Characterization and Imaging by Transmission Spectroscopy

April 2022

Vincent DiNella
Faculty Mentor: Dr. Randolph Peterson
The University of the South Department of Physics and Astronomy

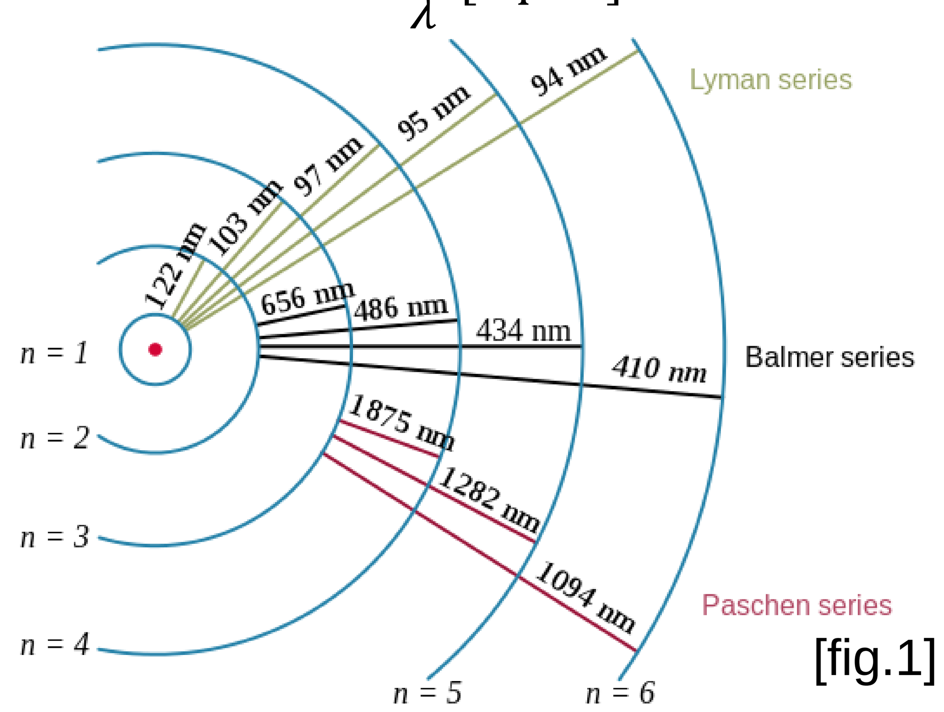
ABSTRACT

I have constructed an array of LEDs of various wavelengths in order to measure the transmission spectra of materials. I used an Arduino to activate each LED individually to measure the transmittance of the particular wavelength through the sample. By taking pictures of the sample backlit by each LED and evaluating them in ImageJ, I obtained the transmittance of light relative to the background. By further analysis in ImageJ, I was able to create these transmission spectra as a function of the distance across samples. This can be used to observe optical phenomena such as Poisson's spot, a bright spot in the middle of a shadow that occurs due to diffraction.

TRANSMISSION SPECTROSCOPY

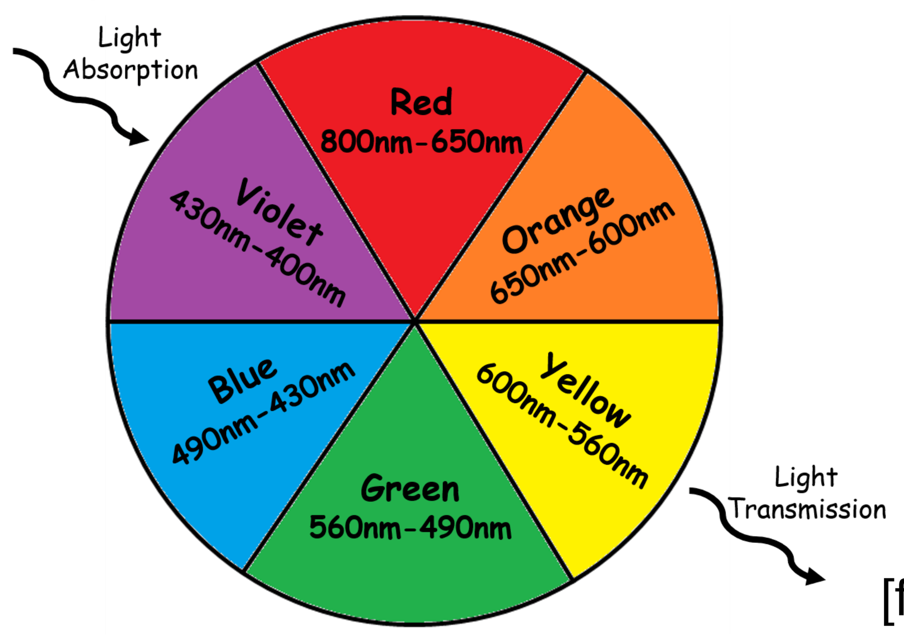
Transmission spectroscopy is a method of defining the characteristic wavelengths that a material allows to pass through it unabsorbed. Absorbed Wavelengths correspond to the excitation energies of the bonds or valence electrons in the sample material. If the energy of the light, which is related to the wavelength by equation 1, matches the energy required to promote an electron to one of the exited states then the light is absorbed, and its energy is used to excite the electron. For example, some of these energies for hydrogen are seen in figure 1.

