Comparison of Three Different Methods to Merge Multiresolution and Multispectral Data: Landsat TM and SPOT Panchromatic

Pat S. Chavez, Jr., Stuart C. Sides, and *Jeffrey A. Anderson*
U. S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001

ABSTRACT: The merging of multisensor image data is becoming a widely used procedure because of the complementary nature of various data sets. Ideally, the method used to merge data sets with high-spatial and high-spectral resolution should not distort the spectral characteristics of the high-spectral resolution data. This paper compares the results of three different methods used to merge the information contents of the Landsat Thematic Mapper (TM) and Satellite Pour l' Observation de la Terre (SPOT) panchromatic data. The comparison is based on spectral characteristics and is made using statistical, visual, and graphical analyses of the results.

The three methods used to merge the information contents of the Landsat TM and SPOT panchromatic data were the Hue-Intensity-Saturation (HIS), Principal Component Analysis (PCA), and High-Pass Filter (HPF) procedures. The HIS method distorted the spectral characteristics of the data the most. The HPF method distorted the spectral characteristics the least; the distortions were minimal and difficult to detect.

INTRODUCTION

THE MERGING OF MULTISENSOR IMAGE DATA is becoming a widely used procedure because of the complementary nature of various data sets. For example, the 10-m single band Satellite Pour l' Observation de la Terre (SPOT) panchromatic image data complements the 30-m image data from the six reflective bands of the Landsat Thematic Mapper (TM) (Welch and Ehlers, 1987; Chavez and Bowell, 1988). Merging information from different imaging sensors involves two distinct steps (Chavez and Bowell, 1988). First, the digital images from both sensors are geometrically registered to one another. Next, the information contents—spatial and spectral—are mixed to generate a single data set that contains the best of both sets. The geometric registration is a straightforward process. However, the actual mixing of information into a single data set is not as straightforward. Ideally, the method used to merge data sets with high-spatial resolution and high-spectral resolution should not distort the spectral characteristics of the high-spectral resolution data. Not distorting the spectral characteristics of the data is important for calibration purposes and for ensuring that targets that are spectrally separable in the original data are still separable in the merged data set.

The objective of this paper is to present the results of the three different methods used to merge the information contents of Landsat TM and SPOT panchromatic data and to compare the spectral characeristics of the results with the original Landsat TM spectral characteristics. The results are compared statistically, visually, and graphically. In the paper, the terms TM and PAN are used in place of Landsat TM and SPOT panchromatic, respectively.

DATA CHARACTERISTICS AND TEST SITE

The TM data were collected on 5 April 1986 by Landsat-5. The PAN data were collected on 3 April 1986. The test site is approximately 10 km southwest of Phoenix, Arizona, and covers mostly an agricultural environment with a few small urban areas and a portion of the Salt River. The winter wheat crop was nearing maturity and almost ready for harvesting. The other major mature crop was alfalfa. Cotton, also a major crop in this area, is planted in April so there was no visible biomass. Many of the fields either were being prepared for planting or were just planted with summer fruits and vegetables. A few isolated citrus groves are also in the area.

Any use of trade, product, or firm names in this publication is for disireptive purposes only and does not imply endorsement by the U.S. Government.

METHODS

The geometric registration process used was straightforward. First, the TM data are digitally enlarged by a factor of three in both directions to generate a pixel size similar to the PAN data. These results are smoothed with a 3 by 3 low-pass filter to eliminate the blockiness introduced by the 3X digital enlargement (Chavez *et al.*, 1984; Chavez, 1986). Next, image-to-image control points are interactively selected to register the TM data onto the PAN data (that is, the TM image was the slave and the PAN image was the master). The three methods used to merge the information contents of both data sets were the Hue-Intensity-Saturation (HIS), Principal Component Analysis (PCA), and High-Pass Filter (HPF) procedures.

