Spectral Lab: Segmentation

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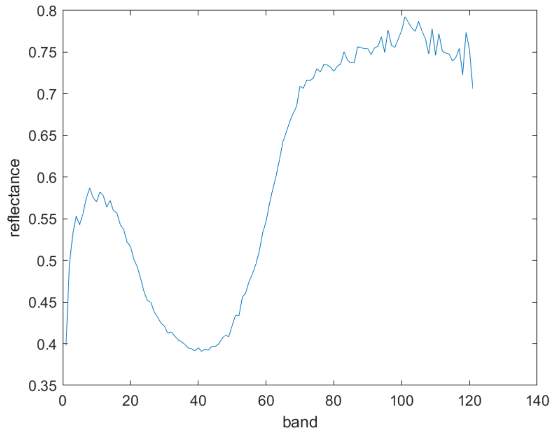
1 Objective

We are given a spectral image of a painting captured by Pika L, a hyperspectral line-scan camera that operates in the visible and near-infrared range (400-1000 nm). The image is shown in figure 1. The image was provided in the form of a hypercube, which contained the information of the image and the wavelengths at which each band was captured. The image has a dimension of 200x900x121 where 121 specifies the number of bands. The aim of this lab activity is to segment the woman from the background and then segment pink, blue, and yellow pigments from the painting.

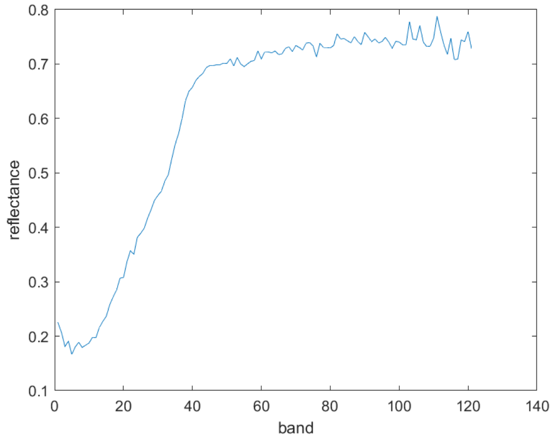
Figure 1: Painting of woman

2 Foreground segmentation

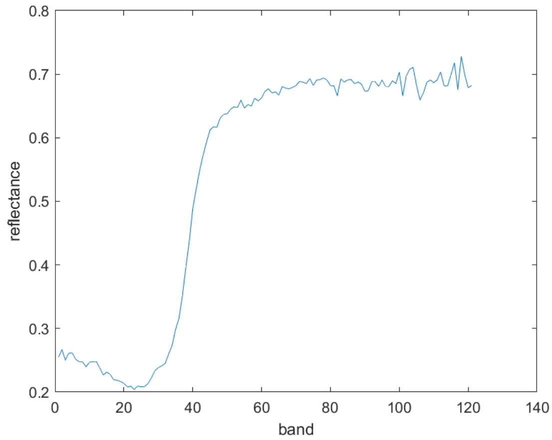
To segment woman in the foreground from the background we used thresholding. Figure 2 shows the spectral reflectance of different pigments in the painting. We can notice that the spectral reflectance curve of the blue, yellow, and pink pigments as shown in figure 2a, 2b, and 2c respectively don't exceed 0.8 while the spectral reflectance of background pixel shows oscillation between 0.9-0.95. So we computed the mean of these spectra and found that the mean of blue, yellow, and pink spectra was below 0.8 whereas, the mean of the background spectrum was above 0.8. Based on this observation, we created a mask where at each pixel of the hyperspectral cube if the mean of the spectrum is below 0.79 it is assigned 1 i.e. the pixel is retained while if the mean is greater than 0.79 the pixel is assigned 0. This threshold value of 0.79 was decided after multiple trials. Finally, we applied the mask to the spectral image and obtained a segmented image without background as shown in figure 3. Figure 3 is an sRGB representation where, the mask was applied to 615 nm (band 44), 550 nm (band 31), and 465 nm (band 14) which represent red, green, and blue wavelengths respectively.



