

# Free Software for Analyzing AVIRIS Imagery



By Randall B. Smith and Dmitry Frolov

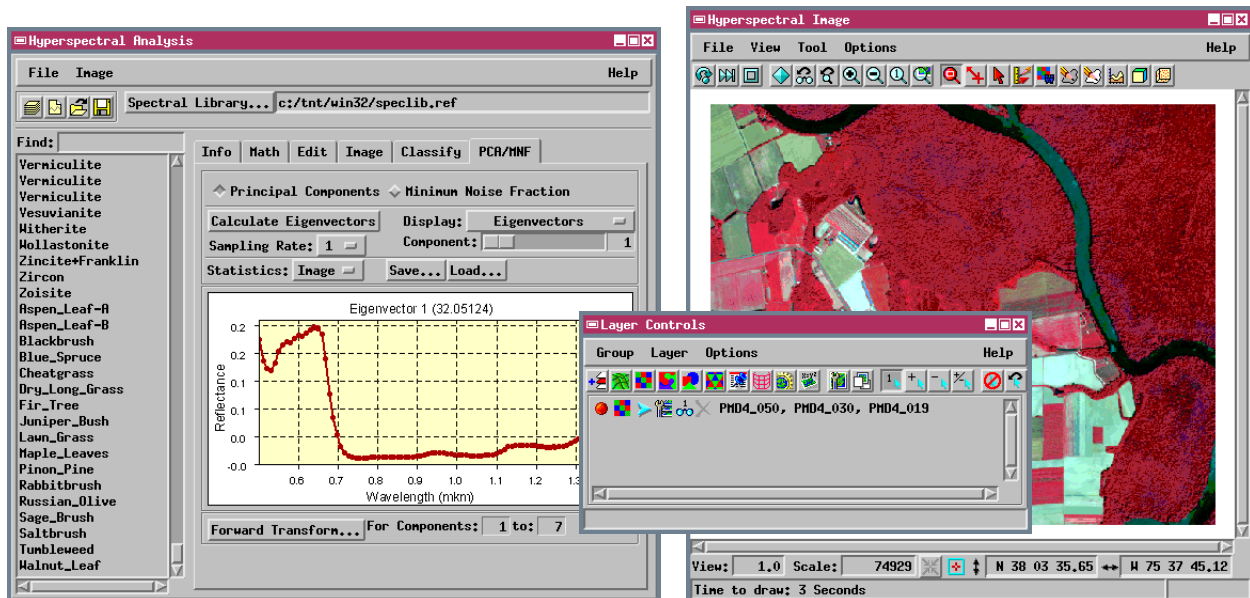
For much of the past decade, imaging spectrometry has been primarily a research tool. With the recent appearance of commercial airborne hyperspectral imaging systems, and the impending launch of satellite-based sensors, imaging spectrometry is poised to enter the mainstream of remote sensing. As hyperspectral images become commonly available, both applications and users of the imagery will become more diverse. Many more researchers, professionals, and students from different disciplines will require the knowledge and tools to understand and interpret the information in hyperspectral images.

The Hyperspectral Analysis module in MicroImages' free TNTlite software package provides a way for anyone to view, process, and analyze AVIRIS scenes or other hyperspectral images. TNTlite is intended for educational use by anyone and is a free version of TNTmips, MicroImages' professional geospatial analysis product. TNTlite can be used on Windows, Mac, and UNIX platforms with as little as 16 MB of memory. It includes all of the visualization and analysis capabilities found in TNTmips but limits the size of the geospatial objects that can be processed. In order to make hyperspectral analysis of standard AVIRIS scenes available to TNTlite users, the maximum raster size limits for TNTlite have been increased to the product of 614 x 512 raster cells, with no limit on the number of bands. TNTlite currently can import hyperspectral images from AVIRIS, DAIS (ENVI format), AISA, and other sensors, and the user can select a lite-sized subarea out of a larger hyperspectral image during import. MicroImages has included hyperspectral analysis in TNTlite in an effort to broaden the understanding and use of hyperspectral imagery and to encourage users of the imagery to contribute ideas on processing algorithms, visualization tools, and interface design.

The TNT Hyperspectral Analysis module provides a wide range of visualization and processing capabilities, including approximate reflectance calibration, extraction and display of spectral plots, dimensional reduction, animated n-dimensional scatterplots, and spectral matching and mapping. In addition, several unique hyperspectral analysis tools are included: an automated process for previewing and choosing an informative three-band color combination, a self-organizing map classifier, and an autocorrelogram process to explore the spatial-spectral variability of the hyperspectral image.