HIS

HIS is one of the most often used methods to merge multisensor image data. Among the first users of this procedure were Haydn *et al.*, (1982). They merged Landsat Multispectral Scanner (MSS) with Return Beam Vidicon (RBV) data and Landsat MSS with Heat Capacity Mapping Mission data. The HIS method has also been used to merge TM and PAN data (Welch and Ehlers, 1987) and SPOT multispectral and PAN data (Thormodsgard and Feuquay, 1987). The method uses three bands of the lower spatial resolution data set and transforms these data into HIS space. The higher spatial resolution image, PAN in some of these cases, has a contrast stretch applied so that it has approximately the same variance and average as the intensity component image. The stretched, higher spatial resolution image replaces the intensity component image before the images are retransformed back into the original space. A main justification used for replacing the intensity component with the stretched higher spatial resolution image is that the two images are approximately equal to each other spectrally.

PCA

The procedure to merge the TM and PAN data using the PCA method is similar to that of the HIS method. The TM data, either

0099-1112/91/5703-295$03.00/0

three or all six reflective TM bands, are used as input to a principal component analysis procedure. As with the HIS method, the PAN data are stretched to have approximately the same variance and average as the first principal component. The results of the stretched PAN data replace the first principal component image before the data are retransformed back into the original space. The justification used for replacing the first principal component image with the stretched PAN data is that the PAN data are approximately equal to the first principal component image. This assumption is made because the first principal component image will have the information that is common to all the bands used as input to PCA, while spectral information unique to any of the bands is mapped to the other components (Chavez and Kwarteng, 1989). The TM data spectrally overlap the PAN data and so its spectral information will be represented in the first principal component image.

HPF

A data compression and reconstruction technique that uses a mixture of spatial resolutions for a multispectral scanner is described by Schowengerdt (1980). He discusses a procedure to extrapolate edge information from a high-resolution band to lower spatial resolution bands. Landsat MSS image data that have been compressed are used to reconstruct the original resolution in a simulation test.

The HPF method discussed in this paper was previously used by Chavez to merge TM data with both digitized National High Altitude Program data (Chavez, 1986) and PAN data (Chavez and Bowell, 1988). In the HPF method the higher spatial resolution data, PAN in this case, have a small high-pass spatial filter applied. The results of the small high-pass filter contain the high-frequency component/information that is related mostly to spatial information. The spatial filter removes most of the spectral information. The HPF results are added, pixel by pixel, to the lower spatial resolution, but higher spectral resolution, data set. This process merges the spatial information of the higher spatial resolution data set with the spectral information of the higher spectral resolution data set.

ANALYSES AND COMPARISONS

The spectral characteristics in the data sets generated by using these three methods were compared with the spectral characteristics of the original TM data. The comparisons were made statistically, visually, and graphically.

STATISTICAL COMPARISON

A basic assumption made by both the HIS and PCA methods is that the PAN data are very similar to the intensity and first principal component images, respectively. Therefore, the PAN data can replace either of these two images in the retransformation of the data back into the original image space. This assumption was investigated both statistically and visually.

The correlation coefficients between the PAN data and the intensity and first principal component images the PAN data were going to replace were computed. Three separate subgroups of the TM data (TM bands 1, 3, and 4; TM bands 1, 4, and 5; and TM bands 1, 3, 4, and 5) were used. The HIS method was applied only to the first two subgroups because this method cannot accept four bands as input. Table 1 shows the correlation coefficients for the PAN data versus the intensity and first principal component images generated from these subgroups of bands. The values in Table 1 show the first principal component images are more correlated to the PAN data than are the intensity images. In fact, the intensity image of TM bands 1, 4, and 5 has a much lower correlation with the PAN data than does the first principal component image generated with these same bands. Both first principal component images generated with the two separate three-band subgroups have similar correlation with the PAN data; this is not the case for the intensity images. The correlation between the PAN data and the first principal component image generated with the four-band subgroup also is high. This correlation is slightly lower than the correlation between the first principal component image generated with TM bands 1, 3, and 4 and the PAN data, but is higher than the correlation between the PAN data and the first principal component image generated with TM bands 1, 4, and 5. This result may be because the spectral window of TM band 5 is not close to, and does not overlap with, the PAN data, and TM band 3, which overlaps the PAN data spectrally, is not used. The correlation of bands that have spectral windows adjacent or close to each other are usually higher than those that are not as close (Chavez *et al.*, 1984). The correlation coefficients between the PAN data and TM bands 1 and 3 are 0.857 and 0.901, respectively (the spectral windows of the PAN and TM band 3 overlap). Some differences in the correlation between the PAN and TM data are caused by the difference in spatial resolution. However, these differences are usually small in comparison to those caused by the spectral window differences.