$$E = \frac{hc}{\lambda} \quad [\text{eqn. 1}]$$



[fig.1]

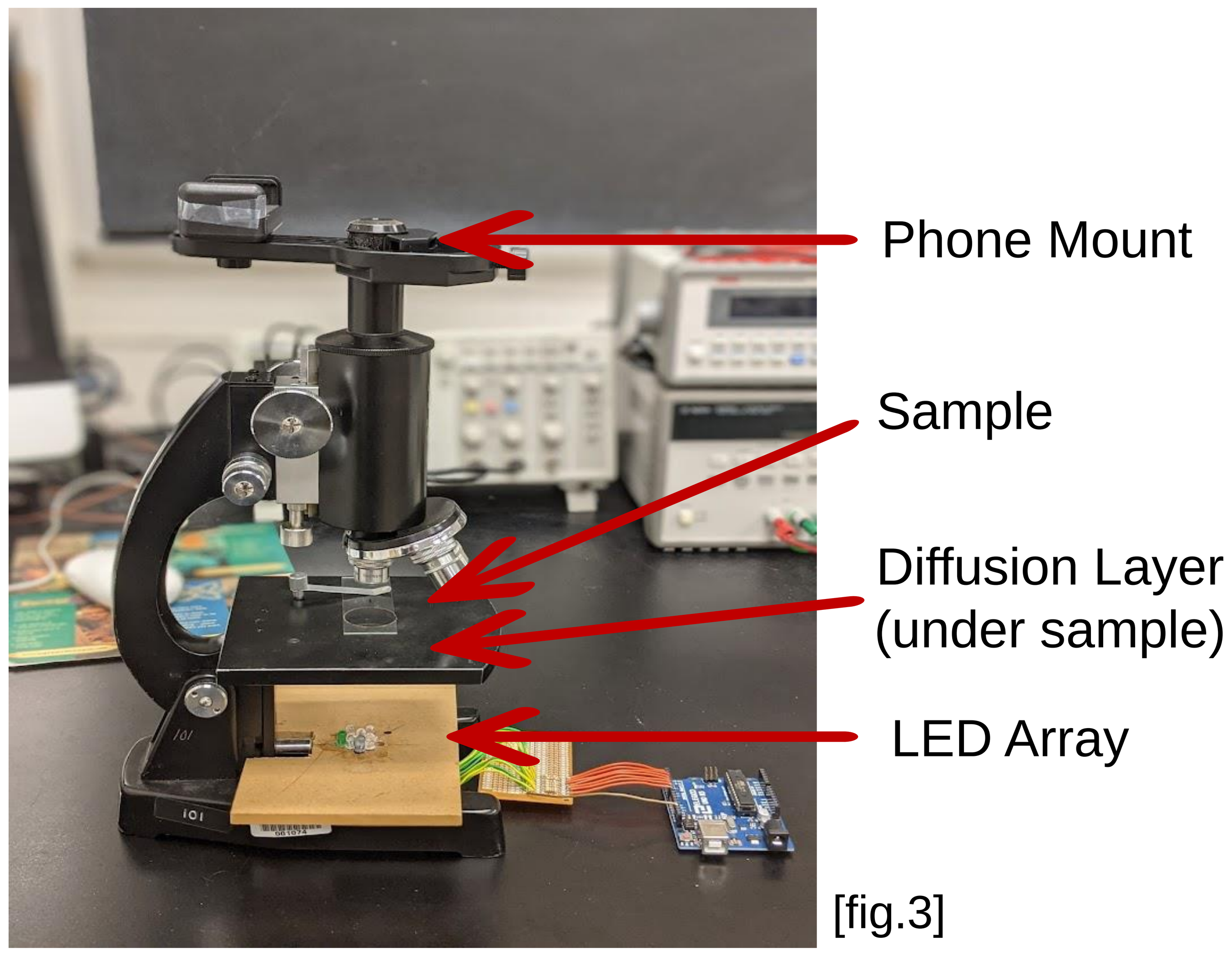
On a macroscopic scale, an object that appears yellow, for example, will absorb violet light, its complementary color, because if both were transmitted then our eye would interpret it a mix of the two, which is brown.



