Camera Spectral Sensitivity

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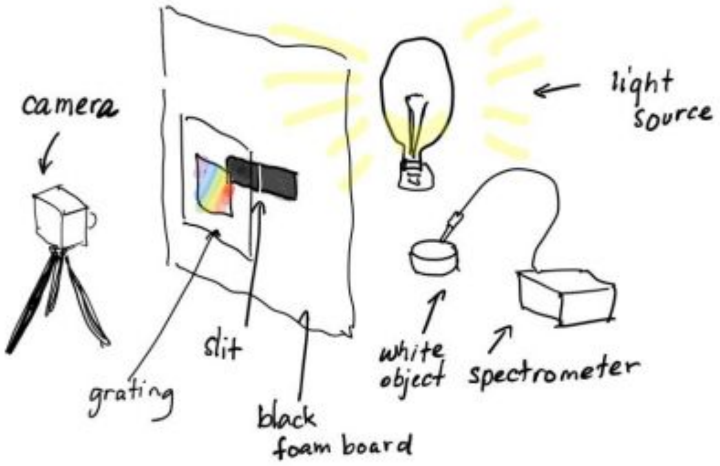
To be able to measure the spectral sensitivity of a camera

Goal

Methodology

- In this activity, we measure the spectral sensitivity of a camera by capturing the spectral bands of a known light source.
- The spiky intensity profile was used to make a pixel-to-wavelength calibration curve. This will then be applied to the RBG intensity profile of the broad spectrum rectangle.
- The emittance spectrum of a spiky light source (Mercury lamp) was measured using a spectrometer



Procedure Setup

Methodology

An improvised spectrometer setup using a slit and an old CD grating was used to obtain images of the spectrum.

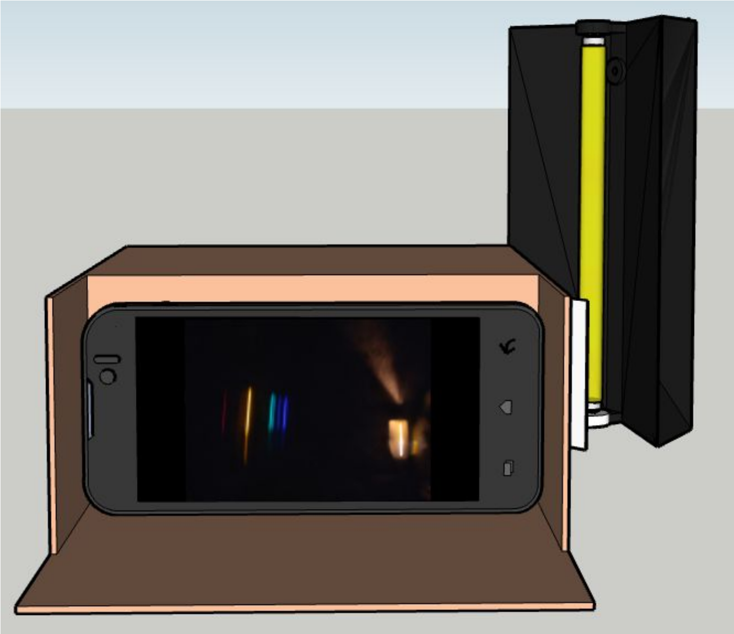


Figure 1. Spectrometer setup

Methodology:Programming Process

Dark Frame Assessment

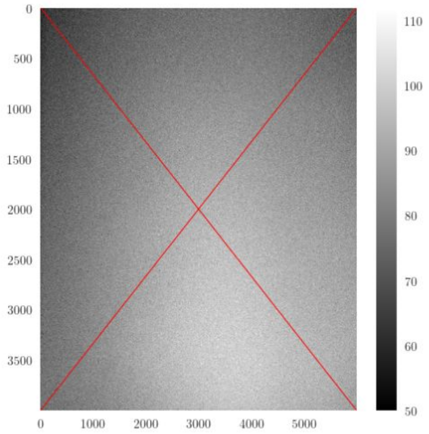
A video of a dark area was recorded for warm up. We then obtain the histogram of the video.

```
cap = cv.VideoCapture('raw/KVD_7135.MOV')
dark = np.zeros((int(cap.get(cv.CAP_PROP_FRAME_HEIGHT)),
                 int(cap.get(cv.CAP_PROP_FRAME_WIDTH)),
                 3))
frames = int(cap.get(cv.CAP_PROP_FRAME_COUNT))
count = 0
while True:
    ret, frame = cap.read()
    if not ret:
        break
    if count >= frames-250:
        dark += frame
    count += 1
dark /= frames
dark = dark.astype('float32')
dark = cv.resize(dark, (6000, 4000))
```