## Hyperspectral Analysis Interface

The TNT Hyperspectral Analysis process provides an interactive graphical interface for working with hyperspectral images (Figure 1). Most interactive procedures are initiated from the various tabbed panels on the Hyperspectral Analysis control window, while some more intensive image-analysis and transformation procedures are accessed from the Image menu. When a hyperspectral image is opened, a three-band RGB color combination is automatically displayed in the Hyperspectral Image view window, with bands chosen to span most of the available wavelength range. The user can also use the Layer Controls window to choose any single band or a three-band RGB color combination to display, or use the Hyperspectral Explorer tool (described in the next section) to explore various color band combinations. Image bands are displayed using a choice of automatic linear or normalized contrast enhancement, or the user can adjust the contrast manually and save the result as a look-up table. The Hyperspectral Image window also provides access to graphic tools for selecting image spectra for display and defining subareas for use with the n-Dimensional Visualizer and certain methods of reflectance calibration.



**Figure 1.** The major process controls for the TNTlite Hyperspectral Analysis process are found on tabbed panels in the Hyperspectral Analysis control window. The image is displayed in the Hyperspectral Image window, which also provides access to graphic tools for selecting image spectra and for defining subareas for use in certain processes. The Layer Controls window allows the user to select single bands or RGB band combinations to display, and provides access to image enhancement tools.

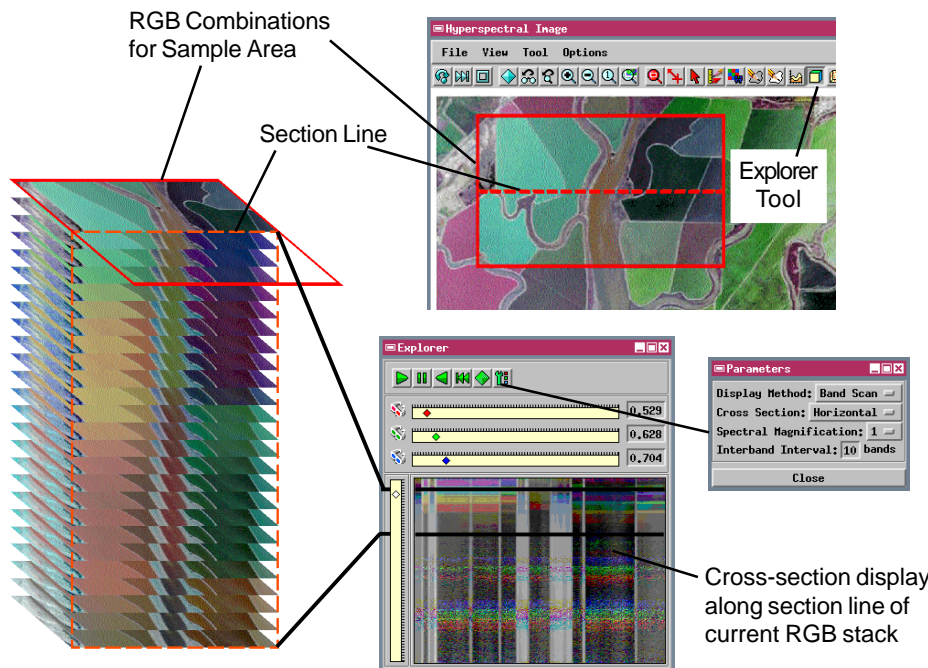
## Image Visualization with the Hyperspectral Explorer

The TNT Hyperspectral Analysis module includes a unique visualization tool called the Hyperspectral Explorer. It allows the user to automatically create a large number of potential RGB color combinations for a sample area, preview the combinations as an animated sequence, and choose as a reference image the combination that best accentuates the spectral features of interest. The rectangular sample area can be up to the product of 256 x 256 raster cells. The process loads the sample portion of each image band into memory so that different RGB combinations can be created quickly.

The Hyperspectral Explorer (Figure 2) creates an initial set of RGB band combinations using a user-defined interband interval (in number of bands). The process creates all possible RGB combinations by using this interval and assigning the shortest wavelength band in each combination to the red color channel and the longest wavelength band to the blue channel. For example, an interband interval of 10 would

create combinations using bands 1, 11, and 21; 2, 12, and 22; and so on until each band has been used in at least one RGB combination. The user can change the interband interval at any time, or use graphic controls to change the wavelength order and set separate blue-green and green-red band intervals.

To provide an overview of the range of colors available in the current set of RGB combinations, the Explorer process creates a cross-sectional view of the set of color images along a line through the middle of the sample area. Each horizontal row of pixels in this graphic shows the colors in a single RGB combination along the section line, with the shorter-wavelength combinations at the top and longer-wavelength combinations at the bottom. The user can choose either horizontal or vertical directions for the section line. The display updates immediately when the interband intervals or wavelength order are changed, so the user can use it to find the optimal choice for these settings. Combinations that include bands with significant noise appear in the graphic as fuzzy horizontal stripes.



