Lab #7 Linear Spectral Unmixing with PCT

Name: ____________________________

Lab #7: FOR 504 Advanced Topics in Remote Sensing

Objectives of this laboratory exercise:

The purpose of this lab is to:
  • Use linear spectral unmixing to produce a sub pixel fractional map of a TM image

This lab aims to introduce the students to an advanced but useful technique that is frequently applied in the remote sensing literature.

Please note that there exist several other techniques to produce sub-pixel measures, and I refer you to look at the literature on Fuzzy Classifications.

The questions provided within this lab are designed to help the student better understand the practical details of using ENVI and are recommended but are not for assessment.

Location: RS/GIS Lab

Login: XXXX
Password: XXXX
Before you start:

Double click the ENVI icon on the desktop:

This starts both ENVI (*The Environment for Visualizing Images*) and the IDL (*Integrated Development Language*) programming interface

Ignore IDL but don’t close it as this closes ENVI as well.

PART 1 Introduction to Linear Spectral Unmixing

Linear mixing assumes that each surface component within a pixel is sufficiently large enough such that no multiple scattering exists between the components (Singer and McCord, 1979).

The linear scattering approximation has been shown to be valid when the size of the pixel is larger than the typical ‘patch’ or component being sensed, which is in agreement with Singer and McCord (1979) who observed that linear mixing can be thought to occur at the macroscopic scale.

The use of linear mixture modelling relies on four assumptions (Settle and Drake, 1993), which are:

1. There is no significant occurrence of multiple scattering between the different surface components.
2. Each surface component within the image has sufficient spectral contrast to allow their separation.
3. In each pixel the total land cover is unity.
4. Each surface component (endmember) is known.

![Figure 1 Linear mixing – as light reaching the sensor has only interacted with a single surface components.](image1)
The linear mixture model is expressed by equation (1):

\[ R_i = \sum_{c=1}^{n} (r_j f_{ij}) + e_i. \]  

Where,
- \( R_n \) = the reflectance for the \( i^{th} \) pixel
- \( r_j \) = the spectral reflectance of the \( j^{th} \) surface component
- \( f_{ij} \) = the fraction of the \( j^{th} \) surface component in the \( i^{th} \) pixel.

The majority of studies using linear mixture modeling to calculate the proportions of the subpixel surface components apply a least squares solution to determine the proportions of the respective surface components within the pixel. The full mathematical theory can be found within Johnson et al. (1985), Smith et al. (1985), Drake and White (1991), and Theseira et al. (2002). However, a brief description of the two most commonly applied methods to collect the endmembers used within such an analysis is presented below:

**Endmember Collection**

In order to use a linear mixture model there is a need to measure the spectral reflectance of the ‘pure’ end-members. Ideally, ground-based spectra would be acquired to produce accurate end-members, since endmembers taken from even very high spatial-resolution imagery may contain multiple components. However, such errors can be minimized through sampling the image endmembers from within the center of known features (lakes, burned areas, grasslands, ploughed fields, etc) or from know locations visited during fieldwork.

![Figure 2 Plot of the first and second principal axes of variation of 92 lunar spectral samples. The candidate endmembers are labelled and are in general located at the vertices of the scatter. Source: Johnson et al. (1985).](image-url)
However, if such ground-based spectral measurements are to be used to define the spectral endmembers, then there is a requirement to atmospherically correct the satellite imagery or to simulate the effect of the atmosphere on the ground-based spectra such that these datasets are comparable. In studies in which ground-based spectra are impossible to collect (e.g. planetary remote sensing or analysis of remote and isolated areas) or in cases in which the sampled spectra components can not be guaranteed to be ‘pure’, additional end-member selection using high spatial-resolution satellite sensor imagery is normally conducted.

Johnson et al. (1985) and Smith et al. (1985) demonstrated that principal component analysis could be used to identify the individual end-members of multiple surface components. They observed that for a mixture of three substances the scatter-plot of the first two principle components produced a triangle in which the ‘pure’ end-members were located at the corners (Figure 2). Several studies have adapted this technique by analyzing different principal component pairs and have managed to successfully obtain image end-members within different environments (Drake and White, 1991; Theseira et al. 2003).

**References Cited:**


**Display the Images to Analyze**

For this lab, we are going to reuse the TM data of Moscow Mountain. This data sets can be found in the lab 10 directory of the class CD.

Using the **File/Open Image File** option from the main ENVI menu bar, select and display the 432 false color composite image of the TM file:
As is frequently the case in ‘real life’ remote sensing, this lab does not have field spectra of the endmembers in this image. Therefore, we will produce the endmembers using the PCA technique mentioned in the introduction section.

PART 2 Producing the TM Endmembers

Task #1 The PCA (or PCT) Transformation

From the main ENVI menu bar select Transform/Principal Components/Forward PC Rotation/Computer New Statistics and Rotate:
Select the TM image and press OK.

In the **Forward PC Parameters box**, keep all the default options, choose a suitable filename, and press **OK**.

Now load the first PCA band into a new display window.

Now, I turn the image auto placement button off by right clicking on the PCA main image window and selecting **scroll/zoom position/Auto Placement Off**.

