N-Dimensional Display of Cluster Means in Feature Space

Michael E. Hodgson
Department of Geography, University of Colorado, Boulder, CO 80309
Reese W. Plews
Department of Geology and Geography, Hunter College—CUNY, New York, NY 10021

ABSTRACT: The visual analysis of cospectral plots of cluster locations is an important tool in the cluster labeling process and in the understanding of the spectral characteristics of land-cover phenomena in general. However, cospectral plots are limited to depicting phenomena locations in only two-band feature space. *N*-dimensional spectral plots of the location of cluster means in feature space can be created using an *X-Y* graph and the monocular depth cues of size, thickness, brightness, and color. Methods for implementing these vision cues to depict the multispectral feature locations in two- to six-band feature space are discussed. Graphic examples are provided to illustrate the use of this new method for analyzing feature space.

INTRODUCTION

THE TWO GENERAL METHODS for mapping land cover-classes using digital remotely sensed data are supervised and unsupervised classification. Each method is a two-step process (Jensen, 1986). Unsupervised classification analysis consists of a cluster identification and a cluster labeling step. The analyst selects the appropriate bands (normally two or more) and performs a cluster analysis of the imagery to produce a desired number of multispectral clusters. The analyst then determines the land-cover category represented by each multispectral cluster, a process referred to as *cluster labeling*.

Labeling of these multispectral clusters is a critical step in the unsupervised classification method. There are two primary techniques for labeling the spectral clusters. First, the image locations of pixels contained within each cluster can be visually correlated to known *geographic locations* of land-cover categories on the ground. Second, *cospectral plots* may be examined to identify land-cover categories by means of their multispectral locations in feature space. These two labeling techniques may be used independently or in conjunction with one another to accurately determine land-cover categories.

The geographic correlation of clusters pixels with known land-cover types is typically performed visually. Comparisons of the cluster map with land-cover types may be analyzed with aerial photography, topographic or other thematic maps, and even with the raw imagery. Where adequate maps of "ground truth" are available, geographic locations of known land-cover phenomena may be visually correlated with the same spatial location on the image cluster map, thus, enabling clusters to be identified. This correlation may also be performed in an automated manner if the known land-cover categories are in digital form. In many instances, ground truth maps either are unavailable or are at a smaller scale than the imagery; thus, this correlation technique may not always be available. (This is particularly true for high spatial resolution imagery collected from airborne sensors). A color composite (e.g., false-color composite) may be analyzed with the cluster map to identify clusters. For example, a cluster category depicted by bright magenta pixels on a false-color composite using green, red, and near-infrared bands is likely associated with some type of vegetation. Deep blue pixels are likely water. A comparison of the "color" of pixels on the natural or false-color composite and the spatial locations of the cluster category on the image map can reveal the actual land-cover category.

Cospectral plots are created by plotting the mean location of each cluster on an *X-Y* graph where the brightness values of the cluster in two bands are depicted by the *X* and *Y* axes (Figure 1). A favorite cospectral plot used by remote sensing analysts is created with brightness values imaged in the red band depicted by the *X*-axis and brightness values imaged in the near-infrared band depicted by the *Y*-axis. Plotting the scatter of pixels or cluster means will produce a red and near-infrared distribution. Pixels or cluster means representing clear water will be located in the lower left corner because these categories reflect low amounts of red and near-infrared energy. Dry soil and concrete will reflect a large amount of both red and near-infrared energy and will appear at the upper right portion of the plot. An imaginary line connecting these two types of phenomena represents the "soil line" and is generally indicative of land cover devoid of vegetation. Pixels or cluster means representing various amounts and types of vegetation

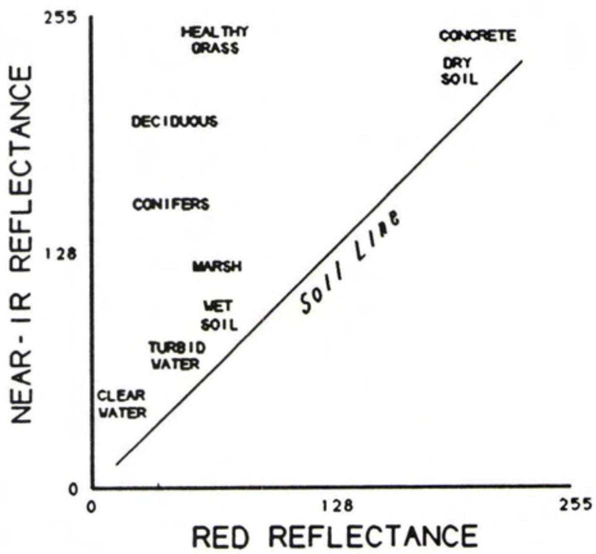

FIG. 1. Near-infrared and red spectral space depicted on a cospectral plot. The major land-cover regions of this two-band plot are labeled.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 55, No. 5, May 1989, pp. 613–619.

0099-1112/89/5505–613$02.25/0

on the surface will appear to the left of the soil line. This typical configuration of land-cover categories is not only of value in cluster labeling, but also in the development of vegetation indices (Richardson and Weigand, 1977; Perry and Lautenshlager, 1984).