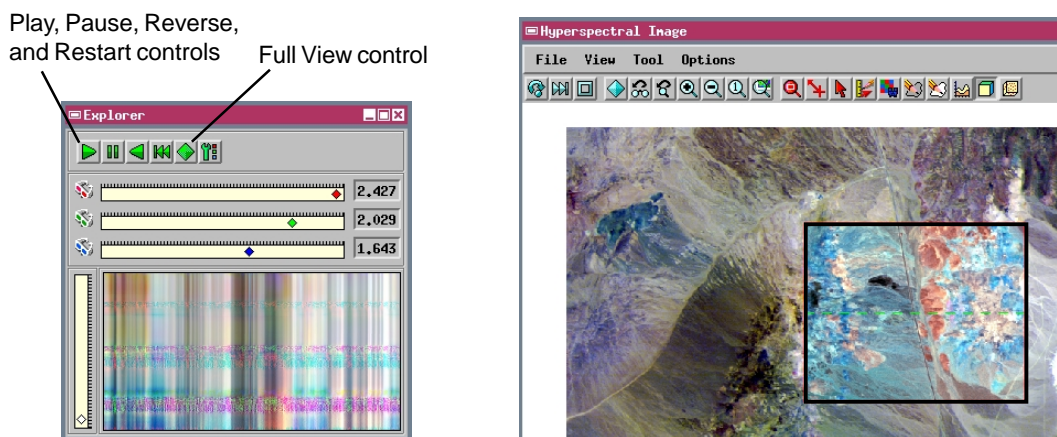
**Figure 2.** The Hyperspectral Explorer creates a series of RGB combinations (left) of the available image bands and allows the user to choose one to use for the reference image. Bands are assigned to red, green, and blue color channels using band-number intervals. A single interband interval can be set in the Parameters window, or the user can move the horizontal sliders in the Explorer window to set band order and interband intervals. The lower part of the Explorer window provides a cross-sectional view of the current stack of RGB images, with the shorter-wavelength combinations at the top. This sectional view gives an overview of the range of colors present in the current set of combinations.

The user can also use controls to “play” the current set of color images (Figure 3). The combinations for the sample area are displayed one by one in increasing wavelength order. The user can pause, reverse, or restart the sequence, or use graphic controls to rapidly move to a particular RGB combination in the sequence. At any time, the user can select a particular combination to use as the reference image and display it for the entire scene. These tools allow the user to rapidly evaluate different band com-

binations and explore the spectral variability within the scene.

### Wavelength Subsetting and Image-based Reflectance Conversion

Basic spectral information is provided for each image band, including band-center wavelength, band-width, and a histogram plot. The user can also specify a wavelength range to select a subset of bands to be used for processing. This feature allows the user to



**Figure 3.** The controls in the Explorer window allow the user to preview a set of RGB band combinations for the sample area. Playing the sequence displays the images one by one in the Hyperspectral Image window. Full View selects the current band combination as the reference image for the scene.





maintain one image file containing all bands but use different sets of bands for different analyses. Future versions will allow specification of multiple wavelength ranges.

The user can choose from several scene-derived reflectance conversion methods that are applied on-the-fly to adjust image radiance values for atmospheric and illumination effects. The adjusted values are used automatically in plots of image spectra and in analytical procedures. Both types of adjustment can be turned off if the user is working with data that has already been converted to surface reflectance.

The Additive Offset methods attempt to correct for atmospheric backscatter by subtracting a constant value from each pixel in an image band, using either the minimum band value (Minimum method) or the average value for a uniformly dark area in the image specified by the user (Dark Field method). More complex Atmospheric Correction methods include the Flat Field, Maximum, and Equal Area Normalization methods. The Flat Field method (Hutsiniller, 1988) reduces atmospheric, topographic, and solar irradiance effects using the mean spectrum of a bright, spectrally flat area (uniform spectral reflectance at all wavelengths) selected by the user. A flat field spectrum should closely resemble the solar irradiance curve as modified by atmospheric scattering and absorption effects. The Flat Field method divides each image spectrum by the flat field spectrum to produce an approximate reflectance conversion. The Maximum correction method uses a similar conversion but assembles an approximate flat field spectrum using the maximum value in each spectral band. For both methods, the main difficulty is producing a sufficiently “flat” flat field spectrum to provide an adequate correction.