[fig.2]

THE SETUP

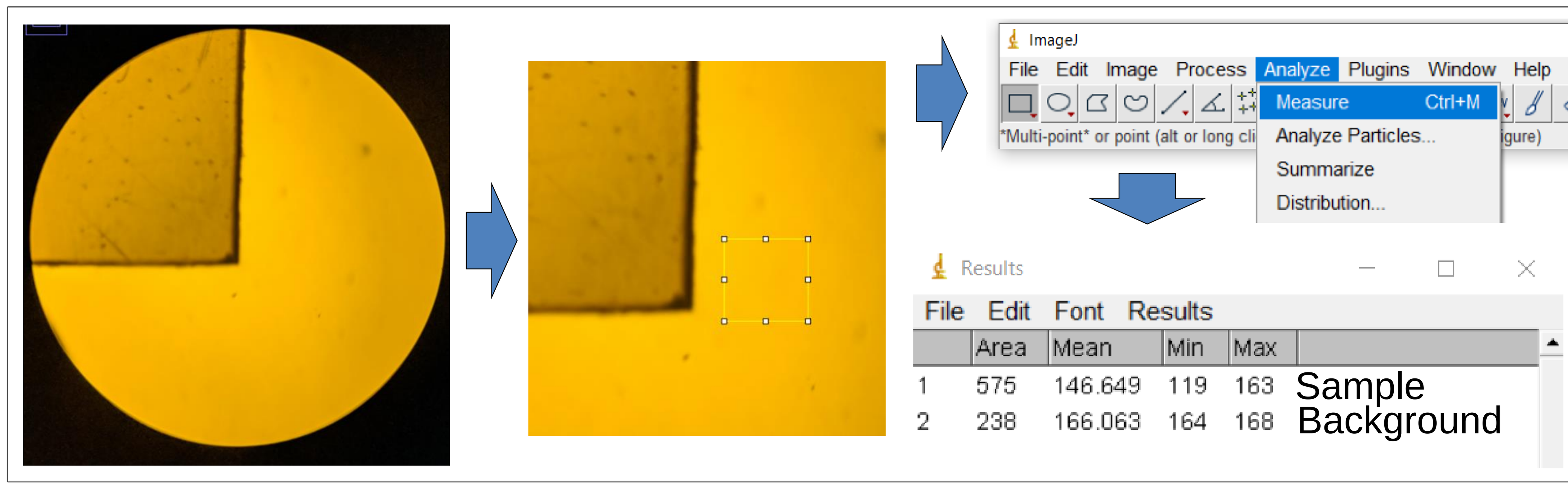
My method of transmission spectroscopy involves illuminating a sample with an array of LEDs of various wavelengths and using my phone's camera to capture the sample illuminated by each LED individually. This allows for the transmission spectrum of the sample to be pieced together from each LED's transmission. Due to the ability for data to be taken from a photo at each of the wavelengths analyzed, this method has the advantage of allowing for the consideration of how transmission changes over an area of the sample. With this data it is possible to analyze the optics of the sample and how the different wavelengths of light are refracted or diffracted, such as in figures 7 and 8.