Labeling of clusters is facilitated by a visual analysis of the location of cluster means plotted on the red and near-infrared cospectral plot, noting their location with the familiar regions in cospectral space, such as bare soil, water, and healthy vegetation. The cospectral plot is also used as a tool to analyze the movement of multispectral phenomena in change detection or phenology studies (Jensen, 1981; Curran, 1985; Kauth and Thomas, 1976) and to communicate feature space related discoveries to others in presentations and papers.

In all of these applications of cospectral plots, the multispectral *location* and *proximity* of a cluster to other clusters are important cues to the labeling of clusters and identifying relationships between land-cover phenomena. As stated previously, the actual land cover of a cluster may be inferred from the cluster's cospectral location on a red and near-infrared cospectral plot. Also, clusters located in close proximity to one another in multispectral space are likely of the same or similar land-cover type. The land-cover type of an unlabeled cluster can, in many instances, be identified by noting its proximity to previously labeled clusters and their land-cover type.

A limitation of the cospectral plot is its inability to display multispectral locations in more than two bands. Cluster analyses typically use three or more bands; thus, analyzing the feature space locations of clusters would require a number of cospectral plots. Others have addressed this graphic dimensionality problem as it applies to training classes of a supervised classification in two- and synthetic* three-dimensional space (Jensen, 1979; Anuta, 1977; Robinove, 1977). Jensen (1979) provides an excellent discussion of these graphic methods for depicting the mean location and variance of each training class.

This article describes graphic methods for portraying the location of multispectral cluster means in n-dimensional feature space. Monocular depth cues used in human vision are described and it is shown how they may be used to create a synthetic three-dimensional space. Stereo images of three-dimensional spectral space may also be constructed for depicting cluster locations. The additive primary hues of color can be used in conjunction with the X-Y location on a plot and the typical vision cues to depict clusters in synthetic six-dimensional space. The use of these cues is illustrated in several following black-and-white and color examples shown to depict the improvement in analyzing remotely sensed phenomena in feature space.

METHODS OF IMPLEMENTING VISUAL CUES

Monocular depth cues have been used for some time in computer graphics and cartography to create synthetic three-dimensional surface plots and to portray a visual hierarchy on planimetric maps. The primary monocular depth cues are *relative size, occlusion, convergence of parallel lines,* and *brightness* (Tsotsos, 1984; Foley and Van Dam, 1984). Objects farther from the observer appear smaller than objects of the same size that are closer to the observer. Also, closer objects obscure or occlude objects farther away. Parallel lines appear to converge as they recede into the background. Finally, closer objects appear brighter than objects far away. These monocular vision cues can be used to depict multispectral cluster locations on high contrast black-and-white or continuous tone color graphics.

*The display of three dimensions on a two-dimensional surface is regarded as synthetic because two different perspectives of the same surface (i.e., stereoviewing) are actually required to produce a visual three-dimensional surface.

High Contrast Black-and-White Graphics

The two-band location of a cluster is typically depicted on a cospectral plot by (1) a cluster number and a small dot, or (2) simply a cluster number. An example of cospectral plots of 49 clusters generated from a cluster analysis of Charleston, South Carolina imaged by the Landsat Thematic Mapper (TM) sensor is shown in Figures 2a and 2b (a false color composite of the study area is shown in Plate 1). These 49 clusters were identified using the green, red, and near-infrared bands (i.e., TM bands 2, 3, and 4) of the Thematic Mapper. The two-band location of