Difference images generated by subtracting the HIS, PCA, and HPF merged results from the original TM bands 1, 4, and 5 were also used in the analysis. By HIS, PCA, and HPF merged results we mean the equivalent TM bands after the data have been merged using the corresponding method. For example, the three TM bands have the HIS procedure applied, then the I is replaced with the stretched PAN data, followed by the re-transformation of the H, PAN, and S data back into the original TM space to create the three TM bands again with the PAN data merged. These results are the ones subtracted from the original TM bands. Table 2 shows the standard deviations and percent of pixels

TABLE 1. THE CORRELATION COEFFICIENTS OF THE PAN DATA VERSUS THE INTENSITY AND FIRST PRINCIPAL COMPONENT IMAGES GENERATED WITH TM BANDS 1, 3, AND 4 AND TM BANDS 1, 4, AND 5. THE CORRELATION COEFFICIENT OF THE PAN DATA VERSUS THE FIRST PRINCIPAL COMPONENT IMAGE OF TM BANDS 1, 3, 4, AND 5 IS ALSO GIVEN.

	I TM 1,3,4	I TM 1,4,5	PC1 TM 1,3,4	PC1 TM 1,4,5	PC1 TM 1,3,4,5
PAN	0.785	0.528	0.872	0.824	0.866

TABLE 2. THE STANDARD DEVIATIONS AND PERCENT OF PIXELS WITH A DIFFERENCE OF ONE OR ZERO DNS OF THE DIFFERENCE IMAGES GENERATED BY SUBTRACTING THE HIS, PCA, AND HPF MERGED RESULTS FROM THE ORIGINAL TM BANDS 1, 4, AND 5.

Standard Deviation			
	Original minus HIS	Original minus PCA	Original minus HPF
TM1	16.8	9.2	7.4
TM4	18.1	6.0	7.5
TM5	17.7	13.6	7.5

Percent of Pixels With Differences of One or Zero DN*			
	Original minus HIS	Original minus PCA	Original minus HPF
TM1	6.6%	16.4%	38.8%
TM4	8.6	34.5	38.7
TM5	6.6	11.8	38.7

*The larger the percent of pixel with no change, the more similar the original image and results are spectrally.

with a difference of one or zero digital numbers (DNs) of these difference results. The HIS difference images had the largest variance. The HPF difference images had the smallest. These results mean that the HIS method introduced larger changes than either the HPF or PCA methods. The results of the PCA method were in the middle, with the standard deviation values being closer to those of the HPF method. The standard deviation values, combined with the percent of pixels in the difference images with differences of one or zero DNs, show the extent of the effect on the resulting images. The results of the HIS method had the fewest pixels with no change, or only a one DN change, which implies that it affected the most pixels in the image. The HPF results had the largest number of pixels with no change, or only a one DN change, and so the least number of pixels in the image were affected. The PCA results were again in the middle.

Visual Comparison

Both black-and-white and color products were used in the visual analysis. To continue the same sequence used in the statistical analysis, the individual black-and-white prints of the PAN image versus the intensity and first principal component images are shown in Figure 1. The PAN image is Figure 1A; the intensity image of TM bands 1, 3, and 4 is 1B; the intensity image of TM bands 1, 4, and 5 is 1C; the first principal component image of TM bands 1, 3, and 4 is 1D; the first principal component image of TM bands 1, 4, and 5 is 1E; and the first principal component image of TM bands 1, 3, 4, and 5 is 1F. The area shown is approximately 10 by 16 km, and two rectangular windows are marked in the same locations in all six prints to help in the visual analysis and comparison. Notice the differences between the PAN and the other images; recall that the PAN image replaces these other images when merging the information contents with either the HIS or PCA methods. The intensity images, especially the one generated from TM bands 1, 4, and 5, differ from the PAN image more than the equivalent first principal component images. The PAN data have 10-m resolution and the TM data have 30-m resolution.