[fig.3]

USING IMAGEJ FOR ANALYSIS

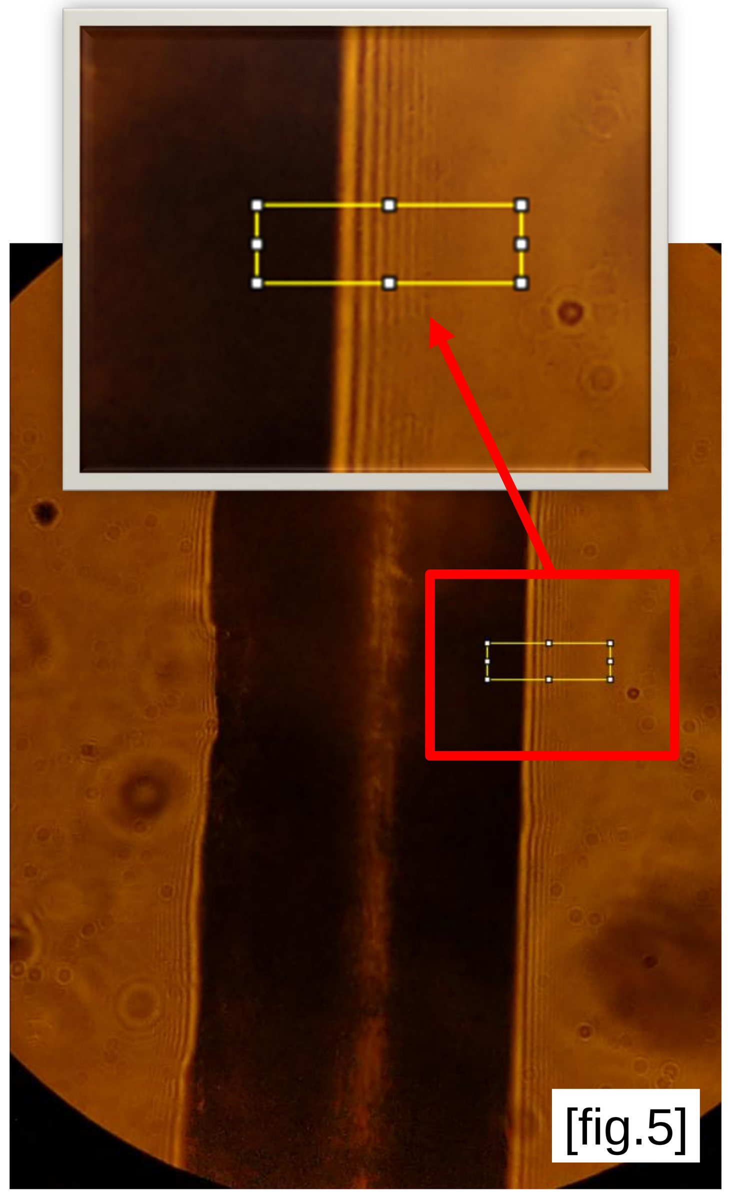
ImageJ was used to analyze each image taken and find the average pixel intensity of the background and the sample. The ratio of these values gives the transmittance. After repeating this for each of the LEDs, a graph of transmission in as a function of wavelength can be made as in figure 6. If instead the pixel intensity is analyzed over an area of the sample [fig.5], the pixel intensity can be found as a function of distance and wavelength allowing for analysis of refraction in a sample such as in figures 7 and 8.