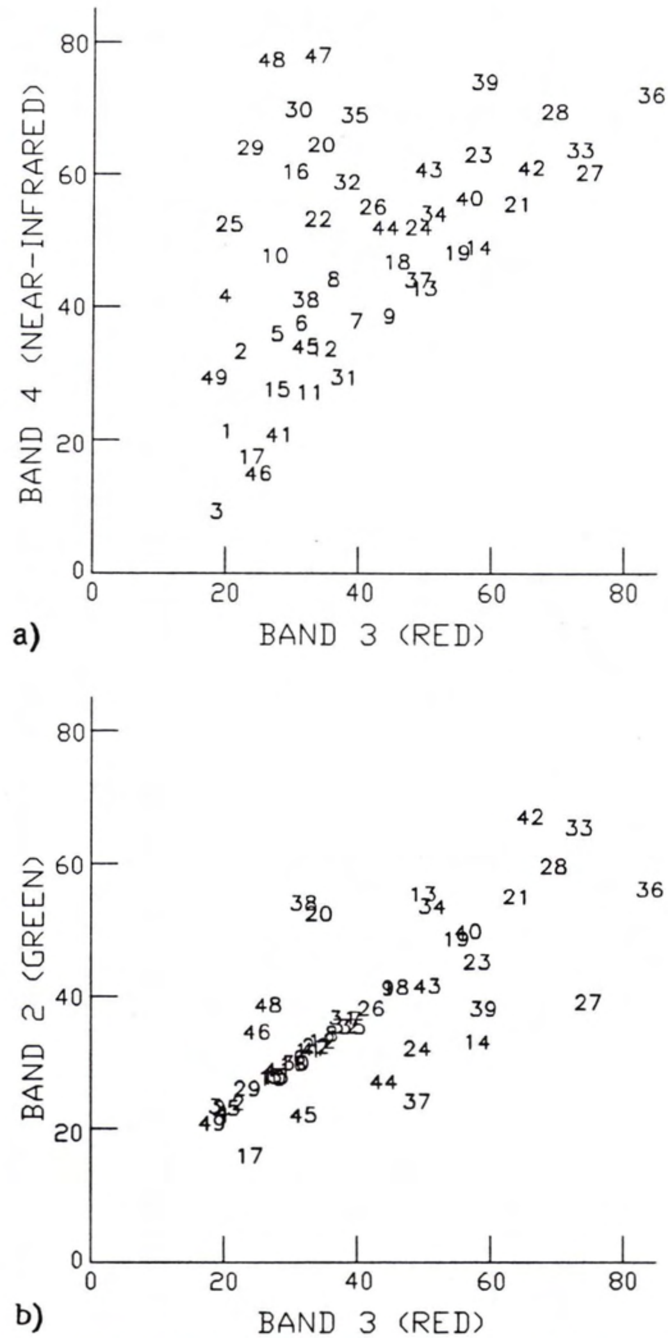

FIG. 2. Cospectral plots of the 49 cluster means portrayed in (a) red and infrared space, and (b) red and green space. Each cluster is identified by a nominal one-or two-digit numeric value. The 49 cluster means were generated from a cluster analysis using three TM bands (i.e., bands 2, 3, and 4).

each cluster is symbolized by the location of the numeric label on the *X-Y* graph. For example, cluster number 3 depicts a mean location of pixels with a brightness value of approximately 20 in the red band, 23 in the green band, and 10 in the near-infrared band.

Spectral location and proximity between clusters in two-band space may easily be discerned from a visual analysis of the clusters in either cospectral plot in Figure 2. However, the clusters may be close in proximity in two-band space but far from one another in another band (such as cluster pair 27 and 33 and pair 13 and 37). To visually depict the proximity of the clusters in another band requires an additional cospectral plot. The use of even more than three bands in the cluster analysis complicates the visual analysis by requiring a number of cospectral plots to determine multispectral location and proximity between clusters (e.g., 15 cospectral plots are needed to depict the relative locations of a cluster set created from six bands).

Size and *thickness* have been used successfully in cartography to depict a third dimension, such as totals or percentages of a ratio variable (Dent, 1985). In cartography the size or thickness of the symbol is constructed in proportion to the value of the third dimension. The locations of the clusters in a third remote sensing band may also be shown by varying the size and thickness of the numeric labels used to depict the co-spectral location of the clusters. The three axes' values of the three-dimensional spectral space are illustrated in Figure 3. Normal viewing of the tri-spectral plot looks "down" the *Z*-axis; thus, the *Z*-axis is not seen. Scaling of the numeral size is performed by simple linear scaling:

$$\text{Size} = (BV_{ib}/\text{Max}PBV) * \text{MaxSize}$$

where Size = the numeral size,
BV_{ib} = brightness value in class_i for band_b depicted by the *Z*-axis,
Max*PBV* = maximum possible brightness value, and
MaxSize = Maximum numeral size.

The numeral size (*Size*) and maximum numeral size (*MaxSize*) desired are in the units of the output device, such as inches for a pen plotter or pixels for a raster display device. The maximum possible brightness value for the sensor collecting the imagery, such as 255 for the Landsat Thematic Mapper and 1024 for the AVHRR sensor, is *MaxPBV*.

By depicting cluster labels farther from the viewer (i.e., with lower brightness values in the *Z*-band) with smaller numeric labels, the relative proximity of the clusters in the third band may be visually interpreted on this tri-spectral plot (Figure 4). Now cluster pair 27 and 33 and pair 13 and 37 are seen as having like brightness values in bands 3 and 4 (as determined by *X-Y* locations) but different brightness values in band 2 (indicated by numeral size). Cluster 34 and 40 have similar *X-Y* locations and sizes; thus, they are in close proximity in all three bands.

For emphasizing a cluster group that has a maximum range of brightness values less than the dynamic radiometric range of the sensor, the equation may be modified in a fashion similar to that linear contrast enhancement of an image:

$$\text{Size} = [((BV_{ib} - \text{Min}_{BV})/(\text{Max}_{BV} - \text{Min}_{BV})) * (\text{MaxSize} - \text{MinSize})] + \text{MinSize}$$

where, Size = the numeral size,
BV_{ib} = brightness value in class_i for band_b depicted by the *Z*-axis,
Max_{BV} = Maximum brightness value in scene,
Min_{BV} = Minimum brightness value in scene,
MaxSize = Maximum numeral size, and
MinSize = Minimum numeral size.

This equation will scale the size of all cluster number labels to range from MinSize to MaxSize.