Figures 2, 3, and 4 show the images generated by subtracting the merged PAN and TM results from the original TM data. These figures show the black-and-white prints generated from the difference images of TM bands 1, 4, and 5. These prints show how each of the three different methods distorted the original brightness and spectral characteristics in the given spectral band. Figure 2 shows the original images minus the HIS results; Figure 3 shows the original images minus the PCA results and Figure 4 shows the original image minus the HPF results. The HIS results show not only more changes but the changes are also larger (these results agree with the statistical analysis, which showed a much larger variance in the difference images). The PCA results do not show as many changes as the HIS results. The contrast stretches used for visual presentation on all the data were 1 and 99 percent linear stretches; this gives approximately the same contrast to all the products. Therefore, some of the changes may visually appear as large in the PCA images as in the HIS images, but from the variance differences shown in the statistical section this obviously is not the case. Figure 4 shows the original image minus the HPF results; it has the least overall brightness changes. Most of the large changes are because of edges and small local detail. These data also had a 1 and 99 percent linear contrast stretch for visual analysis, and so the variance shown in the statistical analysis must also be used in the comparison (Table 2).

The final products used in the visual analysis and comparison were color composites generated by using TM bands 1, 4, and 5 as blue, green, and red, respectively. Color composites were generated by using this three-band combination of the original TM data and the HIS, PCA, and HPF results and are shown in Plates 1, 2, 3, and 4, respectively. Rectangular windows at the same locations are added to each of the color composites to help in the visual comparison. A comparison of the HIS, PCA, and HPF composites with the composite of the original TM data shows the color differences. Changes in colors, if they exist, indicate that the spectral characteristics of the given target were distorted or changed by the method used to merge the information of both data sets. For example, in window B two crop types that were easily separable in the original TM data do not appear to be separable in the HIS results.

Graphical Comparison

DN values of TM bands 1, 3, 4, and 5 of five different cover types within the image were used to generate graphs for this comparison. These five cover types are in the five windows shown in the color composites. Averages using a 5- by 5-pixel kernel inside the rectangular windows shown in Plates 1 through 4 were computed. The locations of these kernels, inside the windows, are marked by a 9- by 9-pixel tic mark. The average DN values were used to generate the plots shown in Figure 5. The HIS method is applied to only three bands at a time, and so it has values plotted for only TM bands 1, 4, and 5. Plotted in the graphs shown in Figure 5 are the average DN values for the original TM data and for the HIS, PCA, and the HPF results.

The locations and cover types used to generate the graphs shown in Figure 5 are window A—soils in an open field that are purple in the Plate 1 composite; window B—mature crop that is bright green in the Plate 1 composite; window C—semimature crop that is a dull yellow/green in the Plate 1 composite; window D—small field that is dark blue in the Plate 1 composite; and window E—small area with unknown cover type that has its spectal characteristics dramatically affected by the HIS and PCA methods (yellow/orange in the Plate 1 composite). The graphs show that the HIS method changed the DN values and spectral characteristics the most, followed by the PCA method. The HPF method changed the DN values the least. In fact, the average DN values of the HPF results almost plot on top of the original TM values, which implies very little change in the original values. The plots of the HIS results appear to have a constant positive or negative offset from the original TM data. This result is as expected because the intensity component is equal to the sum of the three original bands. Therefore, when the PAN image replaces the intensity image and the data are retransformed back into the original space, the difference in DN values between the PAN and intensity image will be transferred equally to all three bands (that is, the positive or negative offset will showup in all three bands and will have the same amplitude).

DISCUSSION

The HIS method distorted the spectral characteristics of the data used in this project the most. The reason is because the intensity image that is replaced by the PAN data can be different depending on the TM band combination used (that is, the intensity image of TM bands 1, 3, and 4 is different from the intensity image of TM bands 1, 4, and 5 and both have large differences with the PAN image). Therefore, the assumption that the PAN image is similar to the intensity image is not always valid. Also, the HIS method has the added disadvantage that only three bands can be merged at any one time.