An advantage of using this TM subset is that this the whole image that will be used in the scatter plot and the image size problem noted in lab 6 is not a problem.

Next, in the Main Image menu bar of the **TM image** select, Tools/2D Scatter Plots, choose PCA bands 1 and 2, and press ok.

This scatter plot of the 1\textsuperscript{st} and 2\textsuperscript{nd} principal components can allow us to select potential endmembers using the method of Johnson et al (1992) mentioned in the introduction.
Now, using the Options/Density Slice option, display the PCA bands 1 vs. band 2 with the density slice:

By the Johnson et al (1992) method, the potential endmembers lie at the vertices of these PCA band vs. PCA band scatter plots.

As you start using the lower bands, it is less likely that you will identify endmembers. In practice for TM imagery, most endmembers are found using plots of

PCA 1 vs. PCA 2 &
PCA 3 vs. PCA 4

PCA bands 5 and 6 generally don’t contain any useful information.

Now comes the nice bit: Lab 6 demonstrated that if you select areas in a scatter plot, the pixels they correspond to in the image are highlighted.

This allows you to use your ‘expert knowledge’ of the imagery to determine WHAT the possible endmember cover types are.

The pink circles are where I think the possible endmembers are, as these are where the vertices of the shape are present.

On the Scatter Plot, draw a circle around the lowest pink circle. You will notice that in the TM image window, the lake has been highlighted in red. This is our first endmember.

Next, right click with the mouse and select New Class. Now choose another of the pink circle areas and draw a new ROI circle.

Repeat these steps for each of the pink circles.
Now using your ‘expert knowledge’ can you identify each potential endmember?

In this image what do you think is represented by:

Yellow:______________________________
Blue:_______________________________
Green:______________________________
Red:_______________________________

Next, we want to save these potential endmembers as a ROI file that we can load into the main image.

This is done by selecting **Options/Export All** from the PCA menu bar. This will load the **ROI Tool**. Now **Save** these ROIs as the filename PCA1v2_set in the lab 10 directory and then delete them all.

As you might have noticed, these endmembers did not include the forested areas. Therefore, let’s looks at the scatter plot of PCA 3 v PCA 4 to see if any additional endmembers are apparent:

To do this select **Options/Change Bands** from the PCA menu bar and select PCA bands 3 and 4.

If you have a middle mouse button and click on the center of the red area, you will see that this highlights the forested area. This means it might be difficult to produce a ‘pure forest’ endmember. Can you provide reasons why this might be the case?
To get the forested endmember, change the PCA bands to PCA 1 vs. PCA band 3 and draw a ROI circle around the area highlighted in pink to the right:

Next, export this ROI, edit the name, and save the ROI file as Forest.

Now, do not delete this ROI, but Restore the ROIs PCA1v2_set.

Finally, close the scatter plot viewer.

You have all the endmembers for this image.

Next, Save all these ROIs as filename TM_endmembers.roi

This is a very useful technique that can be use to select pure cover type pixels in imagery where no ground validation data is present.

Consider the scenarios where you need a supervised classification of a reference image, but do not have any field data.

This technique would allow you to use these ROIs to run a supervised classification, as the vertices in the PCA plots ARE pure pixels of each cover type.
Task #2 Implementing Linear Spectral Unmixing in ENVI

In our lab, we are most interested in the relative proportions of forests and shrubs within our TM image.

The first stage in produce relative fraction maps (These are images scaled between 0 and 1 depicting how much of a certain cover type of these cover types is to use ENVI to run Linear Spectral Unmixing (or mixture modeling as it is sometimes called).

From the main ENVI menu bar select, Spectral/Mapping Methods/Linear Spectral Unmixing, choose the TM image file, and press OK.

In the Endmember Collection window (where we could import field spectra if we had any), select Import/from ROI from Input File and at the prompt press Select All Items. Press OK.

Next Press Apply, and in the Unmixing Parameters window select Yes to the Sum Constraint, set the weight to 1000.0, choose a suitable filename, and press OK.

Now, close all the files, except for the results of the Linear Spectral Unmixing and the original TM image.

View the results of the first endmember in a new viewer. White areas correspond to high proportions, while darker areas correspond to lower proportions.

You will notice that the water images is mostly noise, and the RMS ERROR image is highest in the non forested regions. As the water produces spurious results lets remove this endmember from our analysis.
Close the LSUM results file and from the main ENVI menu bar reselect, **Spectral/Mapping Methods/Linear Spectral Unmixing**, choose the TM image file and press **OK**.

This time, when you load the ROIs, **DO NOT select the water endmember**:

Next, view the four maps in a new viewer.
These maps are relative fraction maps although as the $<0$ and $>1$ constraint is not applied it is possible to have proportions that are either negative or greater than one.

At this stage most of the literature assume the fraction as is and attributes such in accuracies as error. Typically if $>1$ it is assumed to equal 1 and $<0$ to equal 0.

**Task #3** Answer the following questions [You may want to use the Cursor Location/Value Tool to help in your analysis]:

From you knowledge of the local area and the imagery, do these fraction maps make sense? Explain your answer.

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Suggest ways to improve the fraction maps of the Soil class.

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Is Agriculture a good class? Explain your answer.