Cartographic research has demonstrated that two or more visual cues depicting the same dimension aids the visual interpretation of maps (Shortridge and Welch, 1982). The thickness of the lines used to construct the numeric labels may be varied in proportion to the distance from the viewer; thus, adding a double visual cue (Figure 5). Clusters with large brightness values (i.e., closer to the viewer) will have thicker

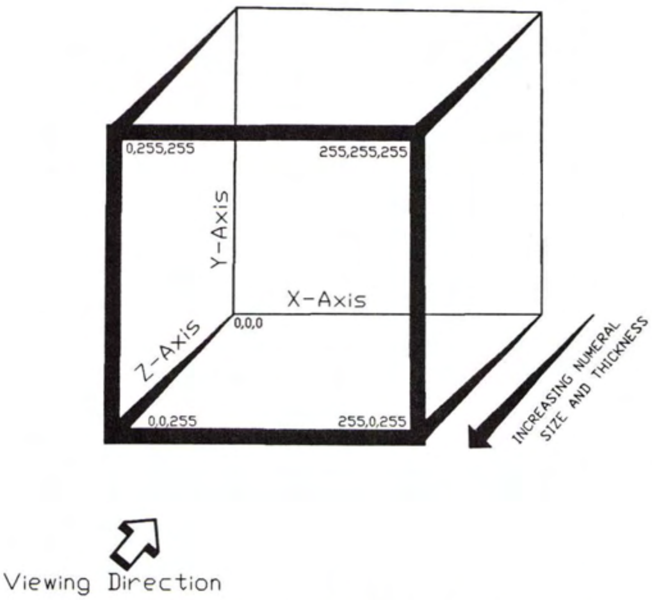

FIG. 3. A synthetic three-dimensional cube showing the origin and orientation of the *X*, *Y*, and *Z* axes used to depict the brightness values of three bands. Phenomena closer to the viewer (i.e., with larger brightness values in the band depicted by the *Z*-axis) are constructed with numerals of a larger size and thickness. Note: In all *n*-dimensional plots (except the stereo plots) the *X-Y-Z* space is not rotated as depicted in this figure.

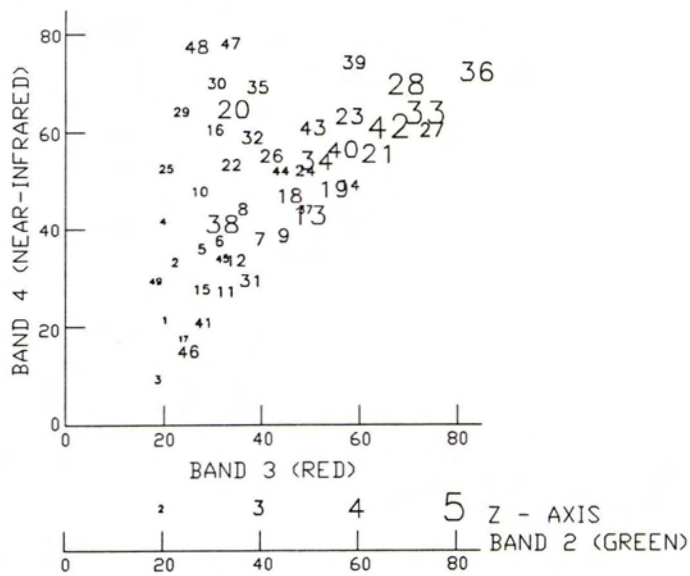

FIG. 4. Cospectral plots of the 49 cluster means portrayed in red, infrared, and green space using the *X-Y* location to depict bands 3 and 4 while the size of the numeral depicts band 2. The 49 cluster means are the same as those in Figure 2.

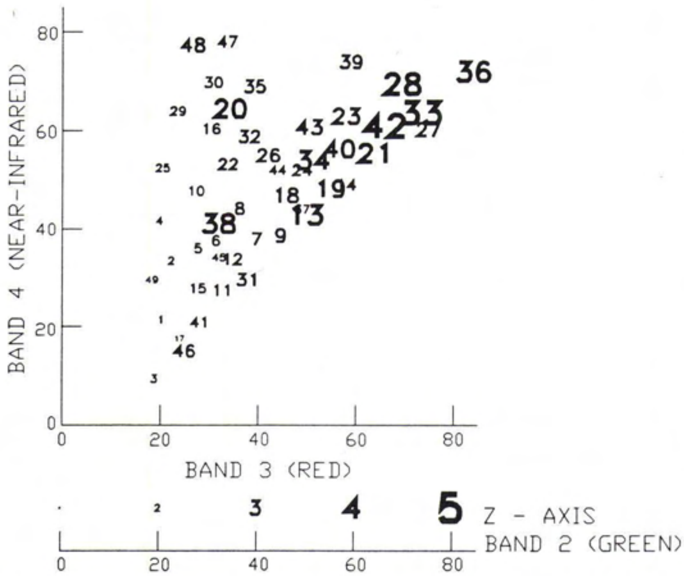

FIG. 5. Cospectral plots of the 49 cluster means portrayed in red, near-infrared, and green space using the *X-Y* location to depict bands 3 and 4 while the size and thickness of the numeral depicts band 2. The 49 cluster means are the same as those in previous figures.

lines for the labels in addition to larger numerals than clusters farther from the viewer. Scaling of the thickness is performed using inverse linear scaling in the same manner as for the numeral size described above.

