SPECTRAL IMAGING

RIVERA, MIB

PHYSICS 301 WFZ

OBJECTIVES

- Render image color given spectral information
- Find hyperspectral image databases
- Demonstrate how color changes under varying illumination.

COLOR OR SPECTRUM?

Do not trust your sight, not even the colors in this Macbeth chart.

- How we see color from an object is dependent on three factors: how sensitive the light source is to different frequencies, how the object reflects the light, and how sensitive our receptors are to different frequencies.
- In this activity, we analyze how much each of these factors affect how colors change.
- We also learn how to characterize what we see by using another parameter called the spectrum of the object.

THE COLOR TRINITY

Source Spectra

$P(\lambda)$

- Inherent to the light source

Reflectance

$R(\lambda)$

- Inherent to the object

Spectral sensitivity

$S_n(\lambda)$

- Inherent to the receiver, e.g. camera
- Usually having three channels for the trichromacity

SPECTRAL CHARACTERISTICS

- Characteristics which are inherent to the object, such as reflectance, transmittance, absorbance, fluorescence, or emittance (Soriano, 2022)
- Objects are better described by their inherent properties, instead of relying on colors

DEPICTING COLOR FROM THE COLOR TRINITY

- Get a light source with defined spectra per wavelength, e.g. CIE Illuminant D65
- Get an object/image with defined reflectance per wavelength, e.g. the Macbeth color checker
- Get a camera with defined spectral sensitivity per wavelength, e.g. Sony DXC930

INTERPOLATION

- To properly combine the trinity, we need to realign the camera's spectral sensitivity with the light source spectra and object reflectance, i.e. to have them all defined on the same wavelengths and same wavelength spacing
- This is done in MATLAB by using `interp1`, which takes an array to be interpolated (including the old spacing between values), and the array of the new spacing. The output is an array of values that takes the new spacing as its x-axis.

ANALOG SIGNAL

- We then calculate the (white-balanced) analog signal, which is the mathematical construction for the light that reaches our eyes. It is a simple element-per-element product of the color trinity, normalized by the analog signal of color white:

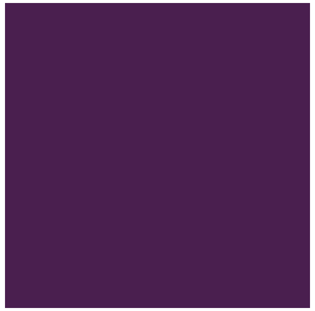
$$\bar{V}_n = \frac{\sum_i P_i(\lambda) R_i(\lambda) S_{n,i}(\lambda)}{\sum_i P_i(\lambda) S_{n,i}(\lambda)} \quad (1)$$

- Here, n is the channel in consideration. Thus, we must have three values for the RGB channels.
- Since this value is normalized, we need to multiply by 255 to get the RGB value of the color that reached us.

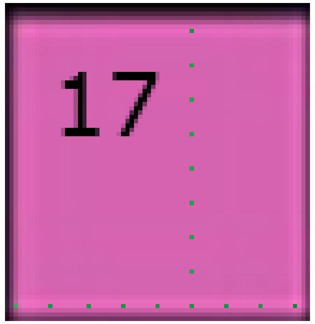
EXAMPLE

- For our purposes, we get the Standard Illuminant D65, Macbeth Patch 17 (shown on the right), and Sony DXC930 CCD camera
- We carry out the computation for the analog signal and show that for Patch 17, the spectral information transformed to the RGB space is given by (74, 31, 78)

COLOR DIFFERENCE



(74, 31, 79) as produced by Microsoft PowerPoint



(74, 31, 79) as shown in the Macbeth color checker picture

- However, the color corresponding to this RGB combination is given by the top patch, which is visibly different from what the color patch is showing
- Therefore, we can assume that the patch as shown in the picture is lit under a different light source, or taken by a camera that is different than Sony DXC930. These kinds of degeneracies deteriorate the reconstruction of colors.

ANALYSIS

- The difference between the reconstructed patch from spectral information and the picture shown in the Macbeth patch can be quantified by using statistical values such as the (Euclidean) distance in RGB space
- However, as said earlier, degeneracies in the error sources can deteriorate the quantification of errors, and so it is better to first assess where the error might come from.
- Of course, we want to be as close to the original color as possible, so further work can be done to change the light sources and cameras individually.

RELATING ELECTROMAGNETIC (EM) AND GRAVITATIONAL WAVES (GW)

ANALOGY

- GWs are longitudinal waves; in this sense, they act more like sound and less like EM waves.
- However, we can also identify spectral information coming from GW signals, which can be decomposed like the color trinity.
- For example, the color signal, which is decomposed into a product of the light source spectra and the object's reflectivity, is considered analogous to the source signal, while the camera's spectral sensitivity can be considered analogous to the detector's noise spectral density
- However, in GWs, the data coming from the detector (the analog signal) is assumed to be a sum of the noise (coming from the detector's spectral sensitivity) and the GW signal itself (color signal), see this website for plotting the spectral sensitivity per source and per detector

FURTHER DISCUSSION

- The decomposition of the color signal implies that for GWs, there might still be information intertwined within the signal. The usual route is to estimate the parameters using matched filtering, or aligning the signal with templates and getting the highest signal-to-noise ratio (SNR). The method's accuracy is deteriorated by external agents, such as gravitational lensing or cosmic expansion, which redshifts the signal further.
- It may be the case that for a given GW signal, the information can be treated as a product of the "light source" spectra (extrinsic information) and the object's "reflectivity" (e.g. information that can be obtained from black hole spectroscopy)

REFLECTION AND SELF-GRADE

- The code for this activity can be found at this GitHub page.
- The errors shown in this activity is a reflection of the limitation of color as a characteristic of the object. I did enjoy the idea that you can quantify this error, but since the time is limited, I was not able to get the light source and camera that produces the least difference from the Macbeth patch.
- Thus, I grade myself 80% for this activity; if only I have more time, I would certainly enjoy calculating the errors myself.