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USB Spectrometer

Name:

UoG ID:

UESTC ID:

My Student ID

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- Background
- Hardware Design
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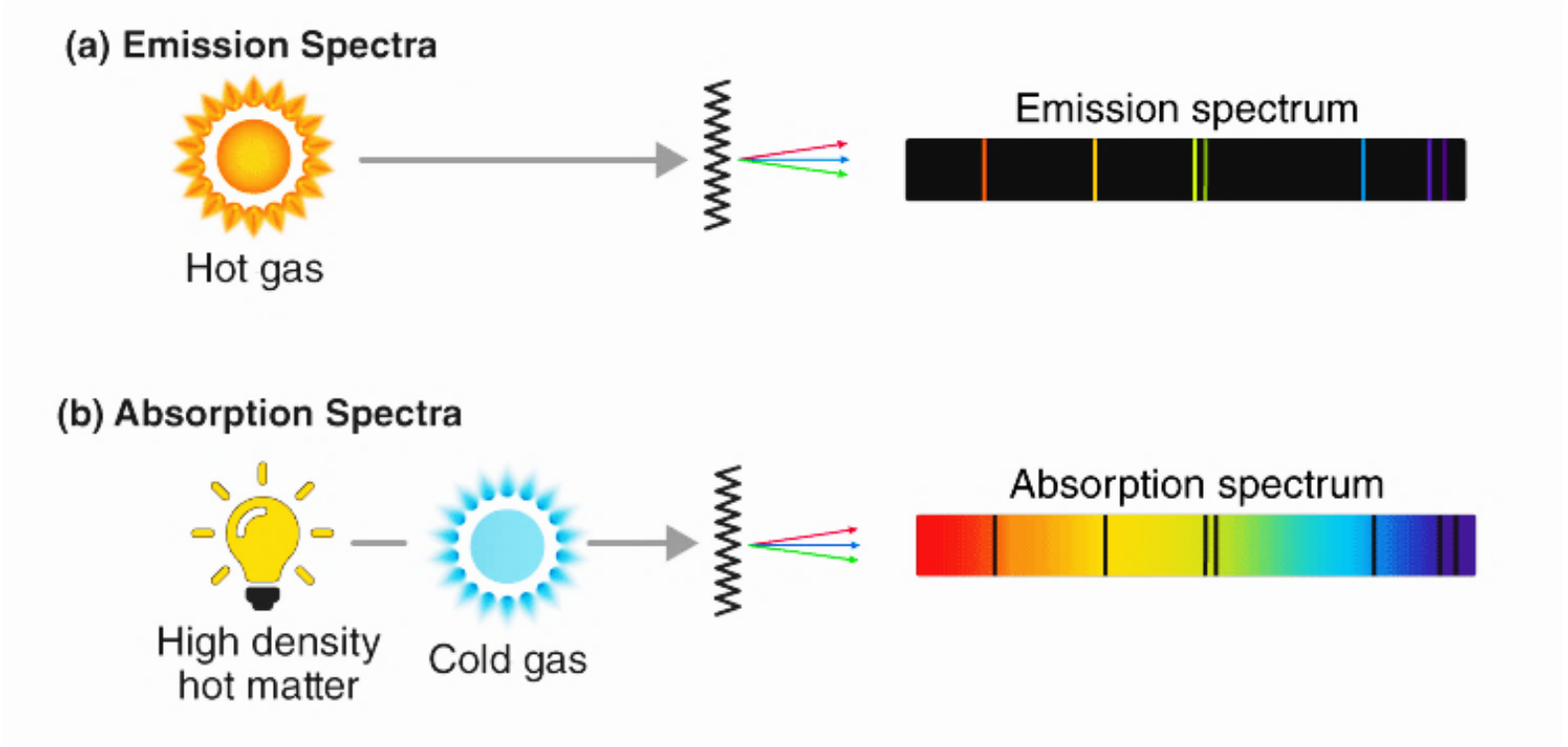
- Result
- Conclusion

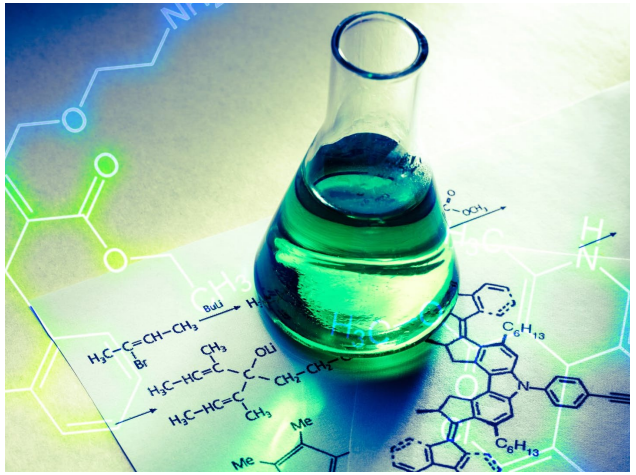
Background

- Spectroscopy
  - Absorption and Emission Spectrum



Background

- Spectroscopy
  - Application



Chemistry

Astronomy

Biology

Background

- Optical Spectrometer

- Commercial Solution:

  Extremely High Price (Thousands of Dollars)

Background

- Optical Spectrometer
  - Current DIY Solution
    - Low Cost
    - Low Resolution
    - Low Accuracy
    - No Compatible Software

Background

- Optical Spectrometer
  - Design Goal
    - Less than 1 nm resolution
    - Wide Wavelength Range (400-1000 nm)
    - Less than 2000 CNY of cost
    - Easy-to-use software
    - Opensource all code, 3D models, and other material

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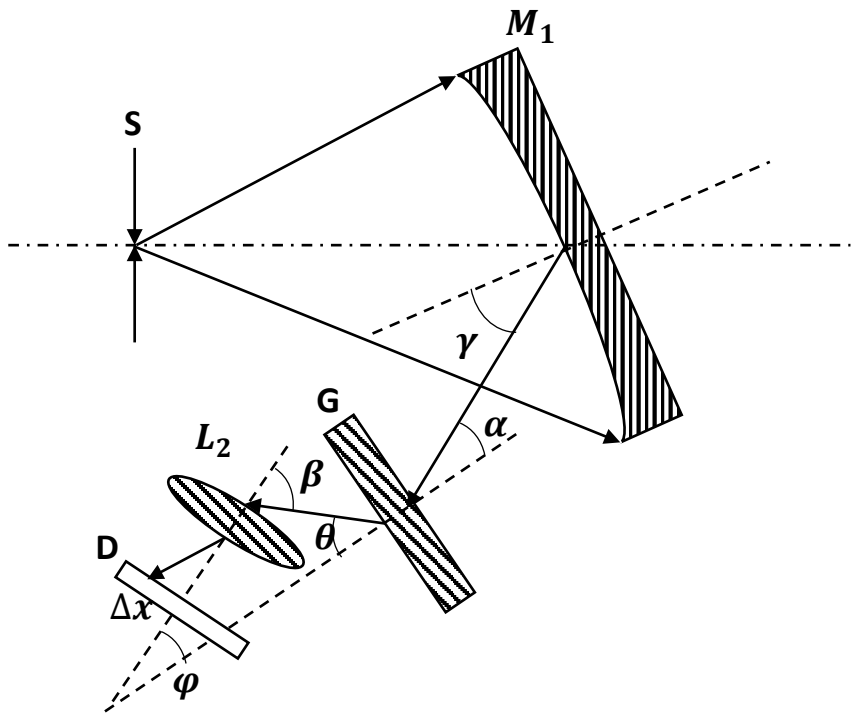
Hardware Design