The cluster locations may be viewed from a vantage point other than a simple frontal view of the *X-Y* axes by using three-dimensional rotation formulae. The feature space may be rotated about any of the axes, although rotation around the *X* and *Y* axes normally provides a sufficient number of viewpoints. The size and thickness of the cluster labels are drawn inversely proportional to the *Z*-values of the rotated cluster means rather than inversely proportional to the brightness value in the band depicted by the *Z*-axis. Rotation about the *X*-axis *t* radians and the *Y*-axis *s* radians is implemented by the following equation (after Foley and Van Dam, 1977):

$$[X\ Y\ Z\ 1] = \begin{vmatrix} BV_x \\ BV_y \\ BV_z \\ 1 \end{vmatrix} * \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos t & -\sin t & 0 \\ 0 & \sin t & \cos t & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} * \begin{vmatrix} \cos s & 0 & \sin s & 0 \\ 0 & 1 & 0 & 0 \\ -\sin s & 0 & \cos s & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

Negative signs are used for counterclockwise rotation and positive signs for clockwise rotation.

A stereoscopic view of the clusters in three-dimensional space may be created using a hand-held stereoscope and two images of the feature space generated with slightly different vantage points. Two different images of the feature space created with a difference of two or three degrees rotation about the *Y*-axis is sufficient for stereoscopic viewing. As in stereo photography, each graphic in the stereo-pair is placed about 6.35 centimetres (2.5 inches) apart and viewed through a hand-held stereoscope. A stereopair of the 49 clusters with rotations about the *Y*-axis of 0 and −3 degrees is illustrated in Figure 6. Relative distances between clusters is easily determined from the stereopair.

CONTINUOUS TONE COLOR GRAPHICS

The addition of *brightness, occlusion,* and *color* can assist in the visual interpretation of the third dimension on a tri-spectral plot. The third band can also be shown by the relative brightness (i.e., dark to light tones) of the numerals depicting the cluster location. Brightness cannot be easily shown on high-contrast black-and-while hardcopy devices, such as dot matrix printers or pen plotters, but can be created on a cathode ray tube and subsequently captured on film. The low spatial resolution of most cathode ray tubes prohibits the use of the thickness of lines as a depth cue. However, size can still be used as a cue. On a white background, darker objects appear to be in the foreground and lighter objects appear in the background. On a black background, lighter objects are foreground while darker objects are background. The brightness of each numeral is varied in an inverse proportion to the brightness value depicted by the Z-band if the background is black. By sorting the numerals from "back" to "front" and plotting the most distant labels first, the visual cue of occlusion is also included in the three-dimensional perception process.

Color (created by varying the brightness of the red, green, and blue hues) can be used as a double cue to make the tri-spectral plot more interpretable. As discussed previously, the remote sensing analyst typically uses color as a visual cue to identify land cover in the interpretation of a color composite (e.g., magenta is normally associated with vegetation and dark blue is related to water on a false color composite). Pixels depicted in different colors are likely to represent different land cover. The more different the colors, the less likely the pixels represent the same land-cover category. Research in color theory indicates that the typical human can distinguish some 350,000 different colors (Foley and Van Dam, 1984). Each of the three bands depicted by an axis location on a tri-spectral plot can also be depicted by one of the three additive hues – red, green, or blue. For example, if the red hue is used to depict the near-infrared band (e.g., TM band 4), then a cluster mean with a large brightness value in near-infrared will be constructed on the graphic as a number with a large amount of red hue. The green and blue hues are similarly used for the two other bands. The resulting color of the cluster label is actually a composite of the contribution of all three hues, representing the multispectral location in the tri-space of the three bands depicted by the hues (Figure 7). The analyst may then determine general multispectral space locations and relative distances between cluster means in tri-space.

To accurately use color to depict spectral space locations and the resultant distances between locations requires correcting for the non-linear response of the human eye to the intensity of light. The eye is sensitive to ratios of intensity levels rather than the absolute differences. For instance, a difference of 10 to 11 in intensity is visually equivalent to a difference of 100 to 110. The result of the non-linear perception of intensities would give an impression that two clusters with brightness values of 10 and 11 are as far apart in spectral space as the two clusters with brightness values of 100 and 110, an incorrect perception of spectral space distance as depicted by intensities. Assuming the eye responds in a similar fashion to relative differences in each of the additive primaries, correcting for the non-linear response of the eye to intensity is performed by (after Foley and Van Dam, 1984)

$$\text{CInten} = \text{TRUNC}(r^{BV} * \text{MinInten})$$

where
- CInten = corrected intensity to display the given hue,
- BV = brightness value of the cluster mean in the band depicted by the hue,
- MinInten = minimum intensity used to display a brightness value of 0, and
- r = constant for the given data set.