The PCA method also distorted the spectral characteristics of the data, but the distortions were less severe than those in the HIS results. The reason is that the first principal component image is more similar to the PAN image than is the intensity image. The PCA method can merge the PAN data with all the TM bands at the same time. Also, if subgroups of three bands are used, the resulting first principal component images are more highly correlated with each other than are the intensity

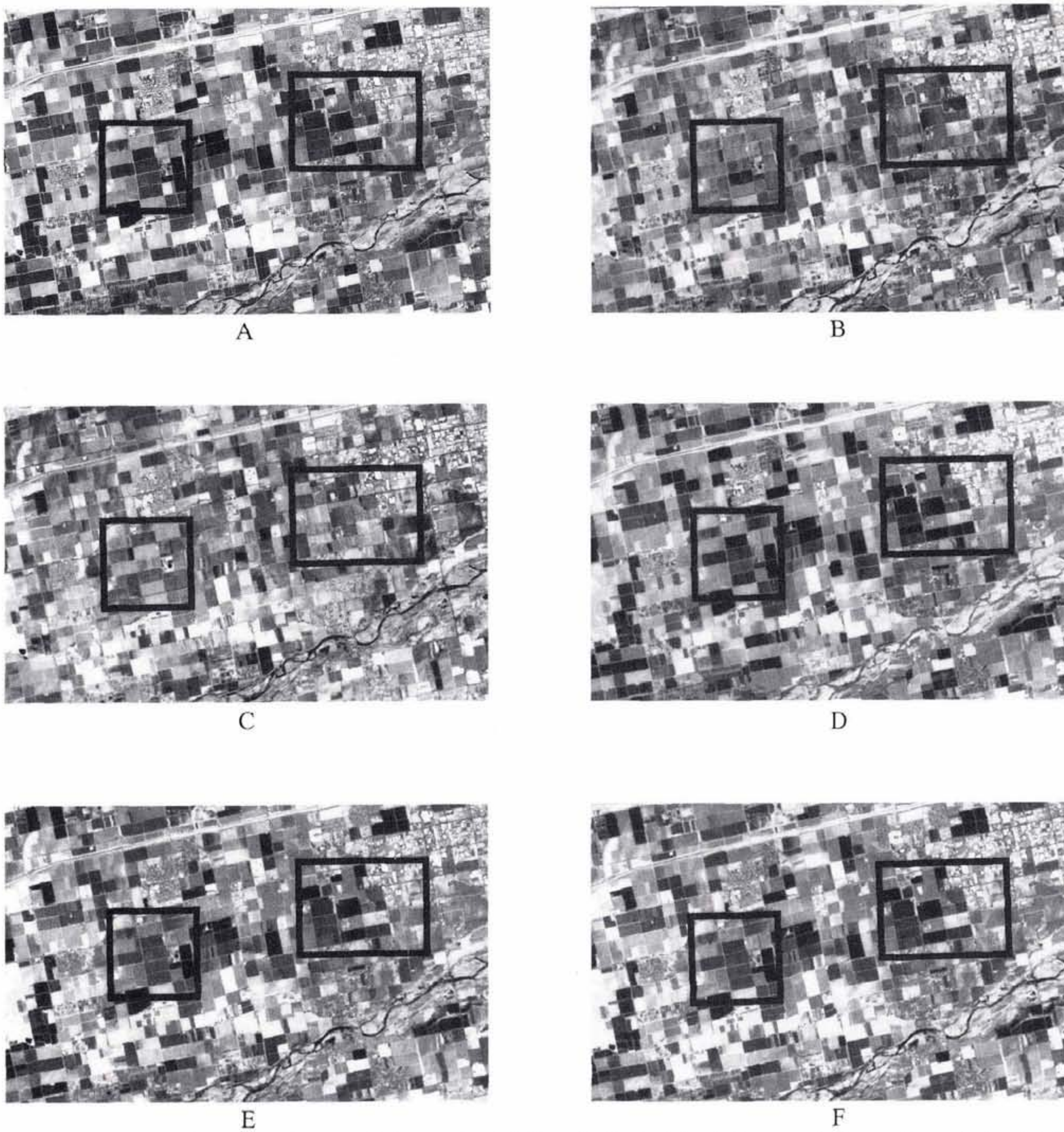

FIG. 1. (A) the PAN image; (B) the intensity image made from TM bands 1, 3, and 4; (C) the intensity image made from TM bands 1, 4, and 5; (D) the first principal component image made from TM bands 1, 3, and 4; (E) the first principal component image made from TM bands 1, 4, and 5; (F) the first principal component image made from TM bands 1, 3, 4, and 5. All six images had a 1 and 99 percent linear contrast stretch applied for visual presentation. The site is approximately 10 km southwest of Phoenix, Arizona, and covers a 10- by 16-km area. The Salt River is visible in the lower right portion of the images.

images generated from these same data. This implies the assumption that the PAN data are similar to the first principal component data remains semiconstant regardless of the subgroup combination. However, a potential problem is that the spatial resolution of the PCA results may be affected because of the possible uneven mixing used to generate the first principal component image. This problem needs further investigation.