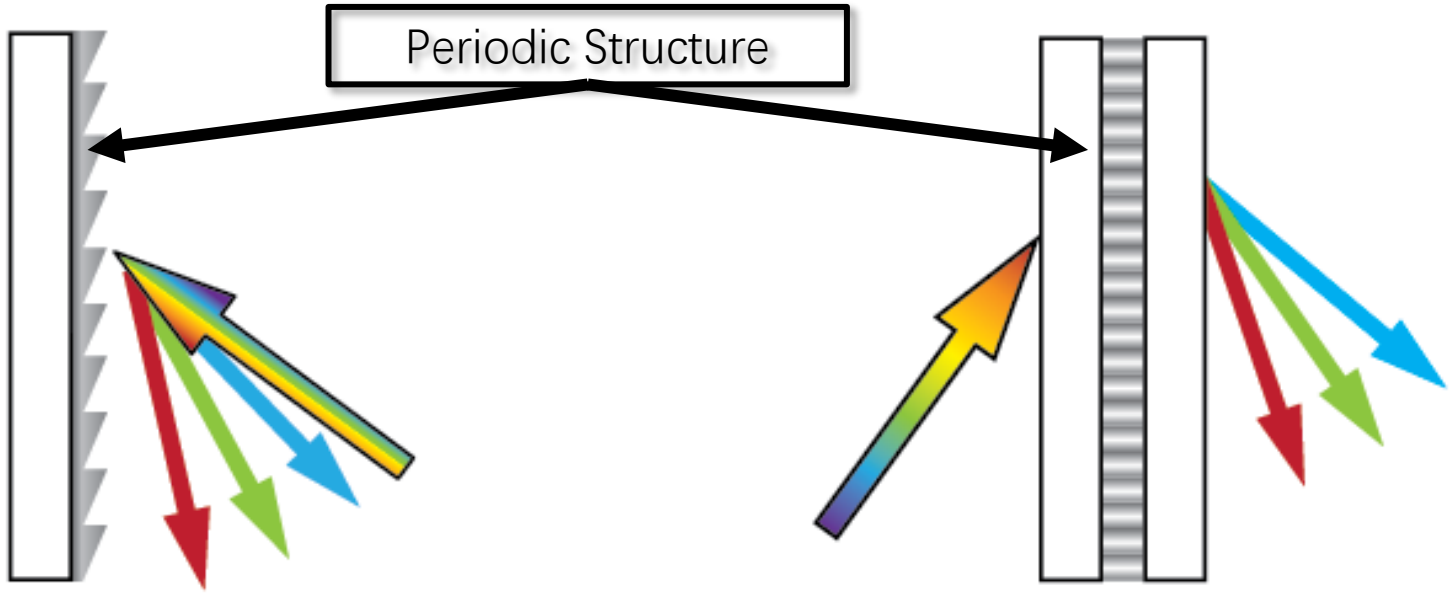
- Czerny–Turner spectrometer



- S: Single Slit
- M_1: Colimitation Mirror
- G: Diffraction Grating
- L_2: Focusing Lens
- D: Detector
  - γ: Reflection Angle
  - α: Incident Angle
  - θ: Diffraction Angle
  - β: Deviation Angle
  - φ: Angle between G and L_2
  - Δx: Linear Deviation

Hardware Design

- Diffraction Grating



Reflected Grating [1]

Transparent Grating [1]

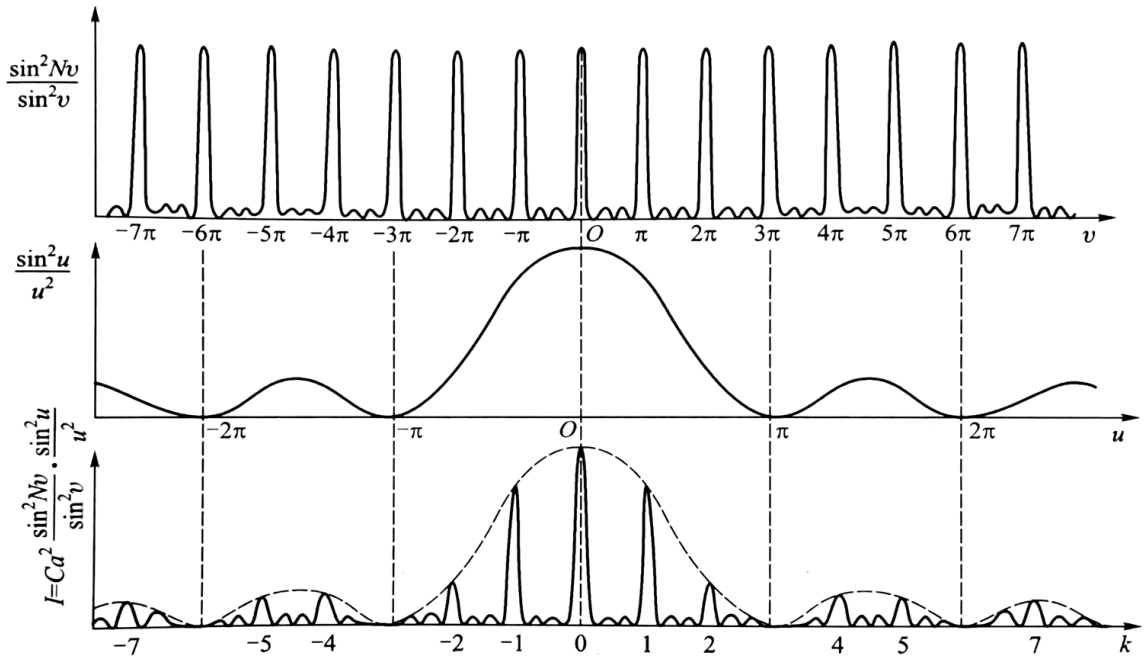
Hardware Design

- Diffraction Grating

$$I = A^2 = C'^2 a^2 \frac{sin^2\, u}{u^2} \frac{sin^2\, Nv}{sin^2\, v}$$

Where $u = \frac{\pi a sin\theta}{\lambda}$, and $v = \frac{[\pi(a+b)sin\theta]}{\lambda}$.

Grating Equation: $d(sin\varphi \pm sin\theta) = k\lambda$



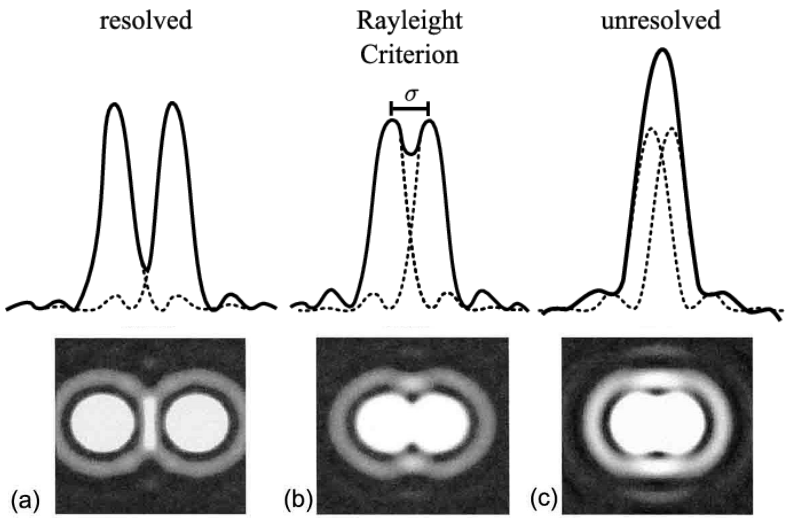
Hardware Design

- System Resolution

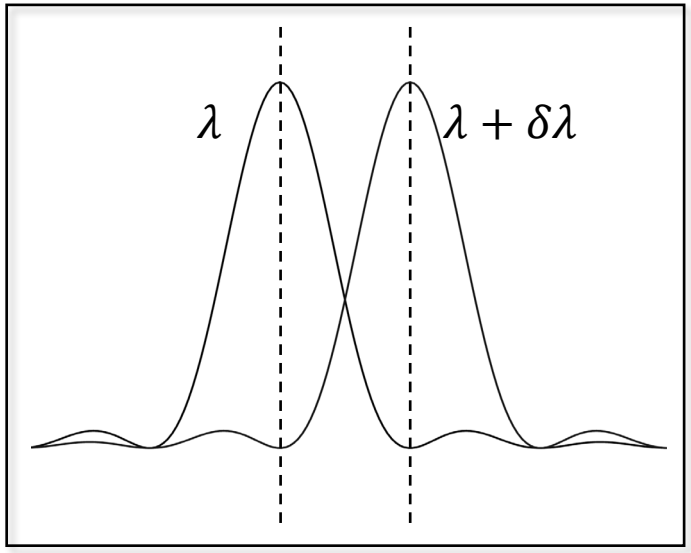
  - Imaging resolution caused by the aperture diffraction limit
  - Chromatic resolution of the grating
  - The width of the slit’s image on the sensor
  - Sensor’s physical resolution.

Hardware Design

- Grating Chromatic Resolution



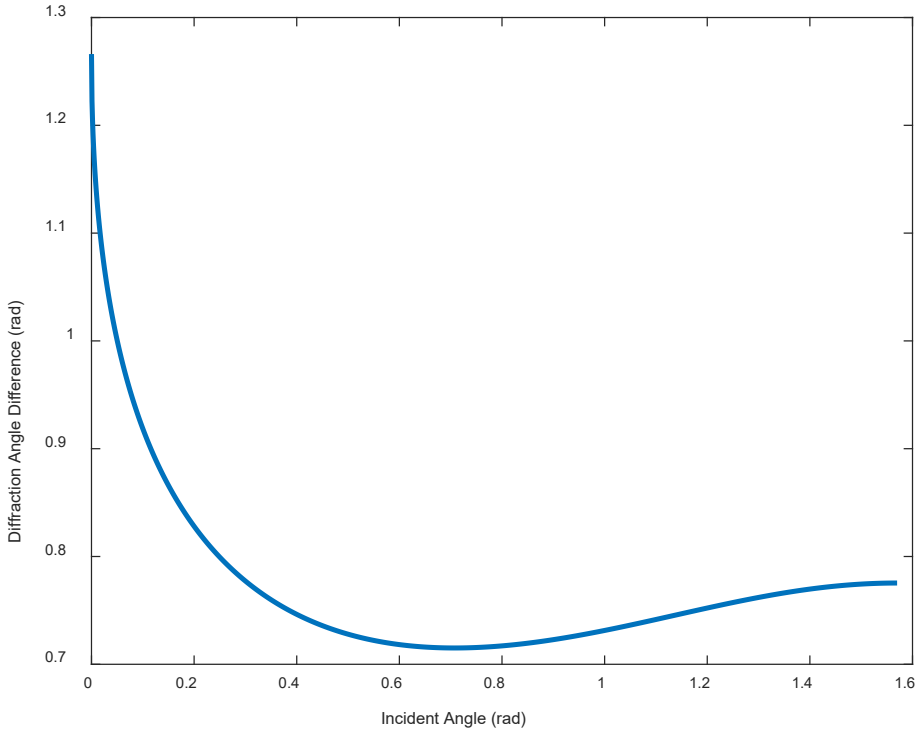
Demonstration for Rayleigh Criterion [4]