Methodology:Programming Process

Flatness of Field

An image of uniformly-lit white background was captured and assessed the flat field.



White Background flat field assessment

```
flat_surface_params = np.zeros((3, 6))
fig = plt.figure(figsize=(5*2, 5*3))

for i, c in zip(range(3), ['r', 'g', 'b']):
    ax = fig.add_subplot(3, 2, (2*(i+1))-1)
    im = ax.imshow(flat[:,:,i], 'gray', aspect='auto')
    ax.grid(0)
    ax.plot([0, 6000-1], [0, 4000-1], color=c, lw=0.75)
    ax.plot([6000-1, 0], [0, 4000-1], color=c, lw=0.75)
    fig.colorbar(im)

for i, c in zip(range(3), ['r', 'g', 'b']):
    ax = fig.add_subplot(3, 2, 2*(i+1))
    trans_tlbr = meas.profile_line(flat[:,:,i], (0, 0), (4000-1, 6000-1))
    trans_trbl = meas.profile_line(flat[:,:,i], (0, 6000-1), (4000-1, 0))
    trans_tlbr /= trans_tlbr.max()
    trans_trbl /= trans_trbl.max()
    trans = np.median([trans_tlbr, trans_trbl], axis=0)
    popt, pcov = opt.curve_fit(fourier, np.arange(len(trans)), trans, p0=np.zeros(6))
    flat_surface_params[i] = popt
    ax.plot(trans, color=c, lw=0.75)
    ax.plot(fourier(np.arange(len(trans)), *popt), 'k', lw=1.0)
```

Methodology:Programming Process

Obtaining the pixel-to-wavelength calibration curve from the spiky spectrum intensity profile and applied to the RGB profile of the broad spectrum.

```
flat_corr = np.zeros_like(flat)
fig = plt.figure(figsize=(5*2, 5*3))

for i, c, cm in zip(range(3), ['r', 'g', 'b'], ['Reds_r', 'Greens_r', 'Blues_r']):
    ax = fig.add_subplot(3, 2, (2*(i+1))-1)
    x = np.arange(flat.shape[1], dtype=float)
    y = np.arange(flat.shape[0], dtype=float)
    X, Y = np.meshgrid(x, y)
    Zx = fourier(X, *flat_surface_params[i])
    Zy = fourier(Y, *flat_surface_params[i])
    Z = Zx + Zy
    flat_corr[:,:,i] = Z
    im = ax.imshow(Z, 'gray', aspect='auto')
    ax.grid(0)
    fig.colorbar(im)
```

Methodology:Programming Process

Pixel-to-wavelength calibration applied to the RGB profile of the broad spectrum.

```
ax[0].imshow(Hg, aspect='auto')
linescan = (Hg.shape[0]//2, Hg.shape[1]-16)
green_max = Hg[linescan[0], :, 1].max()
ax[0].hlines(linescan[0], 0, linescan[1], 'w', alpha=0.25)
ax[0].axis('off')

for i, c in zip(range(Hg.shape[2]), ['r', 'g', 'b']):
    int_profile = Hg[linescan[0], :, i]
    int_profile = sig.savgol_filter(int_profile, 51, 3)/green_max
    pk = peak.indexes(int_profile, thres=0.5, min_dist=15)
    ax[1].plot(int_profile, color=c, lw=0.75, label=c.capitalize())
    ax[1].plot(pk, int_profile[pk], 'co', ms=5)
    for p in pk:
        plt.text(p, int_profile[p]+0.05,
                 str(p),
                 horizontalalignment='center',
                 verticalalignment='center')
ax[1].set_xlim(0, Hg.shape[1]-16)
ax[1].set_xlabel('px')
ax[1].set_ylabel('rel. intensity')
ax[1].legend()
```