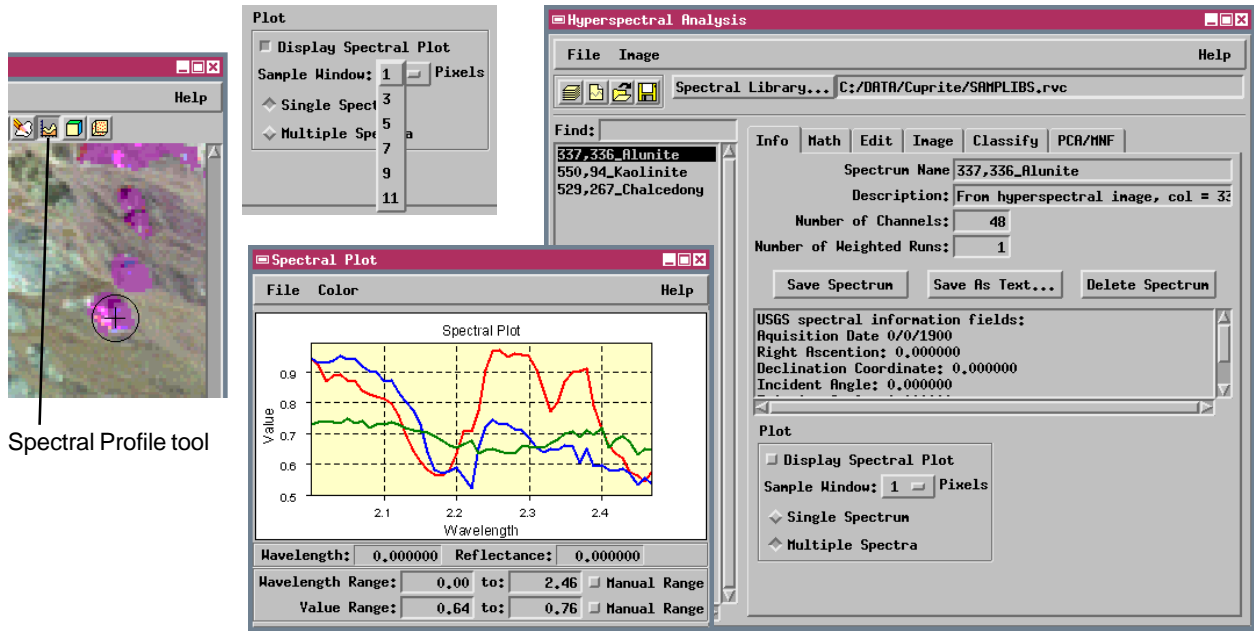
The default Atmospheric Correction option is Equal Area Normalization (Jet Propulsion Laboratory, 1985), which also includes the Internal Average Relative Reflectance correction (Kruse, 1988). Image values are adjusted by scaling the sum of the band values for each image position to a constant

value. This procedure equalizes the overall relative brightness of image pixels, removing topographic illumination variations. Each image spectrum is then divided by the average normalized spectrum calculated from the entire scene. For a scene with a variety of surface materials, averaging should largely remove spectral features attributed to surface materials, and the average spectrum should resemble the solar irradiance curve as modified by contributions from the atmosphere. Dividing individual image spectra by the average spectrum thus provides an approximate conversion to reflectance. In some cases, however, the average spectrum may retain some spectral features related to unusually abundant surface materials, and these features will then introduce spurious features to the adjusted image spectra. For all three of the image-based atmospheric correction methods, large differences in elevation or variations in atmospheric conditions within the scene can result in residual atmospheric effects in the normalized spectra. These conditions also reduce the quality of the reflectance conversion. MicroImages is considering adding more robust reflectance conversions in future versions.

The Logarithmic Residuals reflectance conversion (Green and Craig, 1985) can also be applied to a hyperspectral image. Because of the computational demands, this option cannot be applied on-the-fly, but is instead used to output a set of residual image bands.

### **Image Spectra, Spectral Libraries, and Spectral Matching**

A Spectral Profile tool allows the user to select spectra from the image for viewing or use in analysis (Figure 4). The user can extract the spectrum of a single pixel or the average spectrum for an area up to 11 by 11 pixels. An extracted spectrum is limited to the range of the currently selected wavelength subset. The user can create spectral libraries to store image spectra and select library spectra to plot or to use in processing. Spectral curves in ASCII text format can be imported into a TNT spectral library, allowing the user to incorporate field or laboratory reflectance spectra in analysis procedures. The USGS Spectral Library has also been included as a



**Figure 4.** Spectra can be extracted from the hyperspectral image (single pixels or sample window averages) using the Spectral Profile tool and stored in spectral libraries. Controls for spectral plots and spectral libraries are found on the Info panel on the Hyperspectral Analysis window. The Spectral Plot window can be set to display single or multiple spectra and provides controls for the wavelength and value ranges to be displayed.

