EXELIS

Visual Information Solutions

ENVI Classic Tutorial: Using SMACC to Extract Endmembers

Using SMACC to Extract Endmembers

This tutorial is designed to introduce you to the SMACC endmember extraction tool. In this tutorial, you will extract endmembers from an image of an airfield in San Diego, California.

Files Used in this Tutorial

Download data files from the Exelis website.

File	Description
`sandiego_reflectance.img (.hdr)`	Hyperspectral data of an airfield in San Diego
`sandiego_mask.dat (.hdr)`	Mask for removing saturated pixels from the airfield data

The hyperspectral image (`sandiego_reflectance.img`) is of a naval air station in San Diego, California, collected by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) sensor. The image was atmospherically corrected using the Atmospheric Correction Module: QUAC® and FLAASH®, resulting in a reflectance image.

Introduction to the SMACC Endmember Extraction Method

The Sequential Maximum Angle Convex Cone (SMACC) spectral tool finds spectral endmembers and their abundances throughout an image. This tool is designed for use with previously calibrated hyperspectral data. In comparison to the Spectral Hourglass Wizard, SMACC provides a faster and more automated method for finding spectral endmembers, but it is more approximate and yields less precision.

Endmembers are spectra that are chosen to represent pure surface materials in a spectral image. Endmembers that represent radiance or reflectance spectra must satisfy a positivity constraint, in which the abundance images contain no values less than zero. Other physically-based constraints may be imposed, such as a sum-to-unity constraint (the pixels are weighted mixtures of the endmembers) or a sum-to-unity or less constraint (the pixels are weighted mixtures of the endmembers plus black). If the hyperspectral data are calibrated to either radiance or thermal IR emissivity, you should use a sum-to-unity unmixing constraint. If the data are calibrated to reflectance, you should use either a positivity only or sum-to-unity or less constraint. SMACC allows you to select of any of these constraints.

SMACC uses a convex cone model (also known as Residual Minimization) with these constraints to identify image endmember spectra. Extreme points are used to determine a convex cone, which defines the first endmember. A constrained oblique projection is then applied to the existing cone to derive the next endmember. The cone is increased to include the new endmember. The process is repeated until a projection derives an endmember that already exists within the convex cone (to a specified tolerance) or until the specified number of endmembers are found.

In other words, SMACC first finds the brightest pixel in the image, then it finds the pixel most different from the brightest. Then, it finds the pixel most different from the first two. The process is repeated until SMACC finds a pixel already accounted for in the group of the previously found pixels, or until it finds a specified number of endmembers. The spectra of pixels that SMACC finds become the endmembers of the resulting spectral library.

Unlike convex methods that rely on a simplex analysis, the number of endmembers is not restricted by the number of spectral channels. Although endmembers derived from SMACC are unique, a one-to-one correspondence does not exist between the number of materials in an image and the number of endmembers. SMACC derives endmembers from pixels in an image. Each pixel may contain only one material or it may contain a high percentage of a single material with unique combinations of other materials. Each material identified in an image is described by a subset spanning its spectral variability. SMACC provides an endmember basis that defines each of these material subsets. SMACC also provides abundance images to determine the fractions of the total spectrally integrated radiance or reflectance of a pixel contributed by each resulting endmember.

Mathematically, SMACC uses the following convex cone expansion for each pixel spectrum (endmember), defined as:

$$H(c,i) = \sum_{k}^{N} R(c,k)\,A(k,j)$$

where:

i is the pixel index

j and *k* are the endmember indices from 1 to the expansion length, *N*

R is a matrix that contains the endmember spectra as columns

c is the spectral channel index

A is a matrix that contains the fractional contribution (abundance) of each endmember *j* in each endmember *k* for each pixel.

The 2D matrix representation of a spectral image is factored into a convex 2D basis (a span of a vector space) times a matrix of positive coefficients. In the image matrix (R), the row elements represent individual pixels, and each column represents the spectrum of that pixel. The coefficients in A are the fractional contributions or abundances of the basis members of the original matrix. The basis forms an n-D convex cone within its subset. The convex cone of the data is the set of all positive linear combinations of the data vectors, while the convex hull is the set of all weighted averages of the data. The factor matrices are then determined sequentially. At each step, a new convex cone is formed by adding the selected vector from the original matrix that lies furthest from the cone defined by the existing basis.