Results: Dark frame assessment

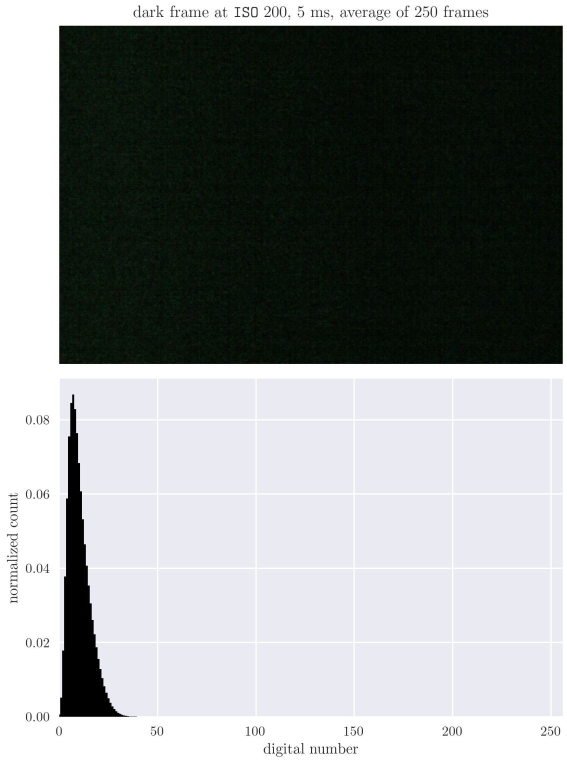


Figure 1. Dark frame image & histogram at ISO 200, 1/200s, average over 250 frames.

The dark frame was obtained by recording a video for a total of 450 frames. This was to allow the camera sensor to warm up. The first 200 frames were then discarded, and the latter 250 frames were averaged and its histogram obtained.

Results: Flat field assessment

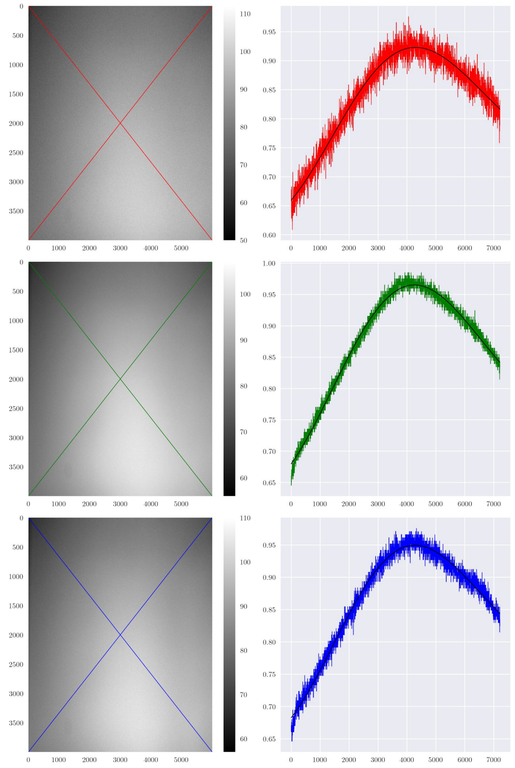


Figure 2. Median of the corner-to-corner transects of a flat-field bright image.

The flat field was obtained by taking an image of a uniformly-lit white background. The same settings were used as before. Additionally a SIGMA 24-70mm lens was used at 70mm (strong vignetting expected, negligible barrel distortion). The two corner-to-corner transects were obtained, and their median per pixel was taken. A second-order Fourier series was fit to the flat field of each channel. The obtained parameters are as follows:

	R	G	B
ω	0.000421	0.000413	0.000428
a0	0.761037	0.785975	0.791803
a1	-0.072683	-0.070368	-0.077732
a2	-0.028726	-0.035699	-0.031371
b1	0.126491	0.138730	0.118573
b2	0.008140	0.009511	0.008367

Results: Spiky Light Source(Mercury)