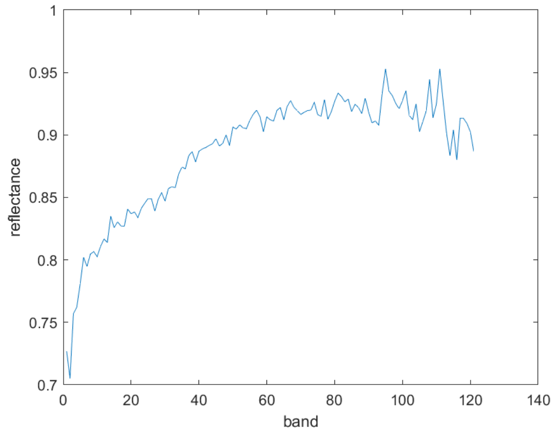
(a) Blue pigment



(b) Yellow pigment



(c) Pink pigment



(d) Background

Figure 2: Spectral reflectance of pigments in the image

Figure 3: Segmentation of woman from the background at 0.79 threshold

3 Spectral Metrics

For the purpose of pigment segmentation, discussed in section 4, we have employed four spectral metrics which are discussed in this section.

3.1 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) is a measure of the difference between two spectra. It is the square root of the average of the squared differences between corresponding values of two spectra. It is used to quantify the degree of similarity between two sets of data, where a smaller RMSE value indicates a better match between the spectra. Mathematically,

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(E(\lambda_i) - E_R(\lambda_i))^2}$$

Where,
n = number of samples (wavelength)
E = reference spectrum
E_R = test spectrum

3.2 Spectral Angular Mapper (SAM)

Spectral Angle Mapper (SAM) measures the angle between the two spectra. It computes the spectral angle between the reference and test spectra, where the angle between them is interpreted as the spectral similarity. The SAM value ranges from 0 to π radians. The smaller the angle between two spectra, the more similar they are. SAM has the advantage of being invariant to illumination variations. Mathematically,

$$SAM = \cos^{-1}\frac{\sum_{i=1}^{n} E(\lambda_i)E_R(\lambda_i)}{\sqrt{\sum_{i=1}^{n} E(\lambda_i)^2 \sum_{i=1}^{n} E_R(\lambda_i)^2}}$$

3.3 Spectral Correlation Mapper (SCM)

Spectral Correlation Mapper (SCM) measures the similarity between two spectra by calculating the correlation coefficient. It ranges from -1 to 1, where a value of 1 indicates that the two spectra are identical, a value of 0 indicates that the two spectra are uncorrelated, and a value of -1 indicates that the two spectra are inverted versions of each other. Mathematically,

$$SCM = \frac{\sum_{i=1}^{n}(E(\lambda_i) - \overline{E(\lambda_i)})(E_R(\lambda_i) - \overline{E_R(\lambda_i)})}{\sqrt{\sum_{i=1}^{n}(E(\lambda_i) - \overline{E(\lambda_i)})^2 \sum_{i=1}^{n}(E_R(\lambda_i) - \overline{E_R(\lambda_i)})^2}}$$

Where,
$\overline{E(\lambda_i)}$ = mean of reference spectrum
$\overline{E_R(\lambda_i)}$ = mean of test spectrum