$$R = \frac{\lambda}{\delta\lambda} = Nk - 1 \approx Nk$$

Hardware Design

- Parameter Optimization

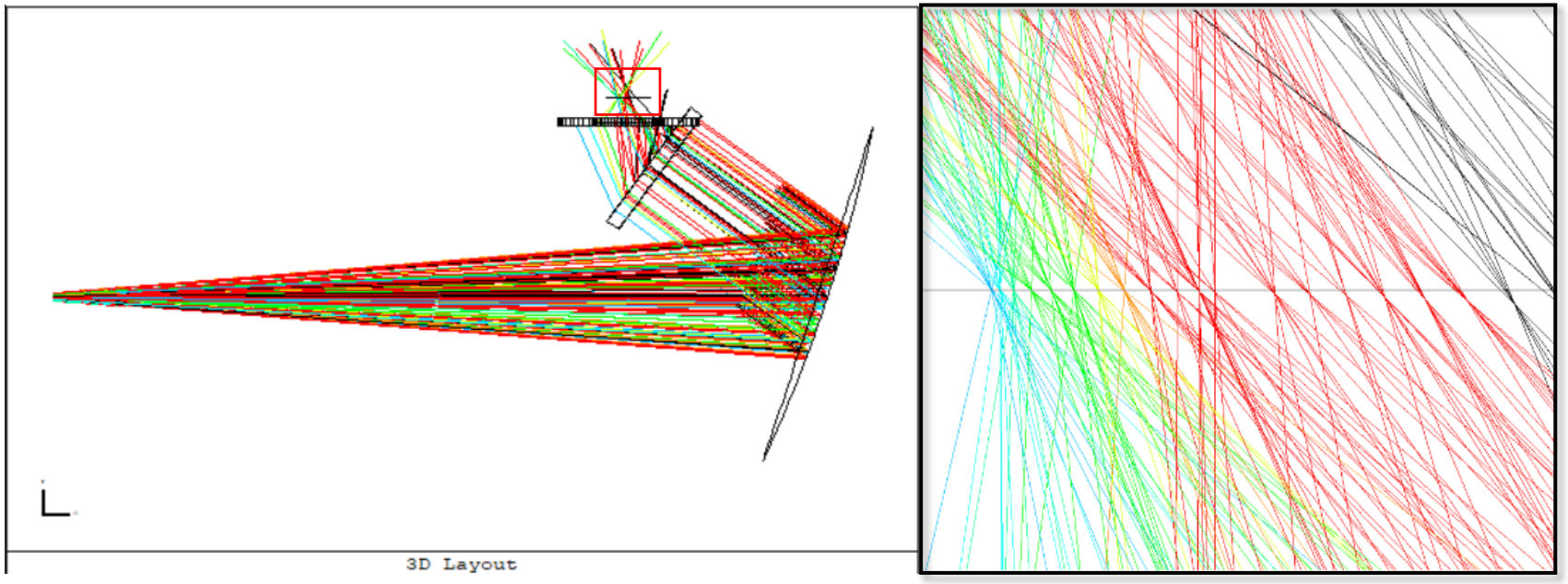


Incident Angle Optimization:

- $\theta_i = \arcsin\left(\sin(\varphi) - \frac{\lambda_i}{d}\right)$
- $\Delta\theta = \theta_2 - \theta_1$
- Using Matlab
- So $\varphi = 0$.

Hardware Design

- Computer Simulation



- Optical Simulation Software:

  Zemax Optical Studio

Hardware Design

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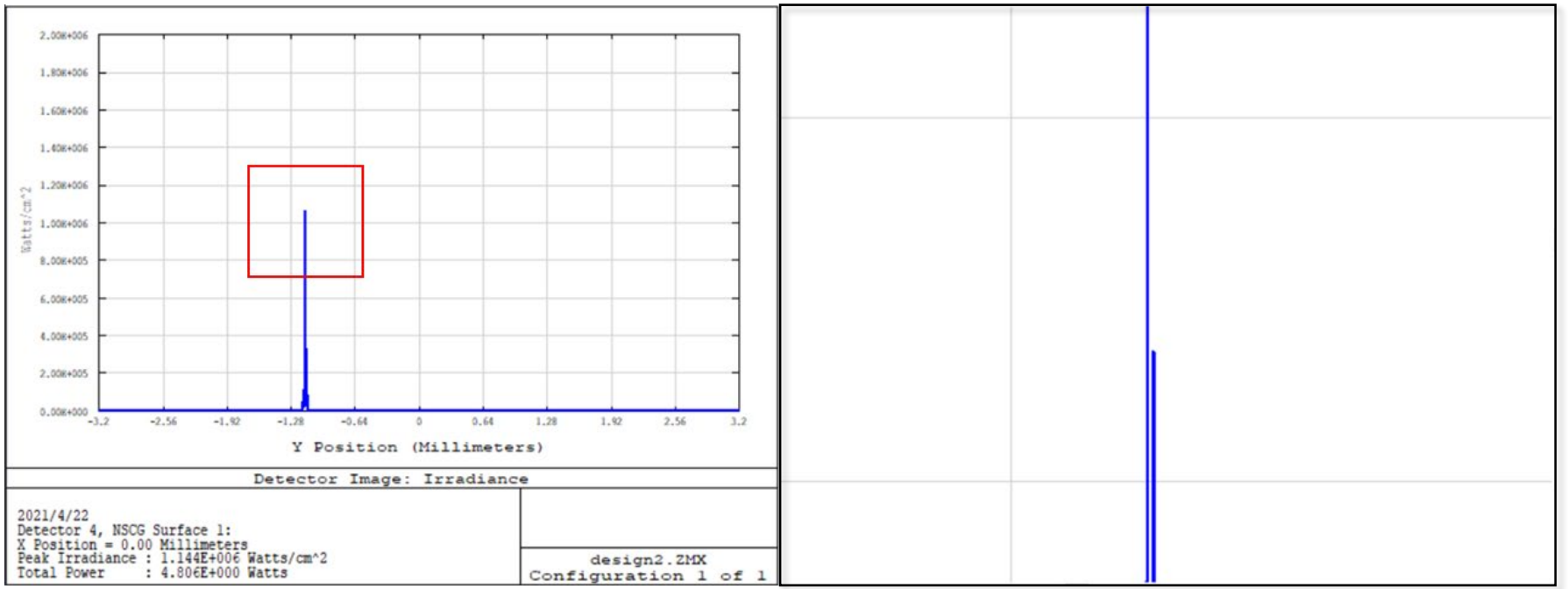
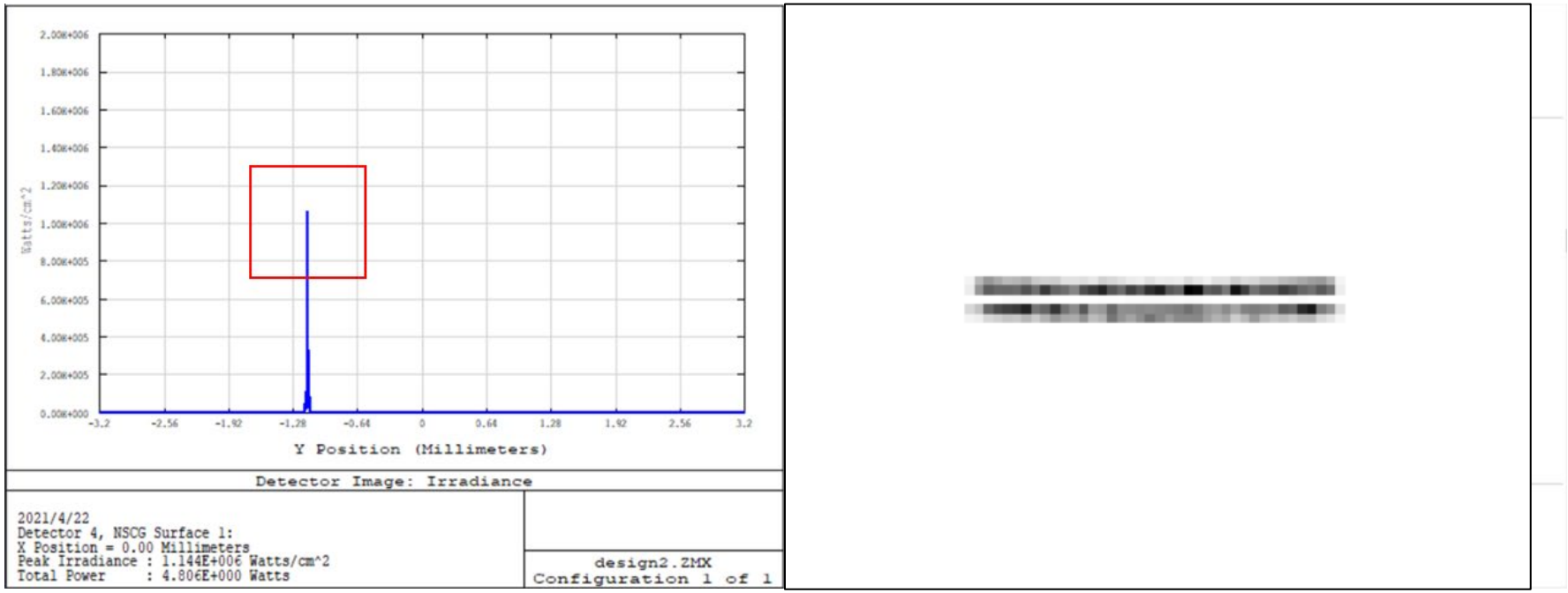
- Computer Simulation