See the following reference for more information on SMACC:

Gruninger, J, A. J. Ratkowski and M. L. Hoke. “The Sequential Maximum Angle Convex Cone (SMACC) Endmember Model”. Proceedings SPIE, Algorithms for Multispectral and Hyper-spectral and Ultraspectral Imagery, Vol. 5425-1, Orlando FL, April, 2004.

Open and Display the Input Data

1. From the ENVI® Classic main menu bar, select **File > Open Image File**. A file selection dialog appears.
2. Select `sandiego_reflectance.img`. Click **Open**. A color composite is automatically loaded into a display group.

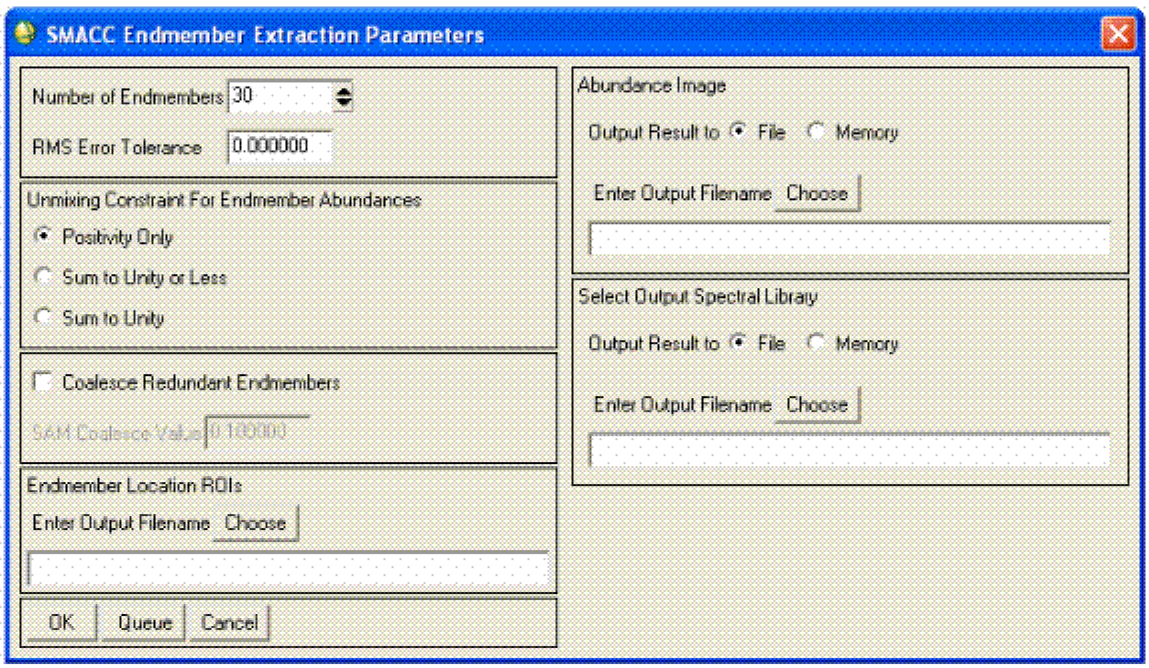
Examine the Data and Start SMACC

1. From the Display group menu bar, select **Tools > Pixel Locator**. A Pixel Locator dialog appears.
2. From the Display group menu bar, select **Tools > Profiles > Z Profile (Spectrum)**. A Spectral Profile window appears.
3. In the Pixel Locator dialog, enter the location (**375, 260**) and click **Apply**. The Spectral Profile shows that the range of the y-axis is 0 to 5,000. The maximum value for this reflectance image is actually 10,000, where 0 indicates no reflectance, and 10,000 indicates 100% reflectance. This pixel has at most a 50% reflectance. This information will be important when deciding the error tolerance of the SMACC process. Keep the Spectral Profile window open for a later exercise.
4. From the ENVI Classic main menu bar, select **Spectral > SMACC Endmember Extraction**. The Select Input Image dialog appears.