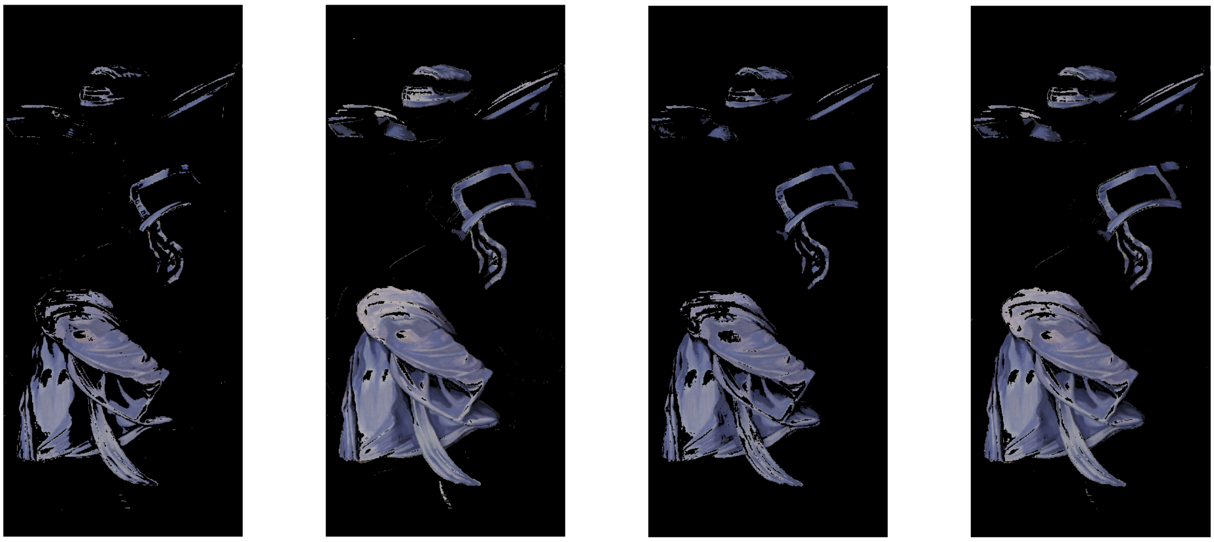
3.4 Goodness of fit coefficient (GFC)

The Goodness of Fit Coefficient (GFC) is used to evaluate how well a reference spectrum matches a target spectrum. It ranges from 0 to 1. A value of 1 indicates a perfect match between the two spectra, while a value of 0 indicates a mismatch. Mathematically,

$$GFC = \frac{\left|\sum_{i=1}^{n} E(\lambda_i)E_R(\lambda_i)\right|}{\left|\sum_{i=1}^{n} E(\lambda_i)^2\right|^{\frac{1}{2}} \left|\sum_{i=1}^{n} E_R(\lambda_i)^2\right|^{\frac{1}{2}}}$$

4 Pigment Segmentation

In this section, we have segmented blue, yellow, and pink pigments from the painting using spectral metrics described in section 3. We considered a pigment spectrum from the painting as a reference and compared it with the spectrum at each pixel and wherever the metric showed dissimilarity between the spectra we removed it from the image by applying a mask. After multiple trials, we set a threshold for each spectral metric so that we could segment the desired pigments of the painting. In the case of RMSE and SAM, the threshold is set closer to 0 for a match while for SCM and GFC threshold is set closer to 1 for a match. Below are the results shown for each spectral metric.



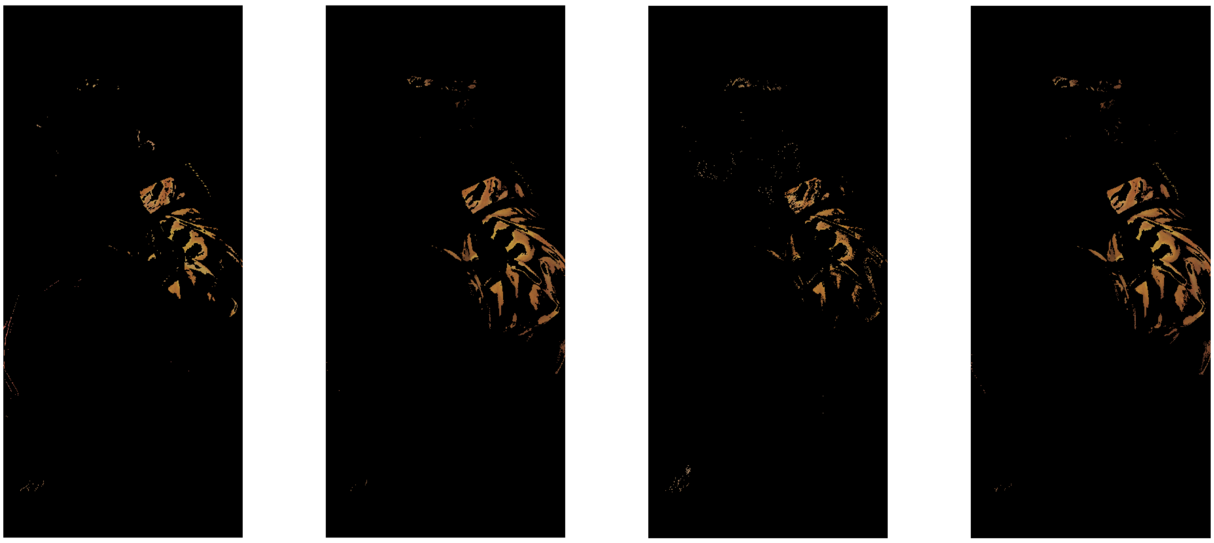
(a) Root mean square error (RMSE)