- D-lines of Sodium (588.9 and 589.5 nm)
  - $Resolution < 0.6\,nm\ < 1\,nm$

Hardware Design

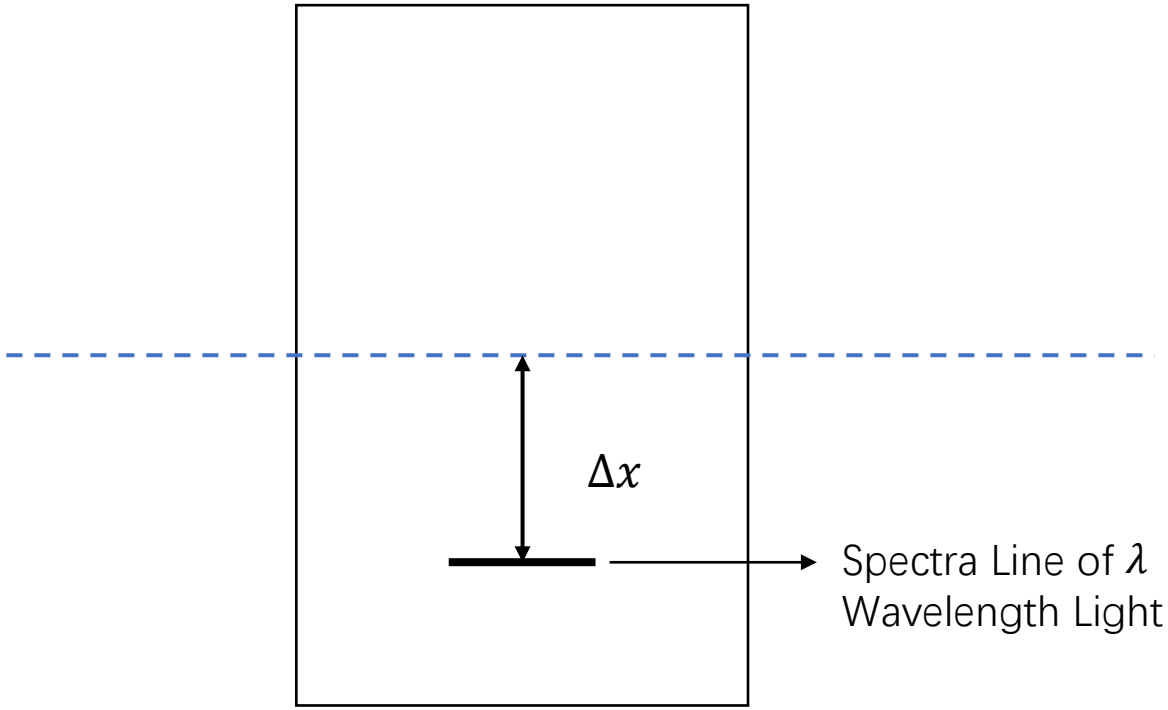
- Computer Simulation



- D-lines of Sodium (588.9 and 589.5 nm)

Software Design

- Linear Dispersion



Using Imaging Formula and Grating Equation:

$$\lambda = d * \frac{sin\alpha + \sin\left(\frac{\Delta x}{F_{L_2}} - \varphi\right)}{k}$$

Software Design

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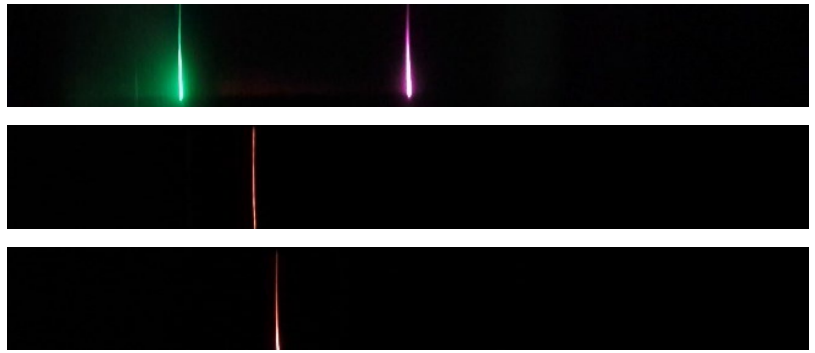
- Linear Calibration



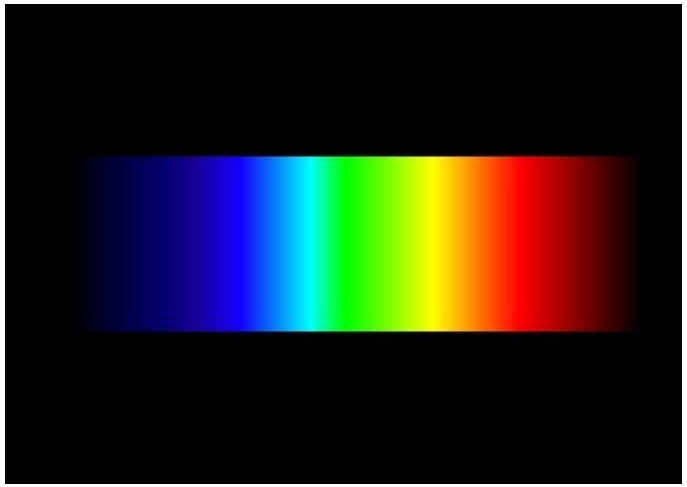
3 lasers' spectrum

Wavelength (λ_i)	Pixel Position (start from zero) (PP)
532 nm	827
808 nm	1919
632.8 nm	1179
650 nm	1289

