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Physical and Perceptual measures

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Context and Objectives

In this lab, students will proceed to manipulate multispectral image.

The objectives are:

- **Acquire** a hyperspectral image.
- **Spectral to XYZ** : Use the caracterized spectra of the illuminant used to capture the image and the reflectance cube of said image to **convert spectral data to XYZ space**.
- **XYZ to RGB** : Given the chromaticity coordinates of an RGB system and its reference white, **compute the transformation matrix to convert from XYZ to RGB**.
- **Color Reconstruction**: Use the computed trnasformation matrix to **convert the image to RGB space**.

Key Definitions

- **Tristimulus** : Three functions representing RGB responses of a sensor, for exemple the human eye.
- **CIE XYZ Color space** : The CIE XYZ color space is a standardized color space established by the International Commission on Illumination (CIE) in 1931. The XYZ components are linear combinations of the RGB cone responses in the standard human eye and represent all perceivable colors.
- **Standard Illuminant** : A standard illuminant is a theoretical light source with a known spectral power distribution (SPD), used as a reference in color measurement. Common examples include:
  - D65 : Represents average daylight (≈ 6500 K).
  - D50 : Warmer daylight (≈ 5000 K).
  - A : Incandescent tungsten light (≈ 2856 K).

  The choice of illuminant affects how a color is perceived and therefore plays a crucial role in accurate color reproduction.

1. Acquire hyperspectral image

- setup the scene (surface, lighting and camera).
- acquire hyperstral image.

Note : The lighting parameters used will be the same as the one used in previous lab.

2. Spectral to CIE XYZ conversion

Input Data :
You will work with a spectral reflectance cube obtained in the previous session. The cube consists of reflectance values over a range of wavelengths for each pixel.

Available Illuminants :
Several standard illuminants will be provided, including D65, D50, and A. You will be asked to perform the transformation for at least one of these illuminants and compare your results.

Equations :

$$N=\int_{\lambda_{min}}^{\lambda_{max}} y(t)I(t)W(t)dt$$

$$X=\frac{1}{N}\int_{\lambda_{min}}^{\lambda_{max}} x(t)I(t)R(t)dt$$

$$Y=\frac{1}{N}\int_{\lambda_{min}}^{\lambda_{max}} y(t)I(t)R(t)dt$$

$$Z=\frac{1}{N}\int_{\lambda_{min}}^{\lambda_{max}} z(x)I(x)R(x)dx$$

x,y,z : tristimulus functions
I : illuminant spectral power distribution
R : reflectance spectra
W : white reference spectra

Tasks :

- Compute the CIE XYZ tristimulus values for each pixel in the reflectance cube.
- Use the appropriate color matching functions and the selected standard illuminant.
- Visualize the resulting XYZ image or slices (e.g., mapping X, Y, Z channels to RGB for visualization purposes).
- Compare and discuss the effect of different illuminants on the resulting XYZ values.

3. CIE XYZ to RGB space conversion

Input Data :
The image you converted into the CIE XYZ color space. The image represents tristimulus values under a specific illuminant.

Provided informations :
You will be given:

- The chromaticity coordinates (x, y) of the primaries (R, G, B) for a specific RGB color space.
- The chromaticity coordinates of the reference white point (e.g., D65 or D50)

Equations :

$$X_r = x_r / y_r \quad Y_r = 1 \quad Z_r = (1 - x_r - y_r) / y_r$$

$$X_g = x_g / y_g \quad Y_g = 1 \quad Z_g = (1 - x_g - y_g) / y_g$$

$$X_b = x_b / y_b \quad Y_b = 1 \quad Z_b = (1 - x_b - y_b) / y_b$$

$$\begin{pmatrix} S_r \\ S_g \\ S_b \end{pmatrix} = \begin{pmatrix} X_r & Y_r & Z_r \\ X_g & Y_g & Z_g \\ X_b & Y_b & Z_b \end{pmatrix}^{-1} \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix}$$

X_w, Y_w, Z_w : White reference coordinates
x_r, y_r : red component coordinates
x_g, y_g : red component coordinates
x_b, y_b : red component coordinates

$$M_{RGB \rightarrow XYZ} = \begin{pmatrix} S_r X_r & S_g X_g & S_b X_b \\ S_r Y_r & S_g Y_g & S_b Y_b \\ S_r Z_r & S_g Z_g & S_b Z_b \end{pmatrix}$$

$$M_{XYZ \rightarrow RGB} = M_{RGB \rightarrow XYZ}^{-1}$$

Tasks :

- Compute the transformation matrix from XYZ to RGB. This requires:
- Deriving the RGB primaries in the XYZ space using the provided chromaticity coordinates.
- Normalizing the matrix so that the white point in XYZ maps correctly to the reference white point in RGB.
- Apply the transformation matrix to the XYZ image to obtain an RGB image.
- Ensure that RGB values are properly normalized and clipped to the valid display range if necessary (e.g., [0, 1] or [0, 255]).