The constant r is computed once for the given set of clusters

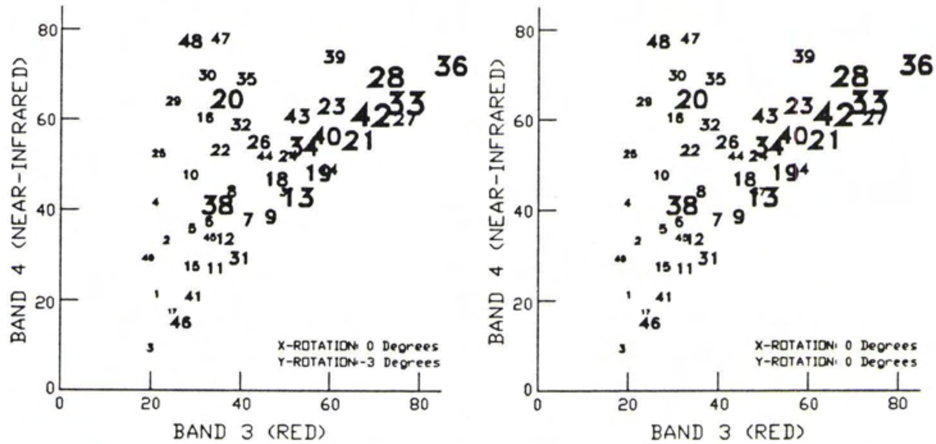

FIG. 6. Synthetic three-dimensional stereopair used to depict the location of the 49 clusters in near-infrared, red, and green space using the *X-Y* location, size, and thickness of numerals, and a rotation about the *Y*-axis. Viewing of this figure may be performed with a simple hand-held stereoscope. The 49 cluster means are the same as those in previous figures.

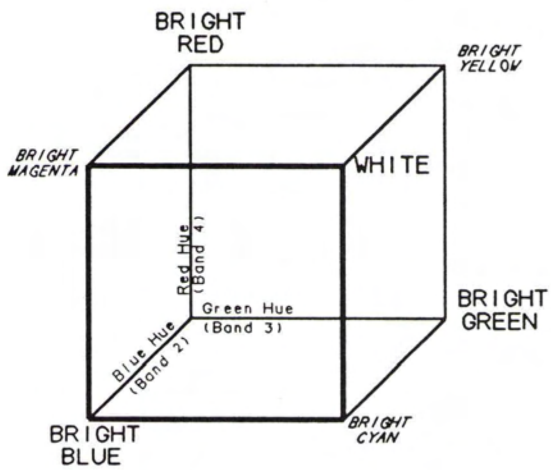

FIG. 7. The RGB color cube in a typical configuration for depicting the TM bands 2, 3, and 4 with blue, green, and red, respectively. All colors in the cube are created by varying the amounts of red, green, and blue hues in relation to the brightness values in the remotely sensed band depicted by the hues.

and the desired minimum and maximum intensities for all three hues to use in displaying these cluster labels:

$$r = (\text{MaxInten}/\text{MinInten})^{1.0/\text{MaxPBV}}$$

where MinInten = minimum intensity used to display a brightness value of 0,
MaxInten = maximum intensity used to display a brightness value of MaxPBV, and
MaxPBV = maximum possible brightness value (e.g., 255, 1024).

In many remote sensing classification applications, cluster means may represent very low mean brightness values (e.g., 5 or 10). If an intensity equivalent to the cluster mean brightness value is used to construct the cluster label, the label may not be discernable on a black background and would be invisible. A minimum intensity (MinInten) can be used to depict low brightness values in a cluster mean set, thus, insuring that all cluster labels will be visible on the graphic. As an example, suppose the maximum displayable intensity level is 255, the minimum intensity we would like to display a cluster mean of 0 is 20, and the maximum brightness value in a cluster set is 85. The value of *r* would be 1.0304. A brightness value of 0 in a band for a cluster would be displayed with an intensity of $1.0304^0 * 20 = 20$ and a brightness value of 40 would have a corresponding intensity of $1.0304^{40} * 20 = 66$. The corrected intensities allow the analyst to perceive "true" locations and relative distance between cluster means in spectral space as depicted by the intensities of the three hues constructing the cluster labels.

The corrected intensity for each band is computed from the original brightness values (BVs) of the three bands depicted by the three primaries. In Plate 2, the three TM bands of red, near-infrared, and green, are depicted by the *X*, *Y*, and *Z* axes as well as the amount of green, red, and blue hues, respectively. The background is black, so the hue for each cluster label is illuminated with an intensity relative (using the corrected intensity formula) to the reflectance in the band the hue depicts. The resulting color combination of the numerals is the same as the pixels of the cluster it represents on a false-color composite (see Plate 1). Clusters representative of healthy vegetation (e.g., clusters 47 and 48) are located to the upper left of the soil line and also depicted in bright magenta. Water clusters (clusters 17 and 46) have a deep blue color and are located in the lower-left corner of the near-infrared and red distribution. However, notice that not only is cluster 46 located at a slightly different position than cluster 17 is in three-and four-band space, but it also indicates a higher reflectance in band 2 (inferred from the size and color). Cluster 46 actually represents the shallow water areas in Charleston Harbor (i.e., higher reflectance in the green band because of water penetration and bottom reflectance and turbidity). Cluster 17 contains the deep water pixels.