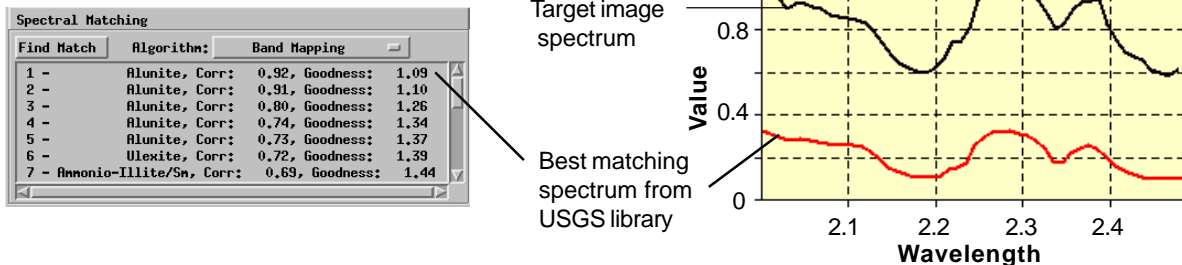
standard reference library within the Hyperspectral Analysis module.

Spectral plots can be set to display only the last selected spectrum or multiple spectra using different line colors. The vertical and horizontal axes of the spectral plot are automatically scaled and labeled using the ranges of values in the current spectra. The user can also set the wavelength and value ranges manually.

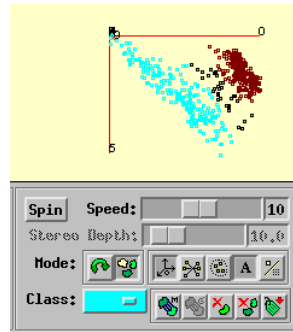
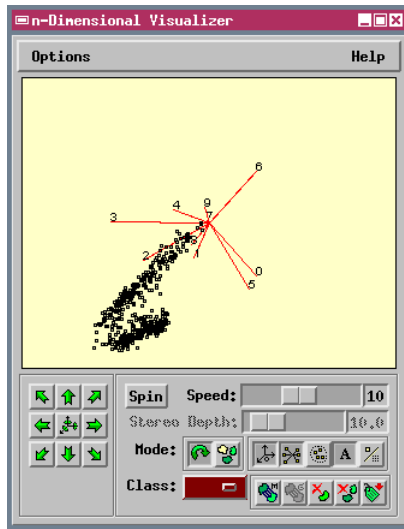
The Hyperspectral Analysis process can perform spectrum matching using either Band Mapping or Spectral Angle Mapper (Kruse et al, 1993) algorithms. The matching process finds the twenty spec-

tra in the current library that best match the selected target spectrum, and ranks them by closeness of fit (Figure 5).

The user can edit values in a spectrum using a spreadsheet-like interface, perform mathematical operations such as averaging and dividing pairs of spectra, and remove the continuum from a spectrum (Clark and Roush, 1984; Kruse et al, 1988). A separate process can produce a continuum-removed set of image bands. Spectra extracted from the resulting band set can then be compared directly with continuum-removed reference spectra.



**Figure 5.** Spectral Matching can be performed using Band Mapping or Spectral Angle Mapper methods, using controls on the Math tabbed panel.



**Figure 6.** The n-Dimensional Visualizer can be used to investigate the spectral properties of pixels within a sample area. The multidimensional scatterplot (left) can be rotated manually or automatically. Points in the spectral plot can be grouped and marked with a class color (center) using a polygon drawing tool, and corresponding pixels can be marked with the same color in the image (right).

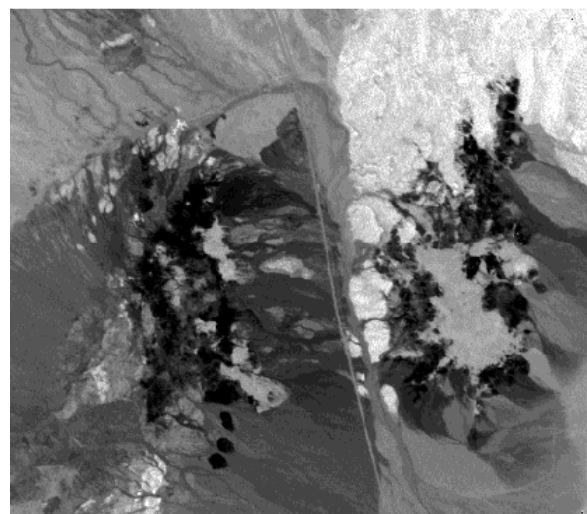
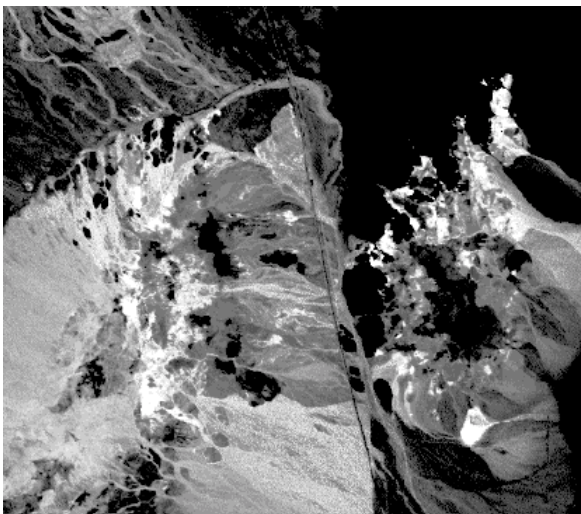
### n-Dimensional Visualizer