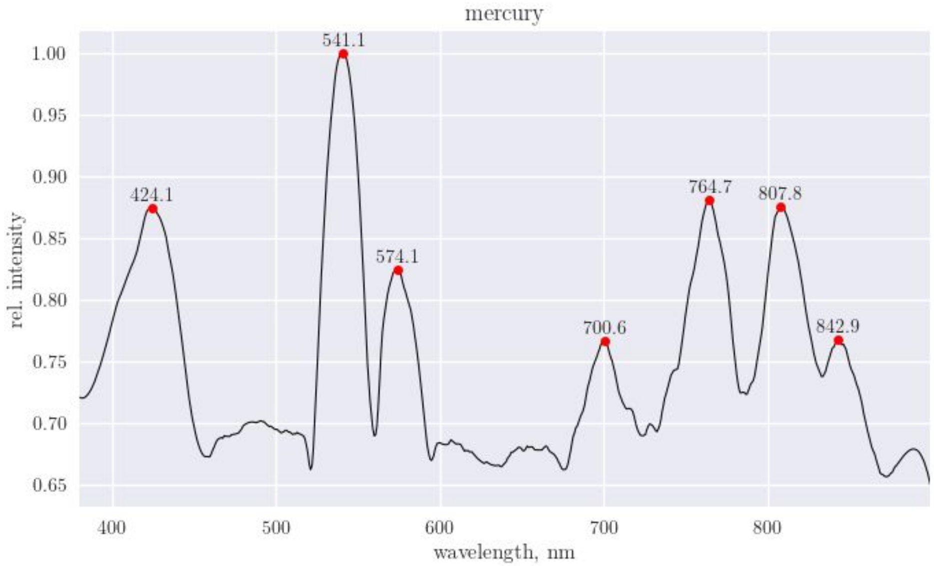


Figure 3. Emittance Spectrum of Mercury

The emittance spectrum of a spiky light source (Mercury lamp) was measured using a spectrometer with the wavelengths of the prominent peaks being identified.

Results: Image correction

$$C = \frac{(R - D) * m}{(F - D)} = (R - D) * G$$

Before performing any processing, the raw image is first corrected using the equation above [1], where R is the raw image, D is the dark frame, F is the flat field, and m is the mean of F-D.

Results: Spiky Light Source(Mercury)

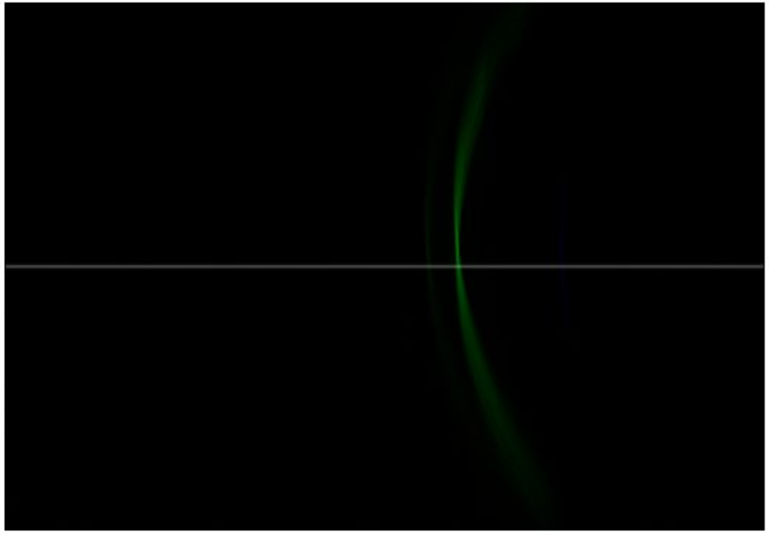


Figure 4. Mercury spectrum image

The emittance spectrum of a spiky light source (Mercury lamp) was captured using a Nikon D3400 SLR at ISO 200, 1/200s, f/2.8, and saved in RAW format.