Select the Input File

1. In the Select Input Image dialog, click **Open** and select **New File**. A file selection dialog appears.

2. Select `sandiego_mask.dat` and click **OK**. This file appears in the Select Input File section of the Select Input Image dialog. The input image contains a few saturated pixels, which do not accurately represent the spectra for the material at that location. Saturated pixels are recognized by their unusual reflectance values. The mask is used to filter out these pixels.
3. In the Select Input Image dialog, select `sandiego_reflectance.img`.
4. Click **Select Mask Band**. The Select Mask Input Band dialog appears.
5. Select **Mask Band** under `sandiego_mask.dat` and click **OK**.
6. Click **OK** in the Select Input Image dialog. The SMACC Endmember Extraction Parameters dialog appears.



Specify the SMACC Parameters

1. In the **Number of Endmembers** field, enter **40**. Endmembers represent the distinguishable materials in the image, and their spectra. SMACC does not automatically determine the number of unique materials in the image. You must identify the possible maximum number of endmembers in the image. This image contains an urban area that may have a large number of endmembers.
2. In the **RMS Error Tolerance** field, enter **100**. The default value of zero indicates SMACC will continue until the number of endmembers specified for the Number of Endmembers parameter is obtained. If a different RMS error is specified, SMACC will stop when that RMS error is achieved. An appropriate value for this parameter depends on the range of the reflectance values in the image. For this input image, 100% reflectance has a pixel value of 10,000. To specify an error tolerance of 1%, set the RMS Error Tolerance parameter to 100.
3. Select the **Sum to Unity or Less** radio button.

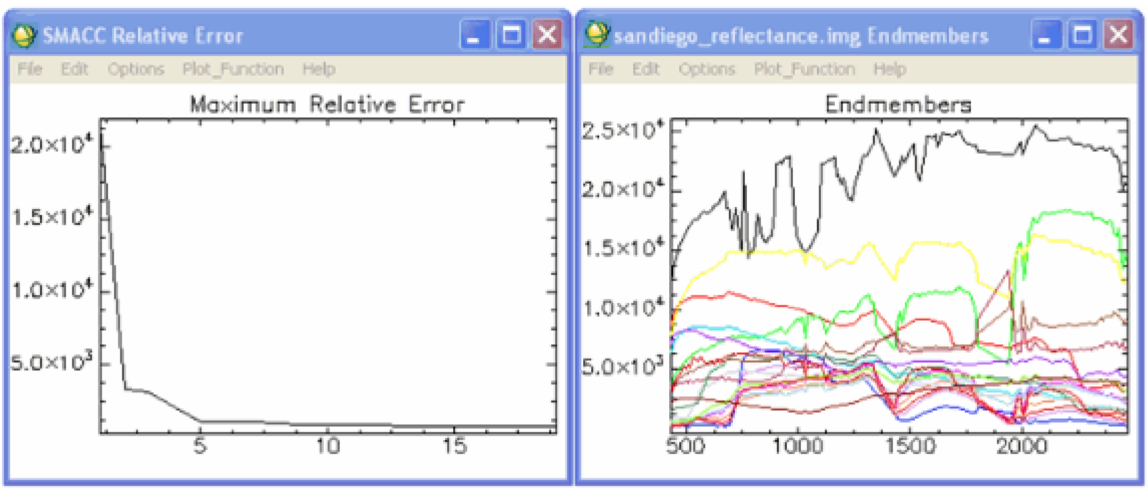
   The Positivity Only option constrains the endmember spectra to positive values for any wavelength. This option is typically used for images corrected to reflectance because a negative reflectance value has no physical meaning. Nevertheless, the other constraint options also apply the positivity constraint, so these other options should also be considered. Positivity Only is the best constraint for unmixing reflectance spectra under conditions of variable illumination. This is the default setting.

   The Sum to Unity or Less option constrains the sum of the fractions of each material calculated for each pixel to one or less. With this constraint, a pixel cannot be more than 100% filled. This option also adds an automatic shadow endmember, and it creates abundance images that can be used for strict physical interpretation of endmember fractions existing inside of each pixel. This option is chosen to obtain a shadow endmember.