Multidimensional scatterplots of image spectra can be created, displayed, and rotated using the n-Dimensional Visualizer tool (Figure 6). This tool can be used with a wavelength subset of the original image bands or with a set of component rasters produced by one of the dimensional reduction procedures. The user defines a polygonal image area to define the selected set of image spectra. The user can rotate the scatterplot manually using arrow buttons or by dragging the plot with the mouse, or set the

plot to automatically rotate in random directions. The n-Dimensional Visualizer is useful for identifying extreme pixels that may be candidate endmember spectra. The user can use a polygon drawing tool to select a group of spectral points in the plot, mark them with a color, and map this color back to the corresponding pixels in the Hyperspectral Image window.

### Spectral Mapping

The TNT Hyperspectral Analysis process also provides several standard methods for subpixel spec-



**Figure 7.** Sample spectral mapping results obtained with TNTlite for a portion of a 1997 AVIRIS scene of Cuprite, Nevada, using a wavelength subset from 1.98 to 2.467  $\mu\text{m}$ . The image on the left is a correlation image produced using the Cross Correlation method for a kaolinite image spectrum, with brighter tones indicating higher degrees of correlation. The image on the right is the Spectral Angle image produced by the Spectral Angle Mapper method for an alunite image spectrum. Darker tones indicate smaller spectral angles, and thus a better spectral match.



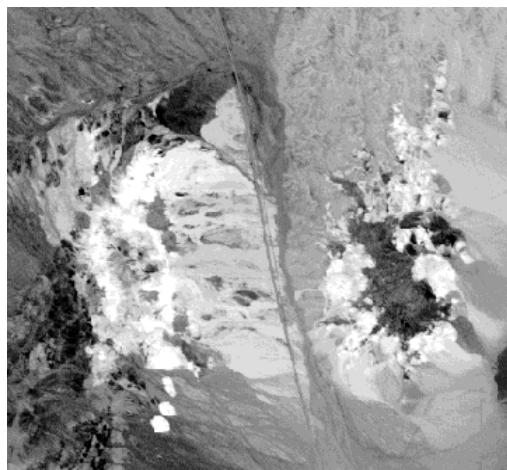
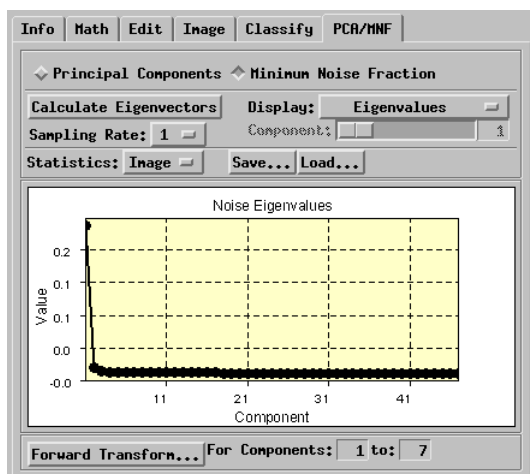
tral detection and mapping the occurrence and approximate relative abundance of one or more target spectra within the image. The user specifies one or more target spectra by selecting them from the image or from a library and adding them to the End Member list. The available mapping methods are the Spectral Angle Mapper (Kruse et al, 1993), Matched Filtering (Farrand and Harsanyi, 1994; Harsanyi and Chang, 1994), Cross-Correlation (van der Meer and Bakker, 1997), and Linear Unmixing (Adams et al, 1985; Smith et al, 1990). The Spectral Angle Mapper and Cross-Correlation methods (Figure 7) produce a class raster in addition to the Spectral Angle and Correlation rasters (respectively). The user can set a threshold value for assigning cells to the target class.

### Dimensional Reduction and Unsupervised Classification

The TNT Hyperspectral Analysis process provides several standard methods of dimensional reduction: Principal Components and the Minimum Noise Fraction Transform (Green et al, 1988; Lee et al, 1990). The user can compute, save, and load the transform statistics and view plots of the eigenvectors, eigenvalues, and the component variance and band variance (in percentage of total variance). The forward transform can then be applied to produce a desired number of output component rasters (Figure