Recorded Data

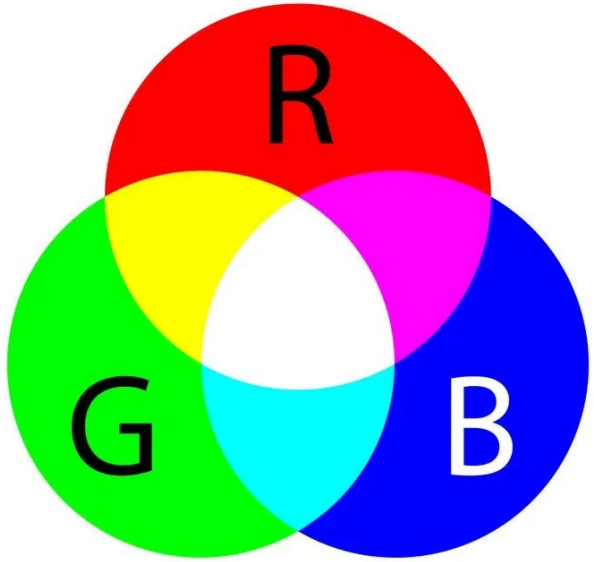
Software Design

- Color Space



Continuous Spectrum

Mapping

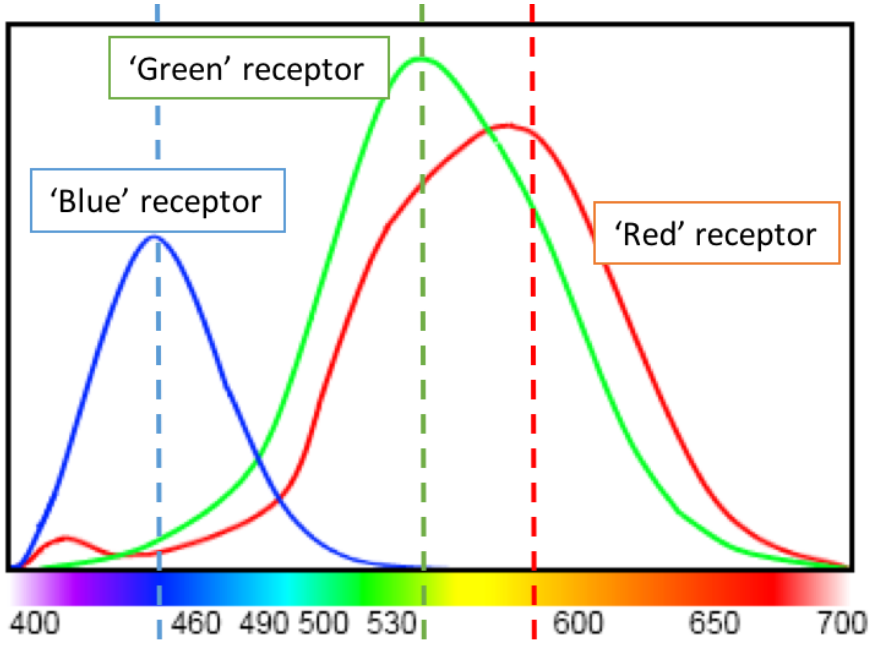


RGB Color Space

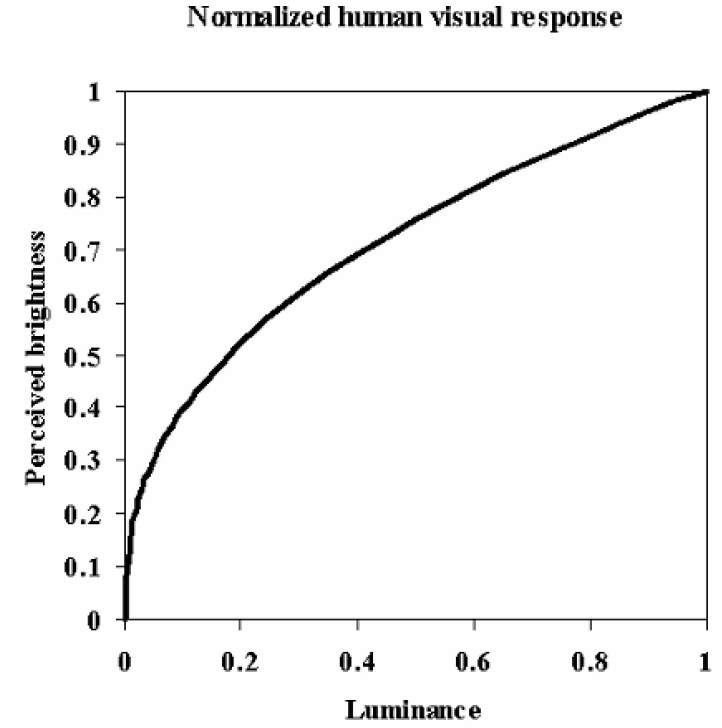
Software Design

- sRGB Color Space

standard Red Green Blue (sRGB): Design to match perceptions of human eyes



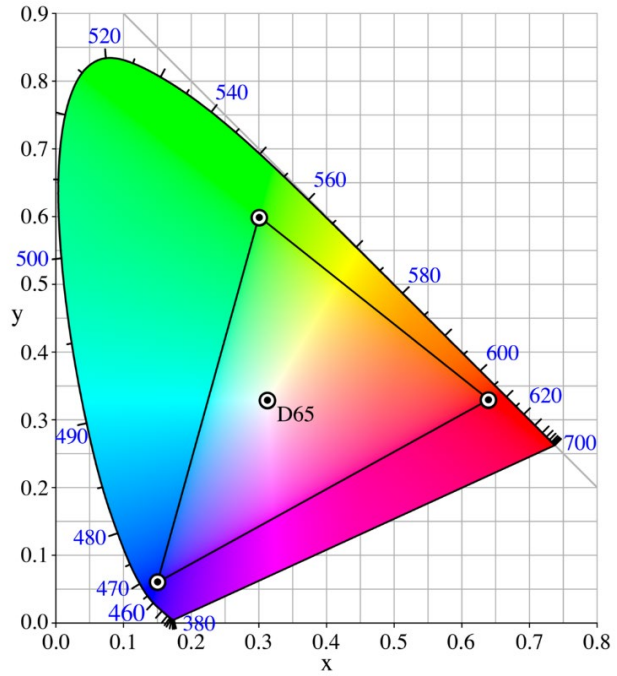
Sensitivity of Human Eyes [2]



Human Visual Brightness Response [3]

Software Design

- CIE 1931 Color Space



Chromatic Graph of CIE 1931 [5]

$$\gamma^{-1}(u)\begin{cases}\frac{25u}{323}, u \le 0.04045\\ \frac{200u+11^{\frac{12}{5}}}{211}, \quad otherwise\end{cases}$$

$$\begin{bmatrix}X\\Y\\Z\end{bmatrix} = \begin{bmatrix}0.4124 & 0.3576 & 0.1805\\0.2126 & 0.7152 & 0.0722\\0.0193 & 0.1192 & 0.9505\end{bmatrix}\begin{bmatrix}R_{linear}\\G_{linear}\\B_{linear}\end{bmatrix}$$

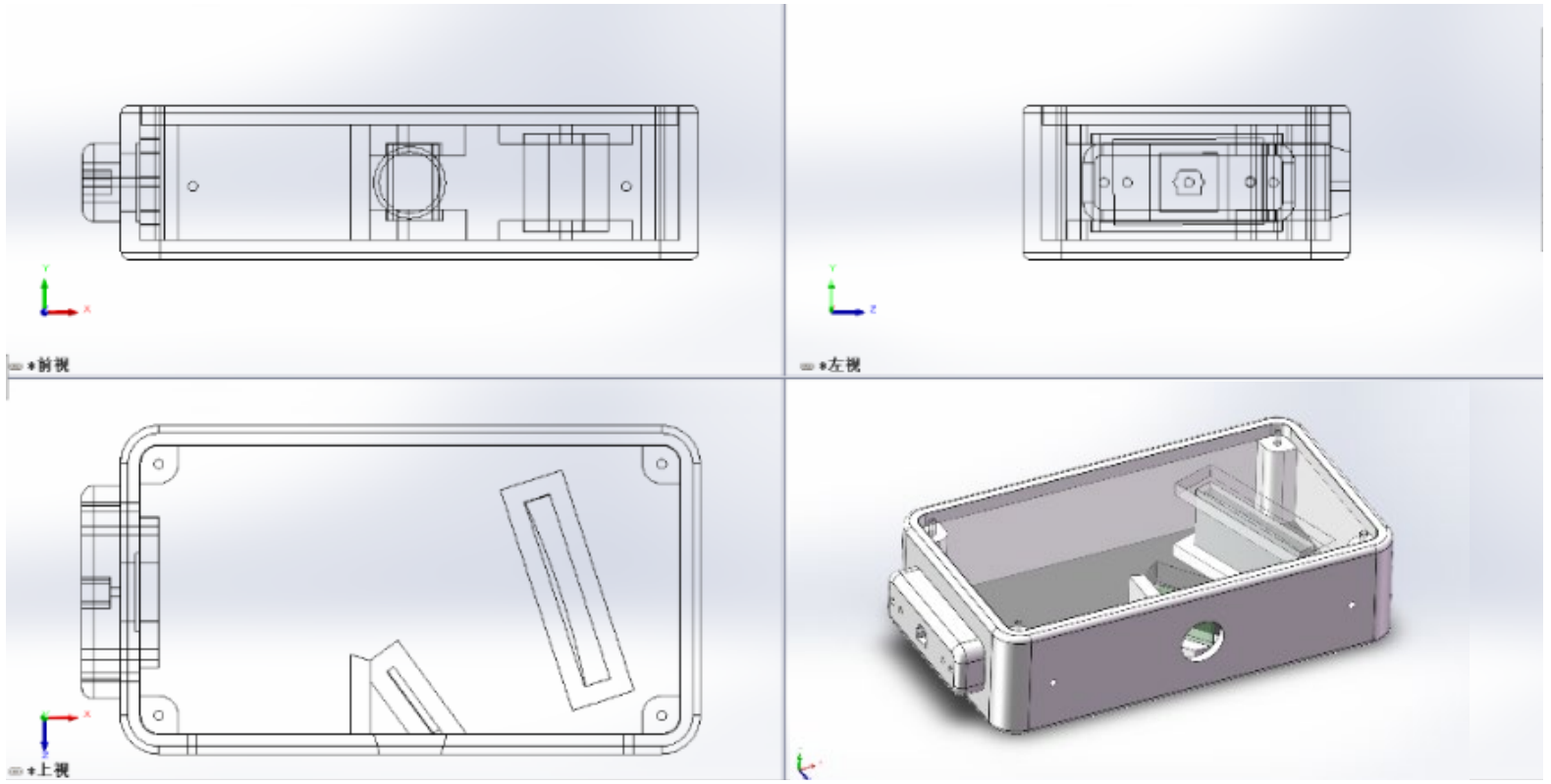
$$Y = Relative\ Luminance$$

Software Design

- Python3 and Opensource Libraries

Hardware Building

- 3D Modeling



Hardware Building

- 3D Printing

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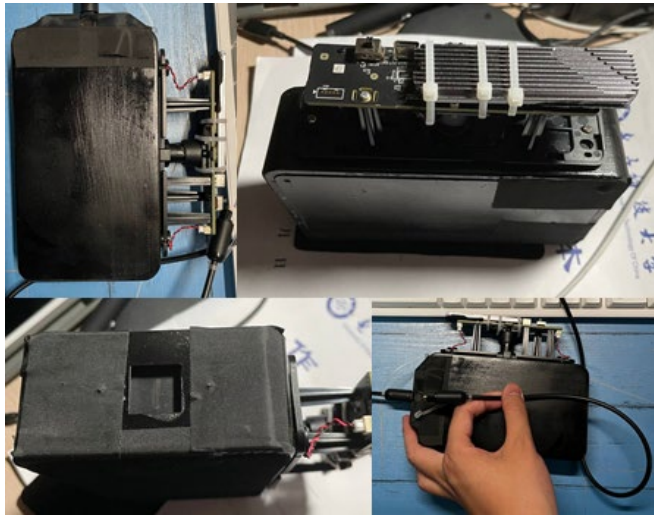
Hardware Building