   The Sum to Unity option constrains the sum of the fractions calculated for each pixel to equal 100%. This constraint is more appropriate for radiance or thermal emissivity images. For these types of images, a shadow endmember is not physically plausible. Use this constraint when a zero endmember is not physically plausible or when you want to find very dark endmembers, such as shadow endmembers. However, this option may also be useful for reflectance images when you want SMACC to find a true shadow endmember spectrum from the image data.
4. Select **Coalesce Redundant Endmembers**, but do not change the SAM Coalesce Value. This option coalesces any endmembers that are within the specified spectral angle mapper threshold (known as SAM Coalesce Value in the dialog) into one endmember. The most extreme spectra are identified and used to represent the entire coalesced group of endmembers. You should not use this option if you are trying to distinguish spectrally similar materials. For this tutorial, you only want general mapping of the materials.
5. Under **Endmember Location ROIs**, enter `sandiego_reflectance.roi` in the **Enter Output Filename** field. This output file will contain point ROIs indicating the pixels from which

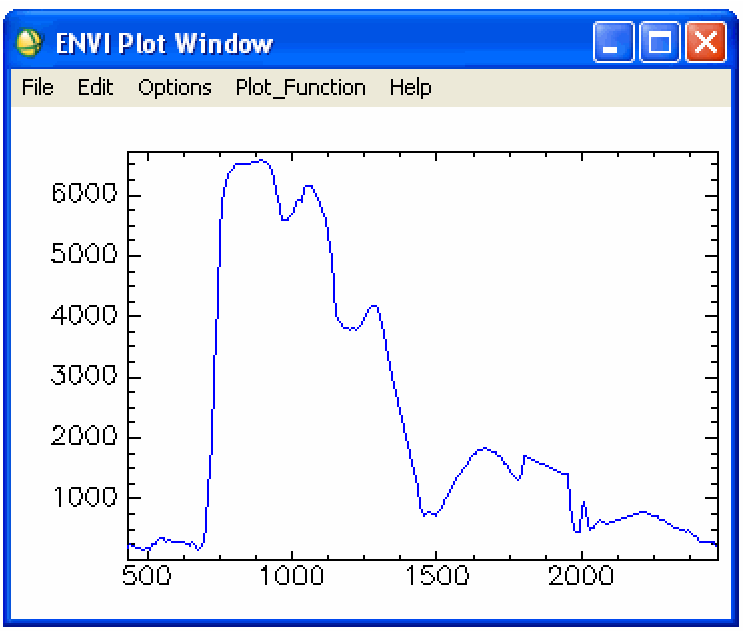
the resulting endmember spectra are derived. This output file is optional. If you do not specify a filename in the text box, this output information is not generated.

6. Under **Abundance Image**, enter `sandiego_reflectance_abundance.img` in the **Enter Output Filename** field. This output file will contain the shadow and endmember abundance images. The shadow image usually shows high fractions where dark objects exist, including asphalt pavements. The endmember images show values that indicate the fraction of the pixel filled by that endmember material. This output image is optional. If you select the File radio button but you do not specify a filename in the Enter Output Filename text box, this output image is not generated.
7. Under **Select Output Spectral Library**, enter `sandiego_reflectance_spectra.sli` in the **Enter Output Filename** field. This output file will contain the spectral library of extracted endmembers. If you select the File radio button, you must specify a filename in the Enter Output Filename text box.
8. Click **OK** to run the SMACC process. A processing status dialog reports the status of the SMACC process. This progress bar is followed by the Unmixing progress bar. When unmixing is complete, the resulting spectral library and abundance images appear in the Available Bands List. The SMACC process also produces plot windows for the relative error and the extracted endmember spectra.