The graphical techniques discussed above are significant improvements in the interpretation of cluster locations in three-band feature space. However, they do not help in the analysis of clusters created from using four or more bands. By using color in a different manner, a synthetic six-dimensional space can be created. The *X-Y* locations, monocular depth cue of size, and the three additive primary hues can each represent a separate band's brightness value. As in previous examples, three bands are depicted by their *X-Y* location and numeral size. Three additional bands are depicted by the amount of red, green, and blue hues. Forty-nine clusters generated from a separate cluster

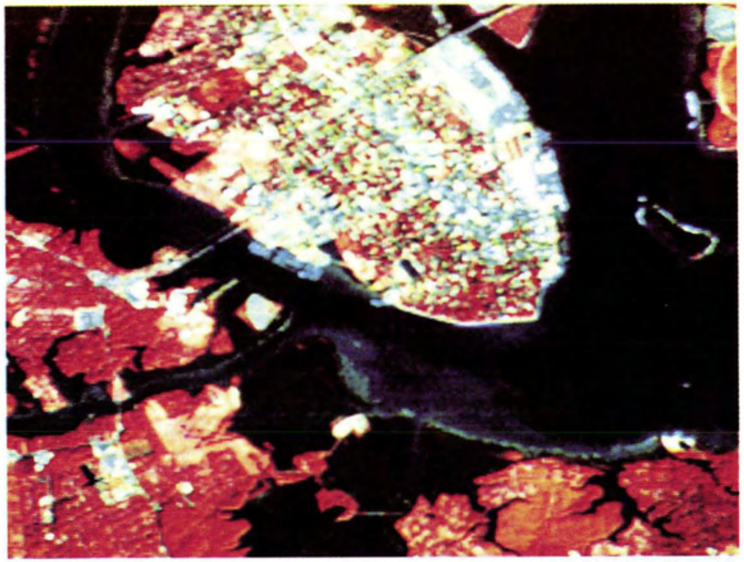

PLATE 1. A false color composite of the study region containing the 49 land-cover cluster sets depicted in the *n*-dimensional plots. The false color composite was created using TM bands 4, 3, and 2 filtered through the red, green, and blue guns, respectively.

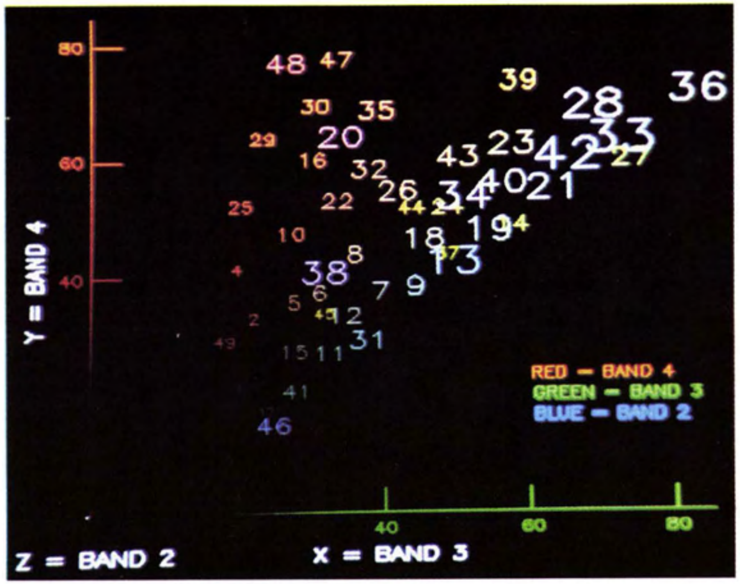

PLATE 2. The 49 clusters are depicted in a trispectral plot with the *Y*, *X*, and size cues indicating the multispectral brightness value in bands 4, 3, and 2 while the red, green, and blue hues also indicate the brightness value in bands 4, 3, and 2, respectively. The 49 cluster means are the same as those in previous figures.

PLATE 3. A six-dimensional plot of 49 clusters with the *Y*, *X*, and size cues depicting the multispectral brightness value in bands 5, 1, and 7 while the red, green, and blue hues indicate the brightness value in bands 4, 3, and 2, respectively. The 49 cluster means were generated from a cluster analysis using six TM bands (i.e., bands 1, 2, 3, 4, 5, and 7).

analysis of the Charleston image using *all six* visible, near-, and middle-infrared bands are shown in Plate 3. Bands 1,5, and 7 are depicted by the *X, Y* and *Z* axes. The red, green, and blue hues used to express the brightness values in bands 4, 3, and 2, respectively. Using these six cues may be somewhat complicated to the interpretation of the viewer at first. However, similar to the use of colors in Plate 2, the color of each cluster label is approximately the same as the pixels the cluster represents on a false-color composite. For instance, healthy vegetation clusters 11, 41, and 45 are depicted in bright magenta – the color the pixels the clusters represent would appear on a typical false-color composite. Bare/soil and concrete clusters (e.g., 18, 19, 25) are almost white. Notice that the bare/soil and concrete clusters generally appear in a similar color and *X-Y* location and size. These clusters may very well depict the same land cover and could be grouped together. The three healthy vegetation clusters are somewhat different. Clusters 41 and 45 are similar with respect to color (bands 2, 3, and 4 space) and *X*-location (band 1 space). However, cluster 45 reflects much less infrared energy in band 5 and band 7 than cluster 41, as noted by the *Y*-location and size of the label. Other differences in spectral space are indicated by color alone, such as clusters 10, 16, and 48, and by clusters 23 and 25.