Results: Spectrometer setup

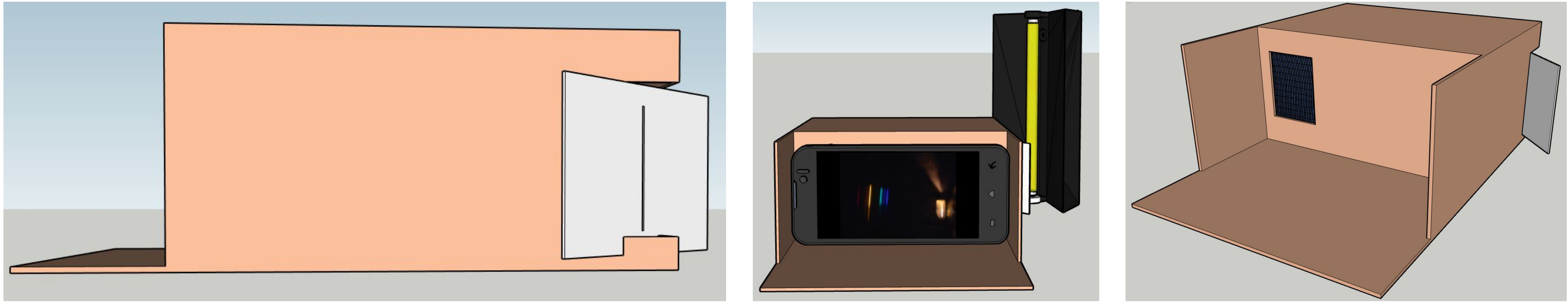


Figure 5. Spectrometer setup: side view (left), front view (middle), isometric view (right).

The images of the spectrum were obtained using an improvised spectrometer setup involving a slit and an old CD grating by [2]. A DSLR camera was used in lieu of a phone camera in order to be able to save images in RAW format.