(b) Spectral Angular Mapper (SAM)

(c) Spectral Correlation Mapper (SCM)

(d) Good of fit coefficient (GFC)

Figure 4: Segmentation of blue pigments from painting using different spectral metrics



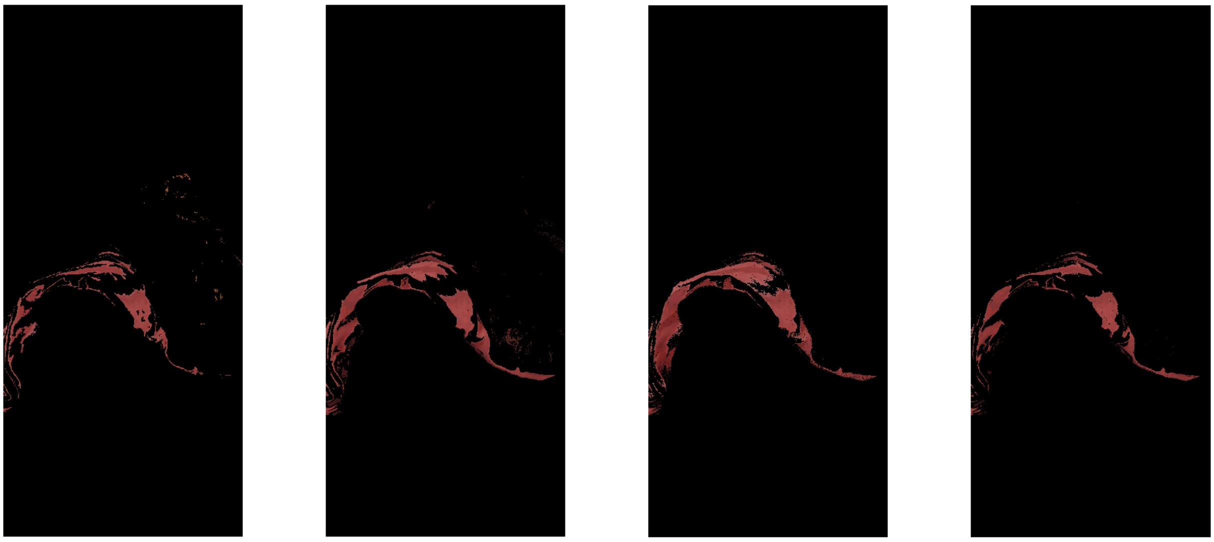
(a) Root mean square error (RMSE)

(b) Spectral Angular Mapper (SAM)

(c) Spectral Correlation Mapper (SCM)

(d) Good of fit coefficient (GFC)

Figure 5: Segmentation of yellow pigments from painting using different spectral metrics



(a) Root mean square error (RMSE)

(b) Spectral Angular Mapper (SAM)

(c) Spectral Correlation Mapper (SCM)

(d) Good of fit coefficient (GFC)

Figure 6: Segmentation of pink pigments from painting using different spectral metrics