- Assembling



Hardware Building

- Total Cost

Name of component	Price with shipping fee (CNY)
Diffraction Grating	165
Collimator Mirror	105
Steel Single Slit	125
Camera	499
3D Printed Case	285
Optical Fibre	20
Lasers	70
Overall	1269

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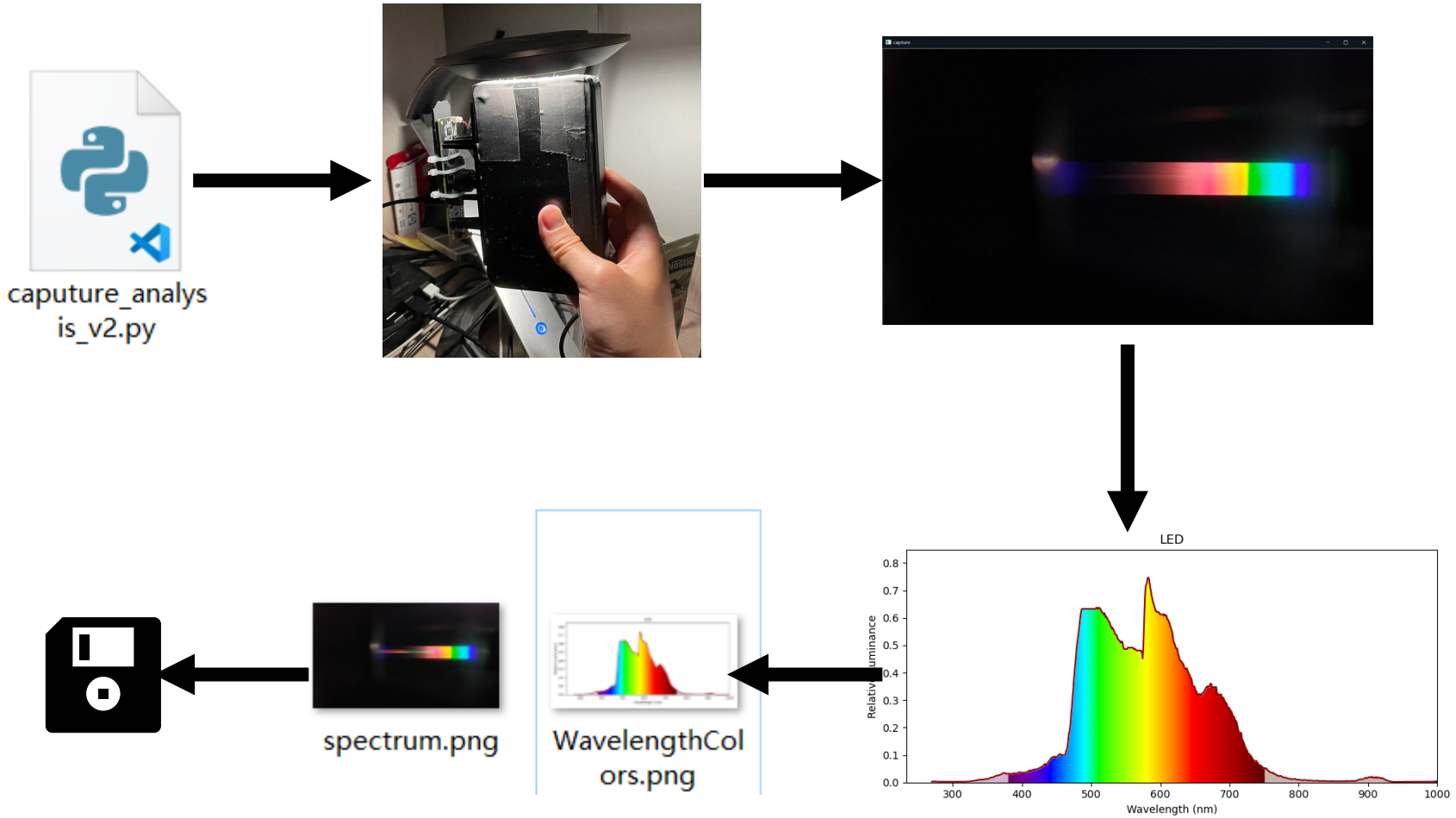
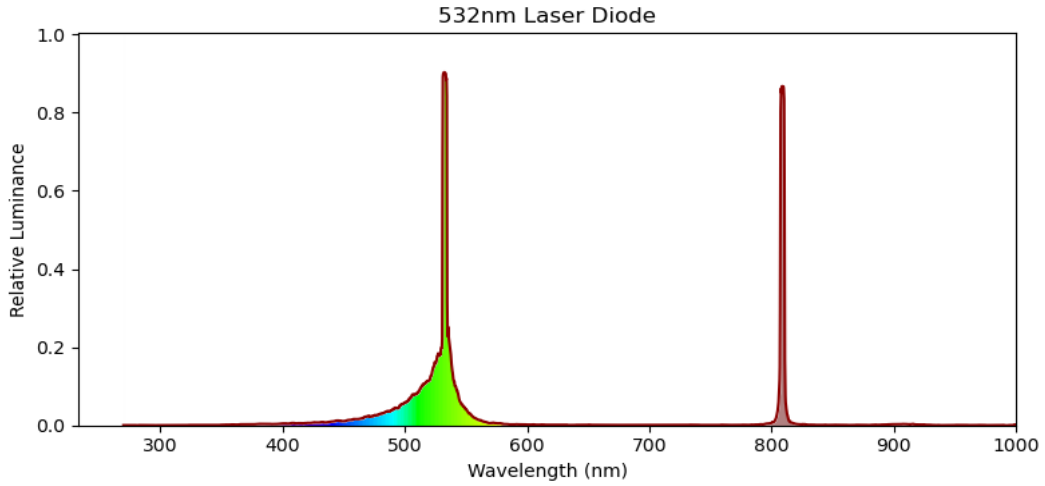
Demonstration