Results: Pixel to Wavelength Calibration

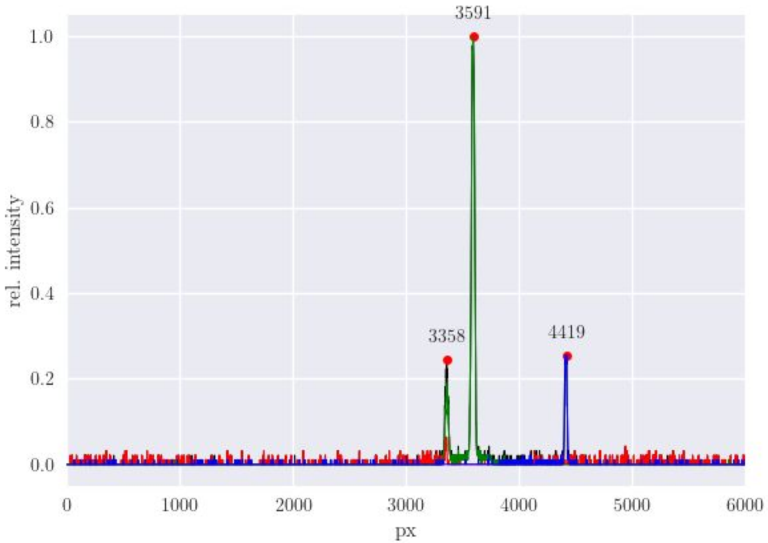


Figure 6. Pixel locations of spectrum peaks

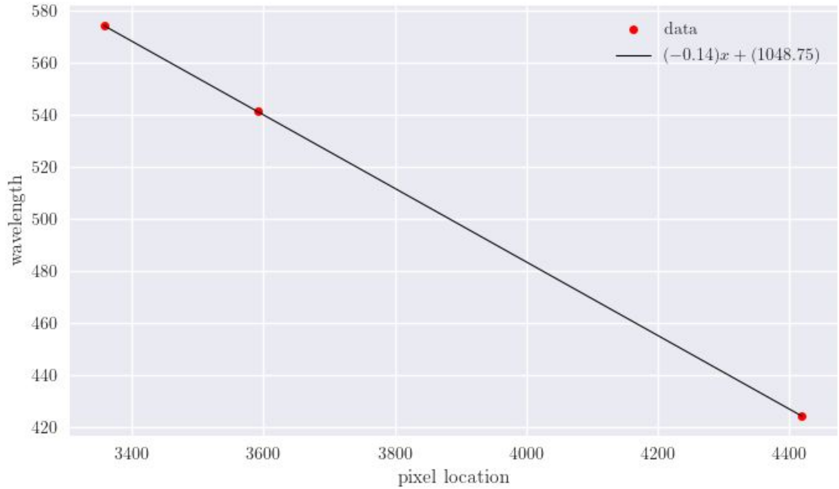


Figure 7. Pixel to wavelength calibration curve

From the image of the spectrum, as well as the emittance plot, a pixel to wavelength calibration curve was constructed by plotting the intensity curve of a line scan obtained from the center of the frame. The peak intensities were plotted vs the known wavelengths from Fig. 1, and a calibration curve was obtained using linear regression.

Results: Pixel to Wavelength Calibration

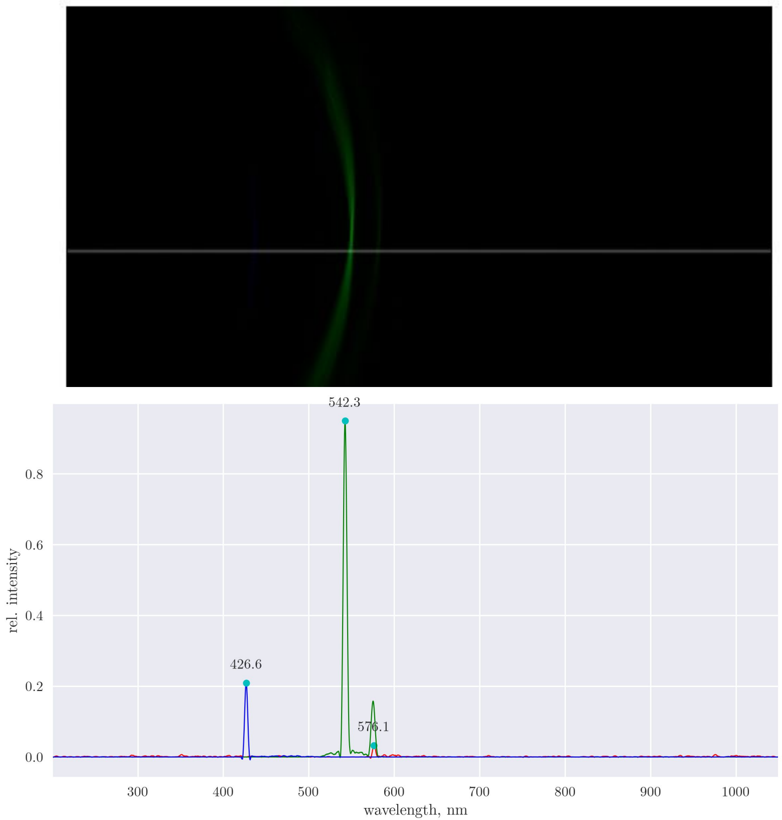
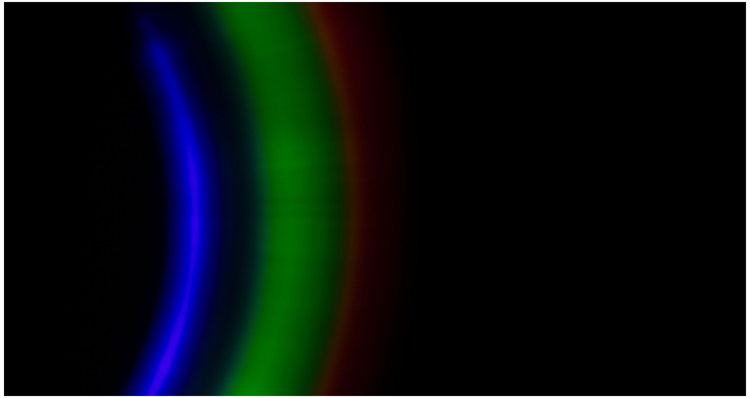


Figure 8. Calibrated wavelength measurements.

Using the obtained pixel-to-wavelength calibration, the wavelengths for the peaks in the captured image was obtained.

