that even for a spectrometer with no cost, there is still some functionality with reasonable precision. However, the main issue is indeed the Bayer filter which produces false peaks and dips as demonstrated previously. In addition, the low spectral resolution is an issue as it prevents finer details like spectral absorption lines from being seen. As an improvement for a future project, instead of my phone camera, I could use a Raspberry Pi camera which would allow me to remove the infrared filter to see a larger spectrum and remove false peaks and dips. It would also have higher spectral resolution to potentially see Fraunhofer lines and would allow me to write scripts to perform even more advanced techniques like background subtraction for a cleaner emission spectrum. To assess the spectrometer further, more testing is required.

References

[1] National Nanotechnology Coordinated Infrastructure: `https://nnci.net/sites/default/files/2020-02/CD_DVD_Diffraction%20grating_Part%201_SG_answers_0.pdf`

[2] Camo Studio: `https://apps.microsoft.com/detail/9pgm3qb3pdrd?hl=en-us&gl=US`

[3] Theremino Spectrometer: `https://www.theremino.com/en/downloads/automation#spectrometer`

[4] CFLs: `https://kids.niehs.nih.gov/topics/reduce/compact-fluorescent-lights`

[5] CFL Emission Spectrum: `https://guidemanualgodel.z21.web.core.windows.net/light-spectrum-of-cfl-bulbs.html`

[6] Bayer Filter: `https://en.wikipedia.org/wiki/Bayer_filter`

[7] Emission Spectrum of the Sun: `https://reefs.com/magazine/light-in-the-reef-aquaria/`

[8] Fraunhofer Lines: `https://en.wikipedia.org/wiki/Fraunhofer_lines`

[9] Bunsen and Kirchhoff: https://www.sciencehistory.org/education/scientific-biographies/robert-bunsen-and-gustav-kirchhoff/