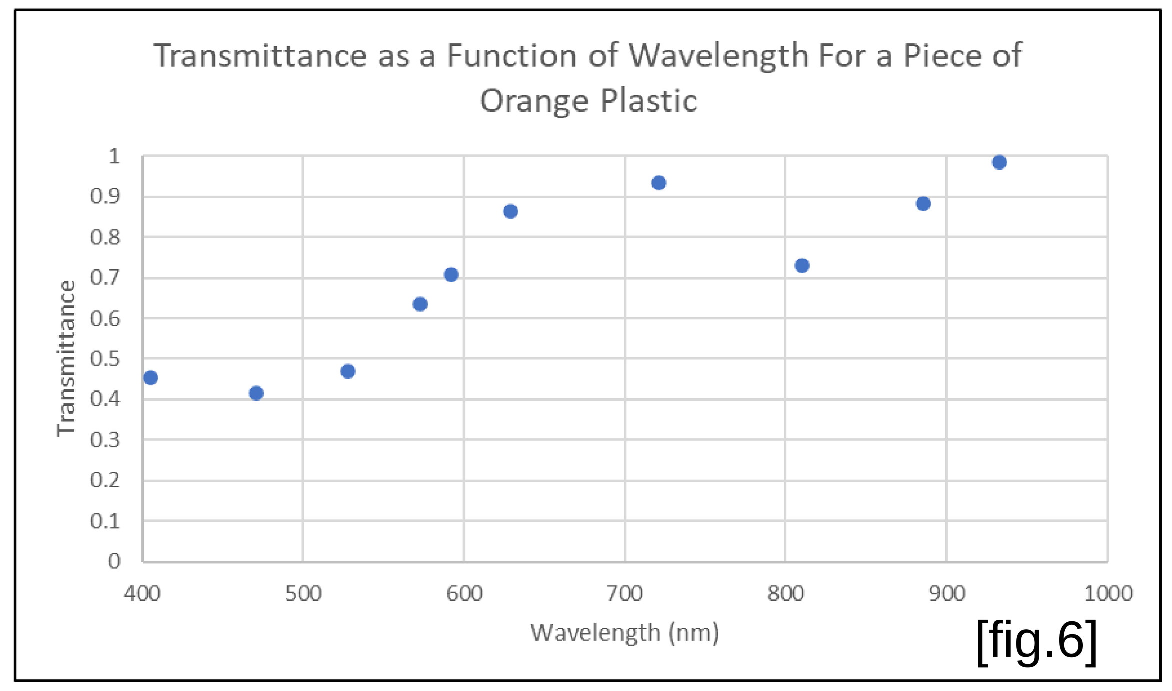
[fig.4]

RESULTS

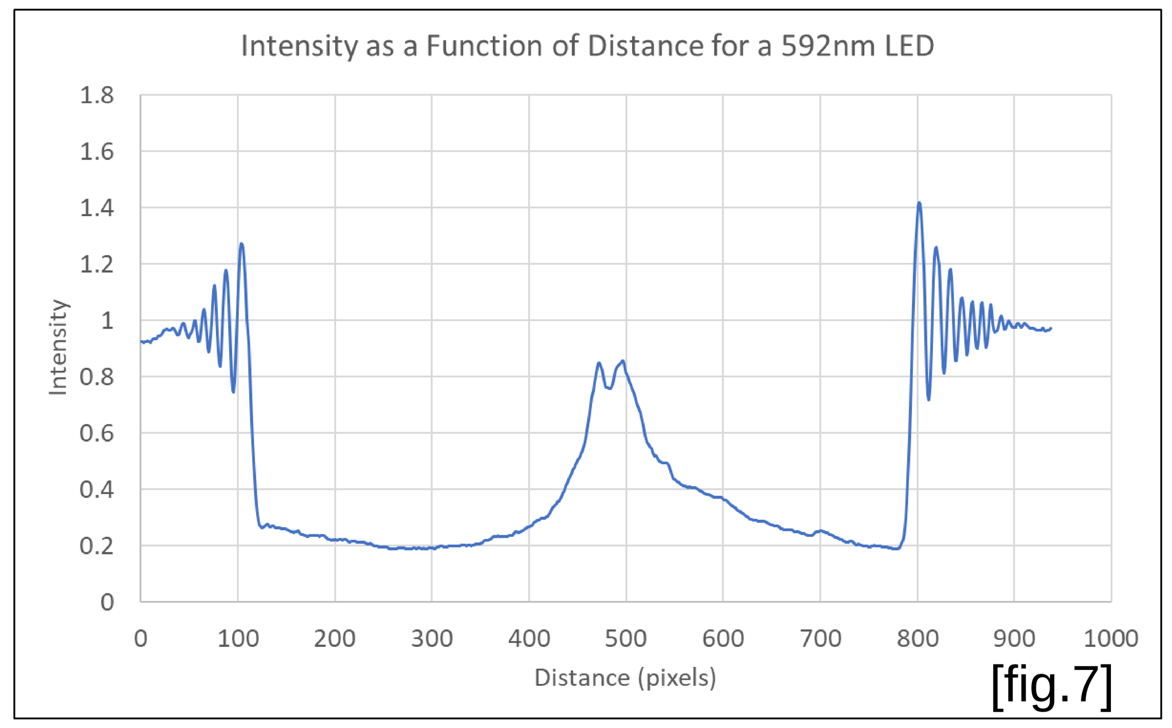
With the transmission of the various LEDs obtained from ImageJ, a plot of transmission as a function of wavelength can be made as in figure 6. This graph shows a transmission spectrum for a piece of translucent orange plastic. As stated previously, an absorption in the blue is expected for an orange object and a drop in transmittance is clearly seen in the blue in figure 6, validating this approach to spectroscopy. Figure 7 shows the diffraction of the thin wire illuminated by 592 nm light. Interference patterns are seen on either side as well as what may be a Poisson's spot, a light spot in the middle of a shadow caused by diffraction. Figure 8 shows this same graph for a 471 nm LED and shows a trend I saw of decreased intensity and closer diffraction maxima with shorter wavelengths.