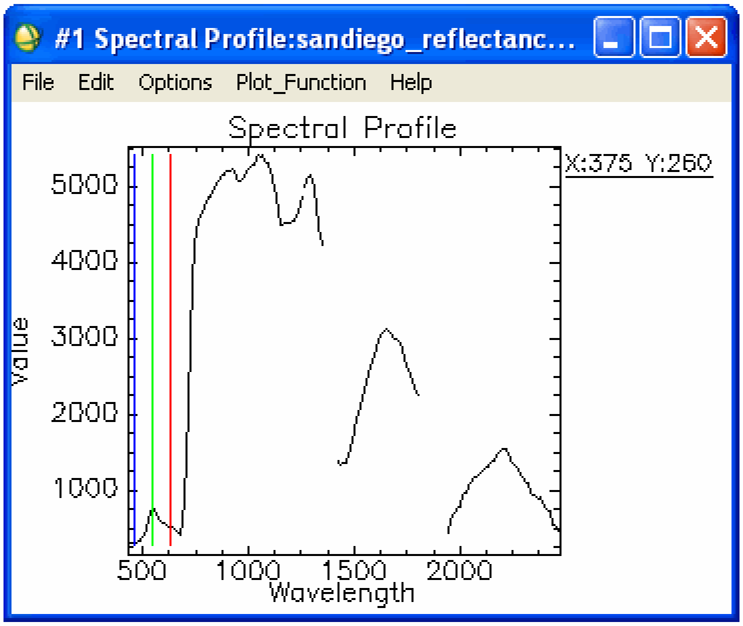


Analyze the Extracted Endmembers and Their Abundance Images

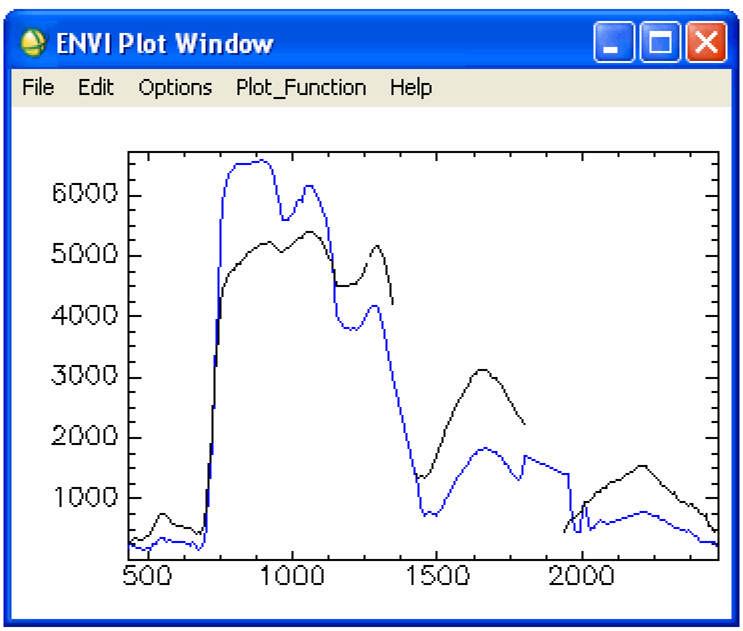
1. In the SMACC Relative Error plot window, the maximum relative error started to converge at five extracted endmembers. The SMACC process actually ended at 19 endmembers. Although you specified a value of 40, the remaining endmembers were coalesced into similar spectra to form the resulting 19 endmembers.
2. From the Endmembers plot window menu bar, select **Options** > **Plot Key**. As with the relative error, the plot key (legend) in the Endmembers window indicates the SMACC process extracted 19 endmembers. However, the material represented by each endmember spectrum is unknown. You could use Spectral Analyst to identify these spectra. For more detailed information, see the ENVI Classic Help. For this tutorial, the endmember for green vegetation can be visually determined as Plot #4.
3. From the ENVI Classic main menu bar, select **Window** > **Start New Plot Window**. An ENVI Classic Plot Window appears.
4. Drag-and-drop the Plot #4 key from the Endmembers plot window to the ENVI Classic Plot Window.



5. Right-click in the Spectral Profile window (which you opened on Page 5) and select **Plot Key**.



6. Drag the X:375 Y:260 plot key from the Spectral Profile window, and drop it in the ENVI Classic Plot Window containing Plot #4.



7. Compare these spectra.
8. In the Available Bands List, select **Endmember 4 Abundance**, and select the **Gray Scale** radio button.
9. In the Available Bands List, click **Display #1** and select **New Display**. Click **Load Band**.

10. From the Display #2 menu bar, select Tools > Pixel Locator.
11. In the Pixel Locator dialog, enter the location (**375, 260**) and click **Apply**. The high abundance of Endmember 4 data values indicates this area is full of green vegetation. From the original RGB image, this area appears to a baseball field.
12. From the Display #2 menu bar, select **Tools > Cursor Location/Value**. The data value at (375, 260) is 0.491435. This value indicates that nearly 50% of the pixel contains the material represented by the extracted endmember.
13. From the Display #2 menu bar, select **Overlay > Region of Interest**. The ROI Tool appears.
14. In the ROI Tool, select the far left column of Endmember 4 in the table. An asterisk appears in the column, and the entire row is highlighted.
15. Click **Goto**. The cursor in the Image window for the abundance image goes to the point ROI corresponding to the pixel from which the spectrum for Endmember #4 was extracted.
16. When you are finished examining the abundance image, select **File > Exit** from the ENVI Classic main menu bar.