SOFTWARE IMPLEMENTATION

A menu-driven software package was developed to implement the various vision cues discussed above and to generate hardcopy output. Text files in AutoCAD or Generic CADD format were created by the software (AutoDesk, 1987; Generic Software, 1987). The CAD packages input the graphic image in the form of text files and communicate with hardcopy output devices to construct the fundamental lines and numerals required to depict the graphic. Also, the CAD packages allowed the user to interactively add titles and other text to the graphic. Color plots were created using a color monitor and a Revolution Number Nine graphics card with a spatial resolution of 512 columns by 512 rows, having capabilities of producing 16.8 million different colors. Copies of the executable software are available without charge from the authors.

SUMMARY

A number of visual cues have been described to depict the location of clusters in *n*-dimensional feature space. The size and thickness of the numeric labels can depict the relative location of each cluster in a third band on a black-and-white tri-spectral plot. Stereo pairs may be generated from three-dimensional rotations of the feature space and two different viewing perspectives. The addition of color may be incorporated to synthetically depict the clusters in up to six-band spectral space. These improvements in the display of clusters in feature space will assist the analyst in the interpretation of the spectral properties of remotely sensed phenomena.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Burl Naugle for his assistance in programming the high resolution graphics card. This article was supported by grants from the Undergraduate Research Opportunity Program and the Council on Teaching at the University of Colorado at Boulder.

REFERENCES

Anuta, P. E., 1977. Computer Assisted Analysis Techniques for Remote Sensing Data Interpretation, *Geophysics*. 42(3):468–481.

AutoDesk, Inc., 1987. *The AutoCAD Drafting Package: Reference Manual*. AutoDesk, Inc: Sausalito, California.

Curran, Paul J., 1985. *Principles of Remote Sensing*, Longman Group Limited: Essex, England, 282 p.

Dent, Borden D., 1985. *Principles of Thematic Map Design*, Addison-Wesley: Reading, Massachussets, 398 p.

Foley, J. D., and A. V. Dam, 1984. *Fundamentals of Interactive Computer Graphics*, Addison-Wesley: Reading, Massachusetts, 664 p.

Generic Software, 1987. *Generic CADD 3.0: Operator's Manual*, Generic Software, Inc.: Redmond, Washington.

Jensen, J. R., 1979. Computer Graphic Feature Analysis and Selection, *Photogrammetric Engineering and Remote Sensing*. 45(11):1507–1512.

———, 1981. Urban Change Detection Mapping Using Landsat Digital Data, *The American Cartographer*. 8(2):127–147.

———, 1986. *Introductory Digital Image Processing: A Remote Sensing Perspective*, Prentice-Hall, Inc.: Princeton, New Jersey, 380 p.

Kauth, R. J., and G. S. Thomas, 1976. The Tassled Cap A-Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by Landsat. *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, West Lafayette, Indiana, pp. 4B41–4B51.

Perry, C. R., and L. F. Lautenshlager, 1984. Functional Equivalence of Spectral Vegetation Indices, *Remote Sensing of Environment*. 8:169–182.

Richardson, A. J., and C. L. Weigand, 1977. Distinguishing Vegetation from Soil Background Information, *Remote Sensing of Environment*. 8:307–312.

Robinove, C. J. 1977. A Radiometric Interpretive Legend for Landsat Digital Thematic Maps, *Photogrammetric Engineering and Remote Sensing*. 43(5):593–594.

Shortridge, Barbara G., and Robert B. Welch, 1982. The Effect of Stimulus Redundancy on the Discrimination of Town Size on Maps, *The American Cartographer*. 9(1):69–80.

Tsotsos, John K., 1984. Knowledge and The Visual Process: Content, Form, and Use, *Pattern Recognition*. 17(1):13-27.

(Received 30 August 1988; revised and accepted 11 January 1989).

New Sustaining Member

AT&T's Digital Record Systems

225 Schilling Circle, Cockeysville, MD 21030
Telephone 301-584-4176; fax 301-584-4207

AT&T DIGITAL RECORD SYSTEMS provides customized service solutions for Land Information Systems projects. The range of solutions applies to any or all of the following service activities: feasibility studies, concept definition, user needs analysis, requirements definition, system design, implementation plan, project prototype, alternative scenarios, database design, facility implementation, software integration, full system data acquisition, and application enhancement. We even offer a variety of LIS/GIS financing plans. And, under AT&T Systems Integration Plan, we will guarantee the success of your project. Call 1-800-2 GET DRS.