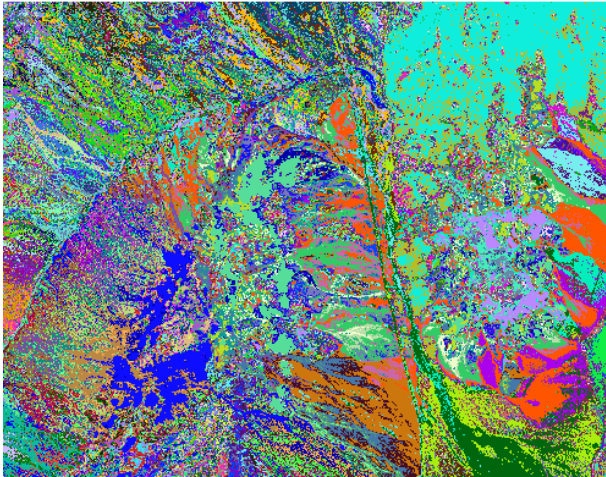
8). Future versions will allow the user to select the relatively noise-free MNF components and run a reverse MNF transform to produce a reduced-noise set of image bands for analysis.

An unsupervised Self-Organizing Map classification process is also available. The process uses a self-organizing map (SOM) neural network procedure (Kohonen, 1995) to find a best-fit set of 512 class centers for the hyperspectral image, then assigns all image spectra to one of the classes using spectral angle as the measure of similarity (Figure 9). The SOM neural network uses a rectangular 16 by 32 array of nodes, which are initially assigned random spectral values. During the class-building (learning) phase, many sample image spectra are compared one by one to the full set of nodes. For each spectrum, the node with the most similar spectrum has its weighting values adjusted to improve the match. Nearby nodes in the array are also adjusted to a lesser extent. Eventually the node values converge to a set of class-center vectors that approximate the distribution of all image spectra in n-dimensional spectral space. Similar class vectors also lie close together in the node array, and the greater the area that similar materials cover in the hyperspectral image, the more classes are used to represent them.

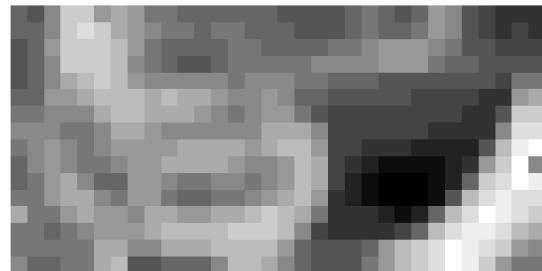


**Figure 8.** The PCA/MNF panel on the Hyperspectral Image window (left) provides controls for calculating statistics for Principal Components and Minimum Noise Fraction (MNF) transforms, and provides plots of the results. On the right is an image of the third MNF component for a portion of a 1997 AVIRIS scene of Cuprite, Nevada. MNF components were calculated using a 48-band subset (1.98 to 2.467  $\mu\text{m}$ ).





**Figure 9.** Sample results from a Self-Organizing Map classification of the 1997 AVIRIS scene of Cuprite, Nevada. The classification was performed using a 48-band wavelength subset (1.98 to 2.467 mm). Left, portion of the class image with colors representing different spectral classes. Right, the distance image produced by the classification. The distance image is a graphical representation of the final state of the 16 x 32 array of neural nodes that make up the self-organizing map. Each pixel in the image represents one class node, with the class 1 in the upper left corner, class 32 in the upper right corner, and class 512 in the lower right corner. Each pixel's gray level represents its average spectral distance to neighboring classes. The group of dark pixels in the right half of the image represents a group of tightly-clustered (closely related) classes.



This property of the classifier ensures adequate spectral discrimination of different varieties of common, widespread materials.

A related VQ Filtering procedure applies the SOM algorithm to classify image spectra into 512 spectral classes then subtracts the appropriate class spectrum from each image spectrum. The process produces a residual (filtered) image raster for each input spectral band. The user can use these images to evaluate the class image produced by the SOM

classifier or to pinpoint the locations of materials in the scene whose spectra differ significantly from their class spectrum.

A new Auto-Correlogram process provides an estimate of the spatial-spectral variability of the hyperspectral image on a pixel by pixel basis (Figure 10). It computes the average spectral angle be-



**Figure 10.** Sample results from the Auto-Correlogram process for the 1997 AVIRIS scene of Cuprite, using the 1.98 to 2.467 mm band subset. Pixel gray levels represent the average spectral angle between each pixel and its adjacent neighbors (with contrast stretch applied). Spectrally uniform areas appear dark, while bright pixels separate areas with contrasting spectral characteristics.





tween each image cell and its eight neighbors, using the standard Spectral Angle Mapper algorithm. The output of the process consists of two floating-point rasters having the same spatial dimensions as the input image. These rasters provide the average spectral angle and its standard deviation for each image cell. Cells with high values in the spectral angle raster represent areas with high spatial variability in spectral properties, such as boundaries between larger, more uniform areas. The auto-correlation procedure thus functions as a hyperspectral edge-detection filter.