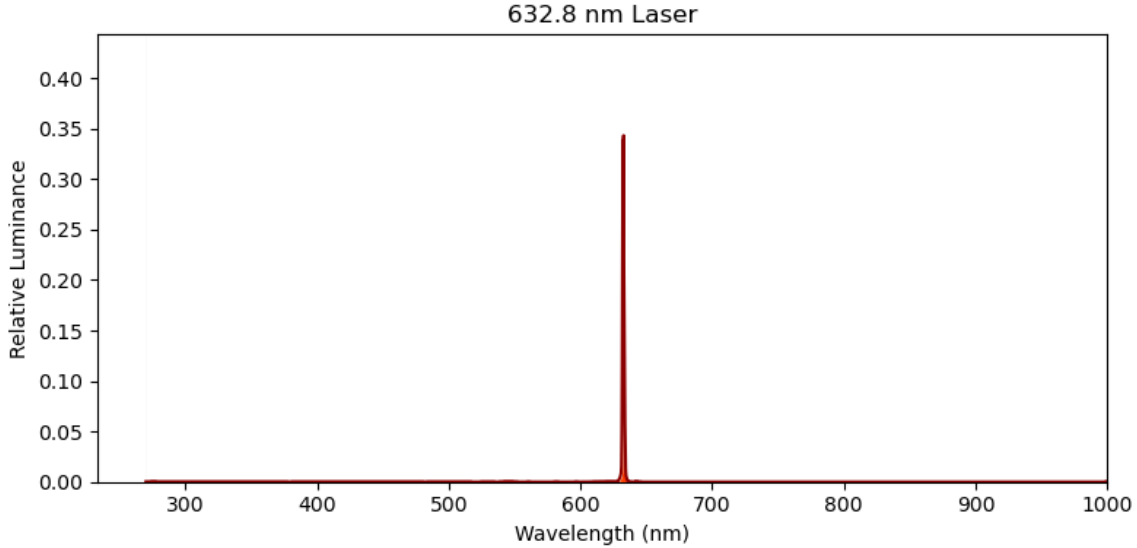


Result

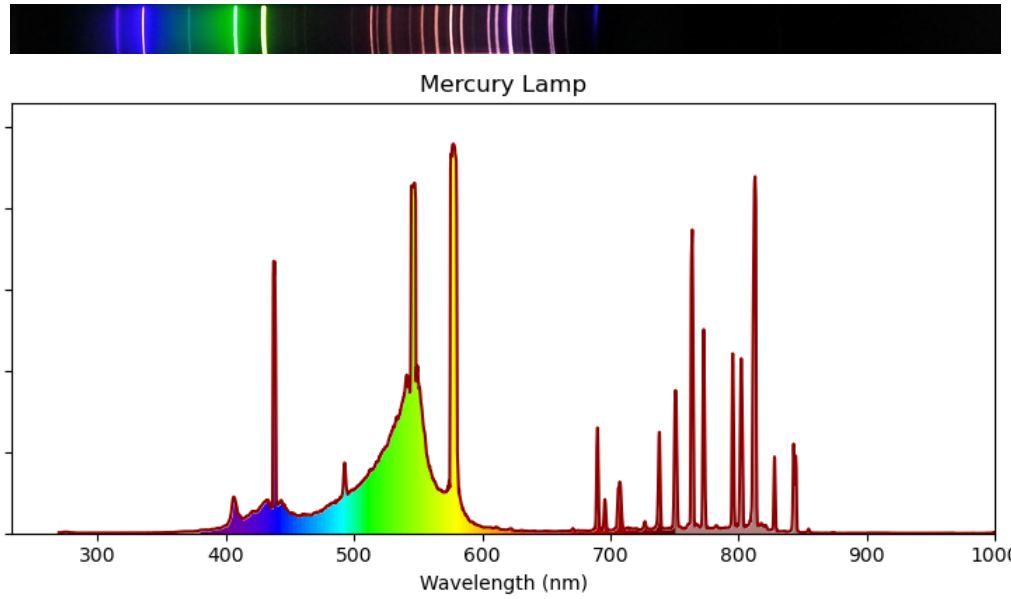
- Measurement of Different Light Source
  - 3 type of Laser, Mercury Lamp, Sodium Lamp, etc.

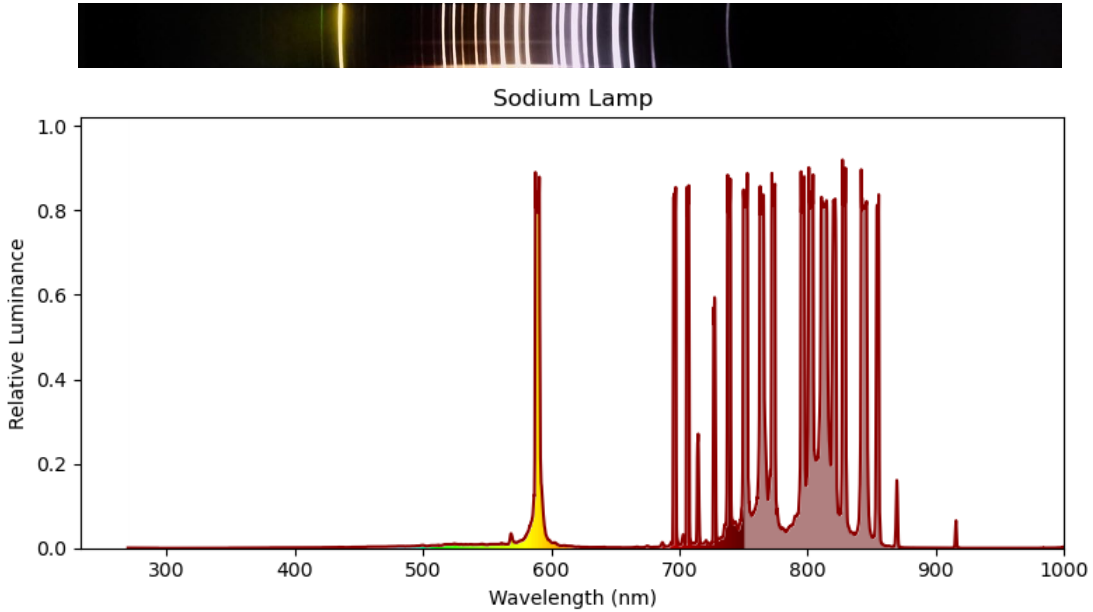
Result


532nm Laser Diode
Relative Luminance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000

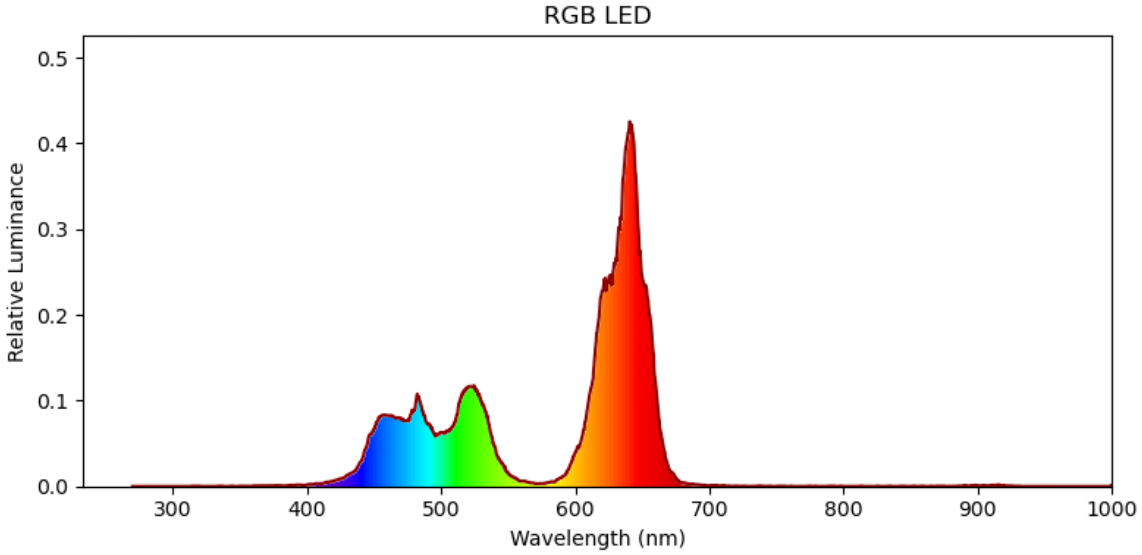

632.8 nm Laser
Relative Luminance
Wavelength (nm)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
300
400
500
600
700
800
900
1000

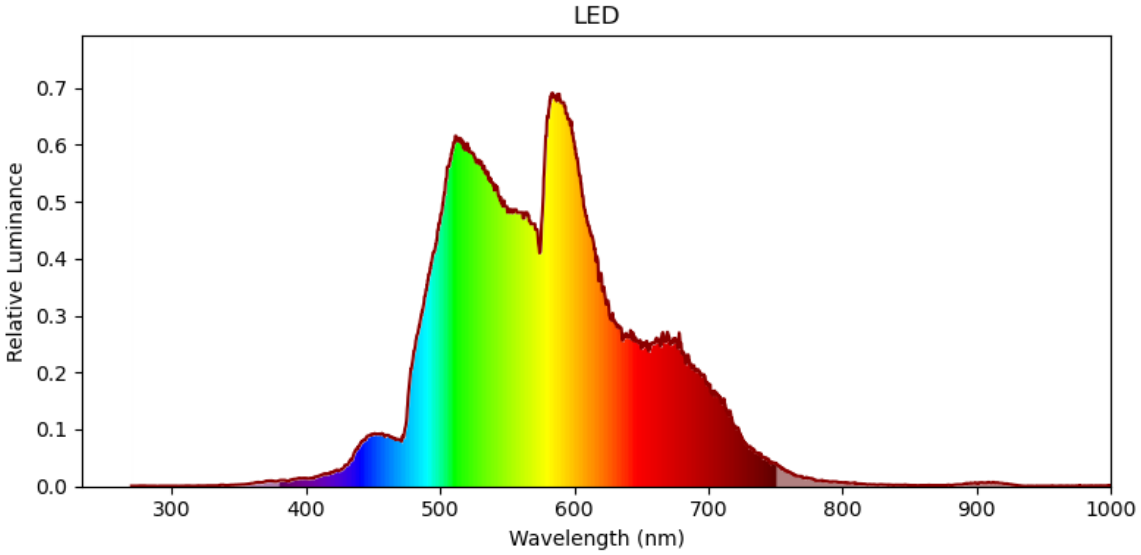
Result


Mercury Lamp
Relative Luminance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000

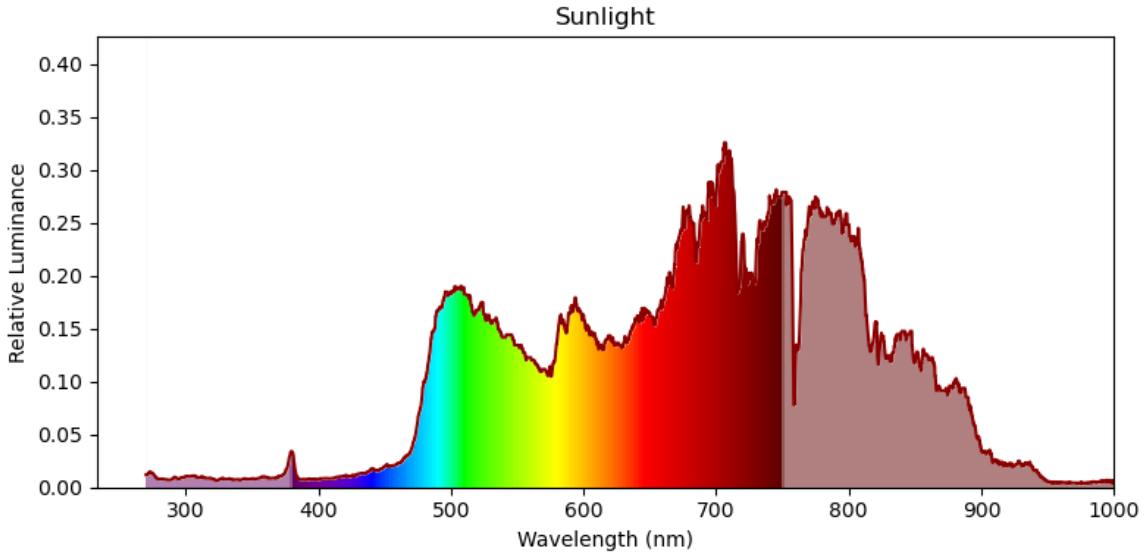

Sodium Lamp
Relative Luminance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
300
400
500
600
700
800
900
1000