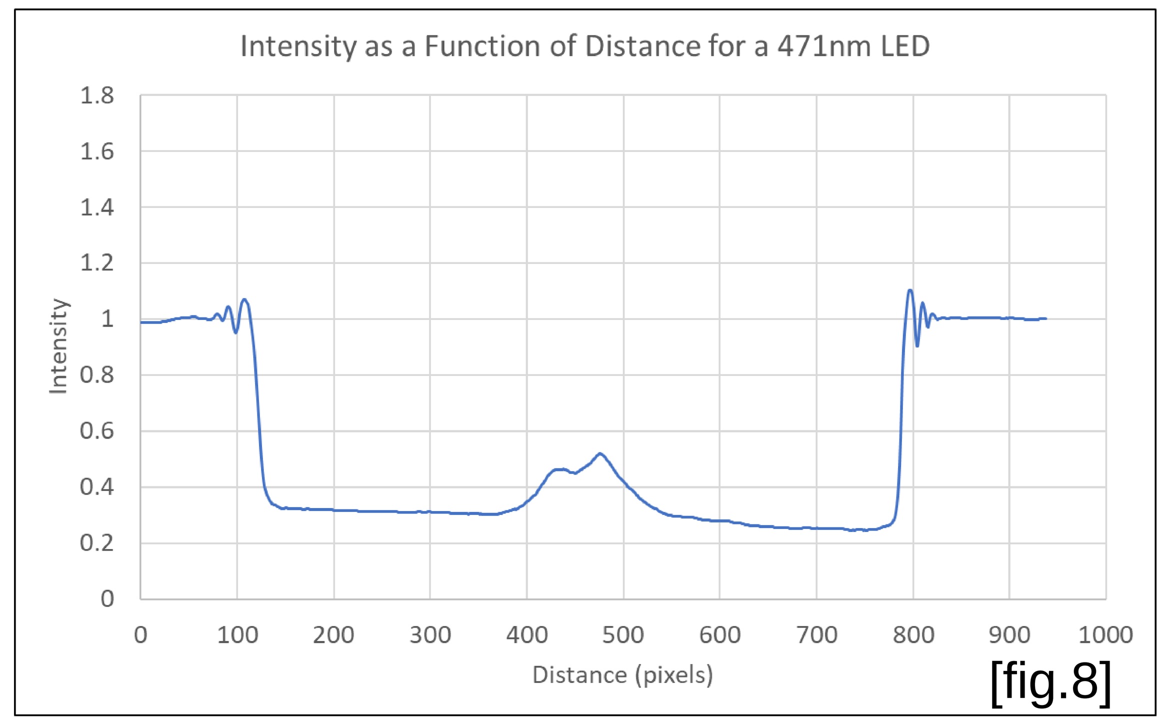
[fig.5]



[fig.6]



[fig.7]



[fig.8]

CONCLUSION

This method of measuring the transmission spectrum of a sample is limited by the number of wavelengths of LEDs used which makes for a less continuous graph than with a spectrometer. However, based on my spectrum for the orange plastic, it is still a valid method of spectroscopy. The main advantage of the system is the ability to consider the change in transmission over an area which presents an advantage over traditional spectroscopy for optical analysis.

REFERENCES

1. Brydegaard, Guan, Svanberg, "Broad-band multispectral microscope for imaging transmission spectroscopy employing and array of light-emitting diodes", American Journal of Physics 77, 104 (2009)
2. Wyttenbach ,Ehrenreich, Lovis, Udry, Pepe, "Spectrally resolved detection of sodium in the atmosphere of HD 189733b with the HARPS spectrograph", Astronomy and Astrophysics, Volume 577, id.A62, 13 pp.