Results: Broad source



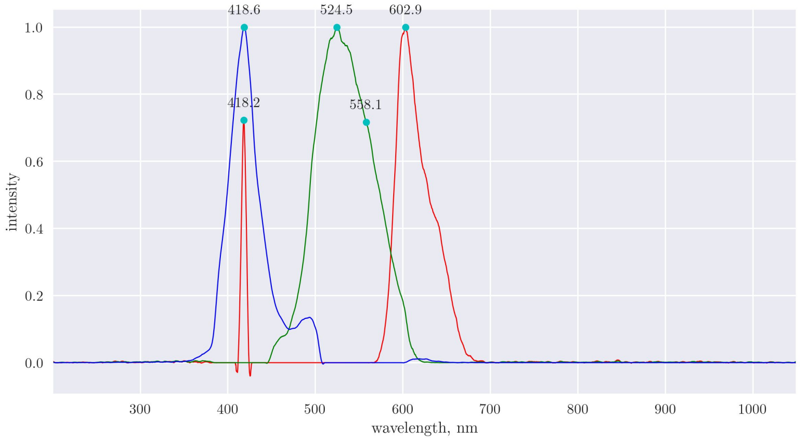


Figure 9. Camera sensitivity.

Using the obtained pixel-to-wavelength calibration, the wavelengths for the peaks in the captured image was obtained.

Results: Leaf color patch

Using the determined spectral sensitivity, we were able to obtain the color patch of a leaf which is green in color.

Discussion

In slide 9, it can be observed that the histogram values were spread out. This means that the video recorded was not purely black or the dark frame image had values other than zero. It can then be said that the camera used does not create or record a completely black or dark image.

In slide 10, a strong vignetting can be observed which might be due to the use of the SIGMA 24-70 mm lens as stated in the slide. Ideally, the intensity profile of a flat field is a horizontal line. However, it cannot be observed in our result. The possible reason for this, aside from the lens, was the uneven distribution of white light as can be observed in the image.

The vignetting property of the camera was corrected using the formula shown in slide 12.

In slide 17, it can be observed that we were able to determine the spectral sensitivity of the Nikon D3400 SLR. Although there was no theoretical spectral sensitivity for Nikon D3400 available online, we were able to validate our result by obtaining a color patch for a leaf as shown in slide 18.

Summary

With the use of an improvised spectrometer, the set up for determining the spectral sensitivity of camera was easily done. With the help of mercury, blank paper and several techniques that was implemented using python, the goal was achieved. In dark frame assessment, 250 frames were averaged and a histogram of the camera was obtained. In flat-field assessment, median per pixel was taken. Parameters of each channel were obtained through fourier series.

A pixel to wavelength plot was constructed using the intensity curve of a line scan obtained from the center of the frame. Using linear regression, a calibration curve was obtained. Using this information, the wavelengths from the images were obtained.

In a nutshell, the goal of the activity to determine the spectral sensitivity of Nikon D3400 was achieved. Using activity 9 results, the validation of the spectral sensitivity came from the leaf color obtained.

References

1. Hessman & Modrow. (2006). *Creating a flatfield calibration image*. http://www.astronomie-und-internet.de/docs/Creating%20a%20Flatfield%20Calibrating%20Image.pdf.
2. A. Advincula, C. Baylon, K. Domingo, and R. Principe. (2019). *Live-Feed-over-LAN Camera Spectrometer (LoLAN-CaS)*, Physics 166 (2nd Semester, A.Y. 2018-19) Final Project. https://github.com/kvdomingo/Physics-166/blob/master/Spectrometer/documentation.pdf.
3. M. Pagnutti, R. Ryan, G. Cazenavette, M. Gold, R. Harlan, E. Leggett, and J. Pagnutti. (2017). Laying the foundation to use Raspberry Pi 3 V2 camera module imagery for scientific and engineering purposes. *Journal of Electronic Imaging* **26**(1). https://dx.doi.org/10.1117/1.JEI.26.1.013014.

Contribution

Domingo - actual experiment, coding, results

Estrada - actual experiment, methodology

Fernan - actual experiment, results

Gaffud - actual experiment, discussion

Go - actual experiment, summary