### Obtaining TNTlite

TNTlite can be downloaded free from the MicroImages web site ([www.microimages.com](http://www.microimages.com)) or ordered on CD-ROM for the cost of shipping and

materials. It does not require a hardware authorization key, and there are no time limits on its use. Online documentation is included, along with sample datasets and a colorful set of tutorial booklets in Adobe Acrobat format covering major processes (including Hyperspectral Analysis). Limited free technical support is available via e-mail ([tech@microimages.com](mailto:tech@microimages.com)).

The TNT products seamlessly integrate data objects of all types: rasters, topological vectors, CAD layers, Triangulated Irregular Networks (TINs), and relational databases. TNTlite provides a full range of import capabilities for varied file formats (subject to object-specific size limits), but export to external file formats is not provided.

### References

- Adams, J.B., M.O. Smith, and P.E. Johnson, 1985, "Spectral Mixture Modeling: a New Analysis of Rock and Soil Types at the Viking Lander I Site," *J. Geophys. Res.*, vol. 91, pp. 8098-8112.
- Clark, R.N., and Roush, T.L., 1984, "Reflectance Spectroscopy: Quantitative Analysis Techniques for Remote Sensing Applications," *J. Geophys. Res.*, vol. 89(B7), pp. 6329-6340.
- Farrand, W.H., and J.C. Harsanyi, 1994, "Mapping Distributed Geological and Botanical Targets through Constrained Energy Minimization," in Proc. Tenth Thematic Conference on Geologic Remote Sensing, San Antonio, TX, 9-12 May 1994, pp. I-419 - I-429.
- Green, A.A. and M.D. Craig, 1985, "Analysis of Aircraft Spectrometer Data with Logarithmic Residuals," in Proc. Airborne Imaging Spectrometer Data Analysis Workshop, Apr. 8-10, 1985, Jet Propulsion Laboratory, Pasadena, CA, JPL Pub. 85-41, pp. 11-119.
- Green, A.A., M. Berman, P. Switzer, and M.D. Craig, 1988, "A Transformation for Ordering Multispectral Data in Terms of Image Quality with Implications for Noise Removal," *IEEE Trans. Geosci. and Rem. Sens.*, vol. 26, pp. 65-74.
- Harsanyi, J.C., and C.I. Chang, 1994, "Hyperspectral Image Classification and Dimensionality Reduction: an Orthogonal Subspace Projection Approach," *IEEE Trans. Geosci. And Rem. Sens.*, vol. 32, pp. 779-785.
- Hutsonpillier, A., 1988, "Discrimination of Hydrothermal Alteration Mineral Assemblages at Virginia City, Nevada, Using the Airborne Imaging Spectrometer," *Rem. Sens. Envir.*, vol. 24, pp. 53-66.
- Jet Propulsion Laboratory, 1985, *Airborne Imaging Spectrometer Science Investigator's Guide to AIS Data*, Jet Propulsion Laboratory
- Kohonen, T., 1995, *Self-Organizing Maps*, Springer, Berlin, pp. 77-130.
- Kruse, F.A., 1988, "Use of Airborne Imaging Spectrometer Data to Map Minerals Associated with Hydrothermally Altered Rocks in the Northern Grapevine Mountains, Nevada, and California," *Rem. Sens. Envir.*, vol. 24, pp. 31-51.
- Kruse, F.A., W.M. Calvin, and O. Sez nec, 1988, "Automated Extraction of Absorption Features from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Geophysical and Environmental Research Imaging Spectrometer (GERIS) data," in Proc. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Performance Evaluation Workshop, Jet Propulsion Laboratory, Pasadena, CA, JPL Pub. 88-38, pp. 62-75.



- Kruse, F.A., A.B. Lefkoff, J.W. Boardman, K.B. Heidebrecht, A.T. Shapiro, P.J. Barloon, and A.F.H. Goetz, 1993, "The Spectral Image Processing System (SIPS) – Interactive Visualization and Analysis of Imaging Spectrometer Data," *Rem. Sens. Envir.*, vol. 44, pp. 145-163.
- Lee, J.B., A.S. Woodyatt, and M. Berman, 1990, "Enhancement of High Spectral Resolution Remote-Sensing Data by a Noise-Adjusted Principal Components Transform," *IEEE Trans. Geosci. and Rem. Sens.*, vol. 28, pp. 295-304.
- Smith, M.O., S.L. Ustin, J.B. Adams, and A.R. Gillespie, 1990, "Vegetation in Deserts: I. A Regional Measure of Abundance from Multispectral Images," *Rem. Sens. Envir.*, vol. 31, pp. 1-26.
- van der Meer, F., and W. Bakker, 1997, "Cross Correlogram Spectral Matching: Application to Surface Mineralogical Mapping by Using AVIRIS Data from Cuprite, Nevada," *Rem. Sens. Envir.*, vol. 61, pp. 371-382.

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