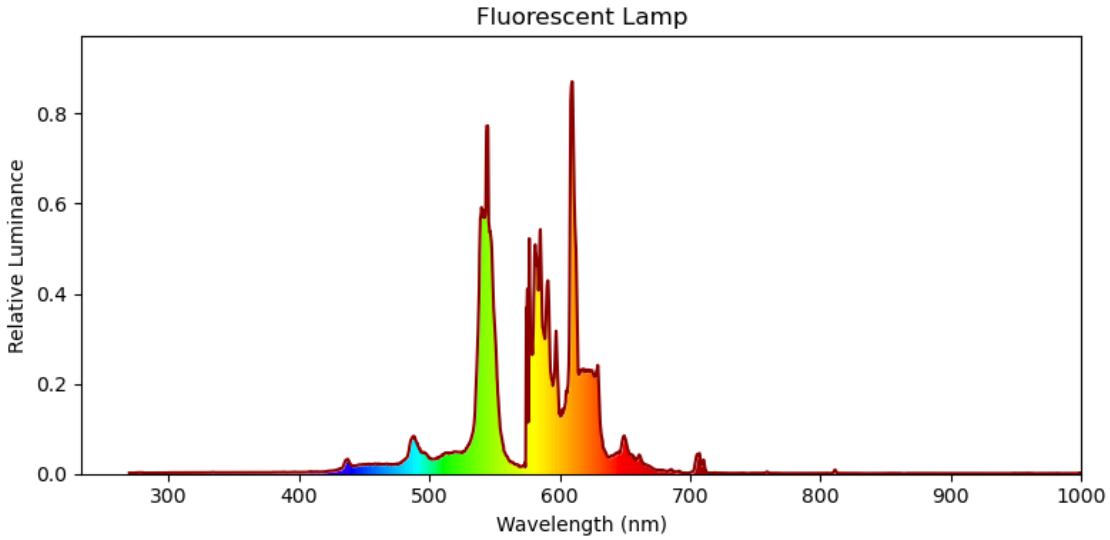
Result


RGB LED
Relative Luminance
0.0
0.1
0.2
0.3
0.4
0.5
300
400
500
600
700
800
900
1000
Wavelength (nm)

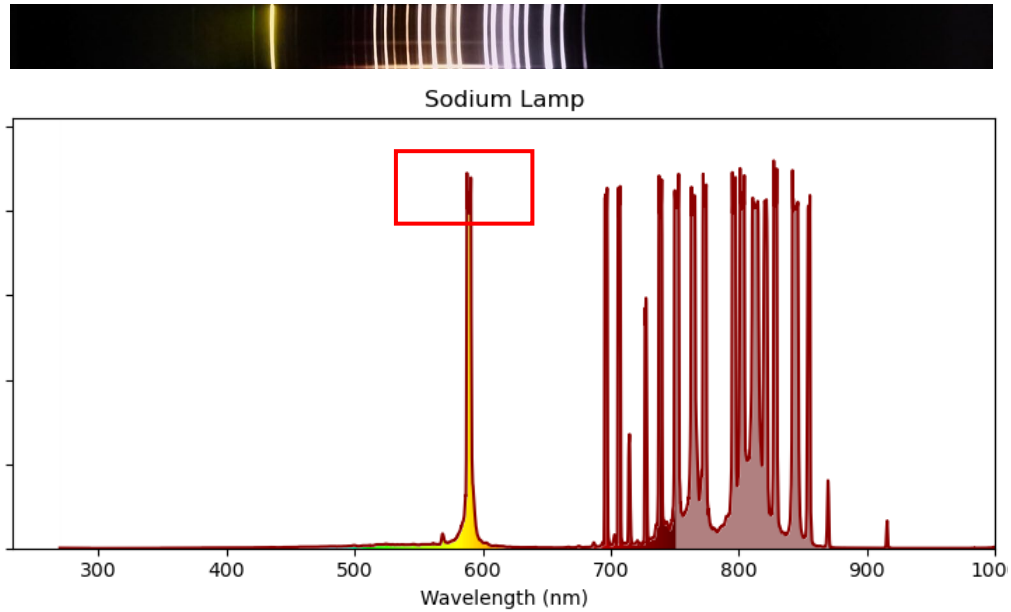

LED
Relative Luminance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
300
400
500
600
700
800
900
1000
Wavelength (nm)

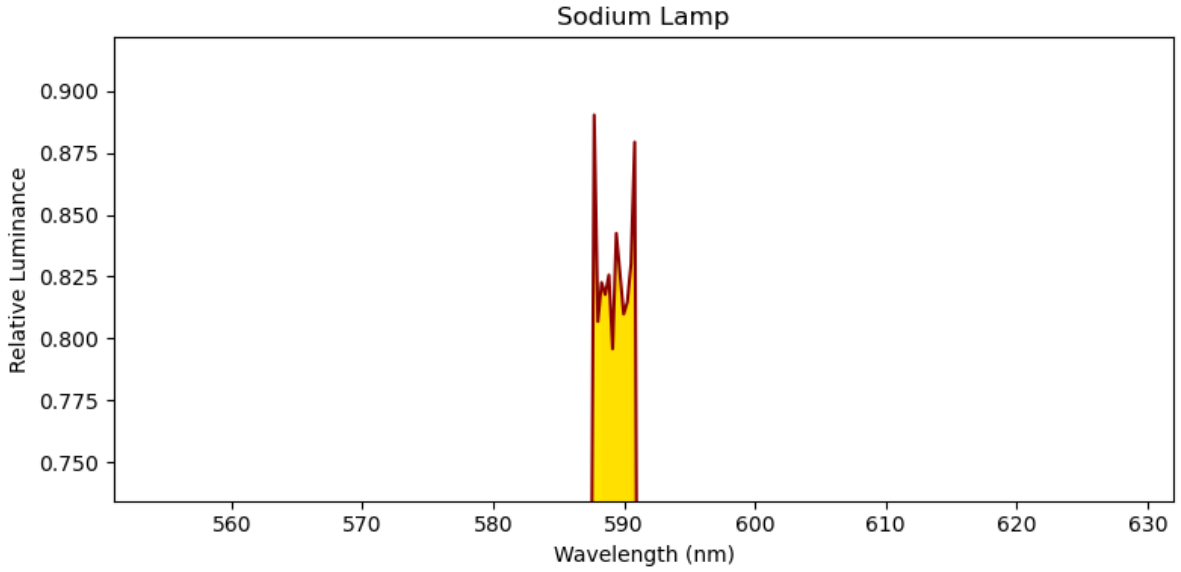
Result


Sunlight
Relative Luminance
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
300
400
500
600
700
800
900
1000
Wavelength (nm)


Fluorescent Lamp
Relative Luminance
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
1000
Wavelength (nm)

Result





- D-lines of Sodium (588.9 and 589.5 nm)
  - $Resolution < 0.6\,nm\ < 1\,nm$

Conclusion

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- The spectrometer achieves the 0.6 nm resolution
- The total cost is about 1200 CNY
- The wavelength range is around 350-950 nm
- An easy-to-use software is built.
- All the material is open-sourced in my Github Repository:

  https://github.com/szl0834

In conclusion, the project satisfied the design goals.

Future Works

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- Using standard luminance light source as the reference to mapping the relative luminance to the physical luminous flux value.

Reference

[1]	Wasatch Photonics., "What Are the Types of Diffraction Gratings?," [Online]. Available: https://wasatchphotonics.com/technologies/types-diffraction-gratings/. [Accessed 7 5 2021].
[2]	C. Zhang, S. Ashwinlal and J. Comins, "Spectral Ray Tracing," [Online]. Available: https://ceciliavision.github.io/graphics/a6/. [Accessed 7 5 2021].
[3]	"The Human Visual System," [Online]. Available: http://what-when-how.com/display-interfaces/the-human-visual-system-display-interfaces-part-1/. [Accessed 7 5 2021].
[4]	D. Tim, "Tomographic reconstruction of combined tilt- and focal series in scanning transmission electron microscopy," ResearchGate, 1 2015.
[5]	BenRG, "CIE 1931 xy color space diagram," 24 09 2009. [Online]. Available: https://commons.wikimedia.org/wiki/File:CIExy1931.png. [Accessed 20 04 2021].

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Thanks for Listening