The HPF method distorted the spectral characteristics of the data the least. In fact, the distortions were very minimal and difficult to detect. With the HPF method the spatial filter results of the PAN data can be used on one or all the bands. A possible problem is the slight ringing caused by the spatial filter at high-contrast boundaries; however, because the kernel size of the filter is so small, this effect is difficult to detect either statistically or visually.

The spatial filter kernel sizes investigated in this project were 3 by 3, 7 by 7, and 11 by 11 pixels. The 3- by 3-pixel kernel size computes the textural information within a single TM pixel but does not adequately merge the spatial resolution of the PAN data into the TM data. This size may be acceptable to generate

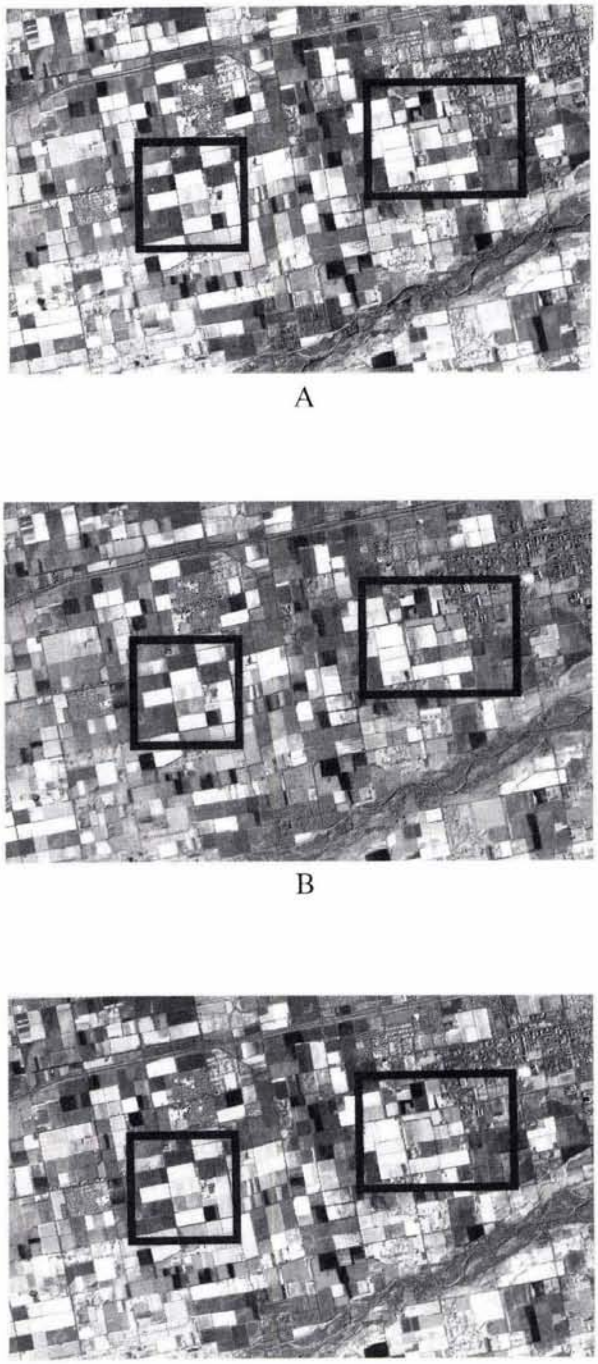

FIG. 2. Difference images generated by subtracting the HIS results for the (A) TM band 1 image; (B) TM band 4 image; and (C) TM band 5 image. These data had a 1 and 99 percent linear contrast stretch applied for visual presentation.

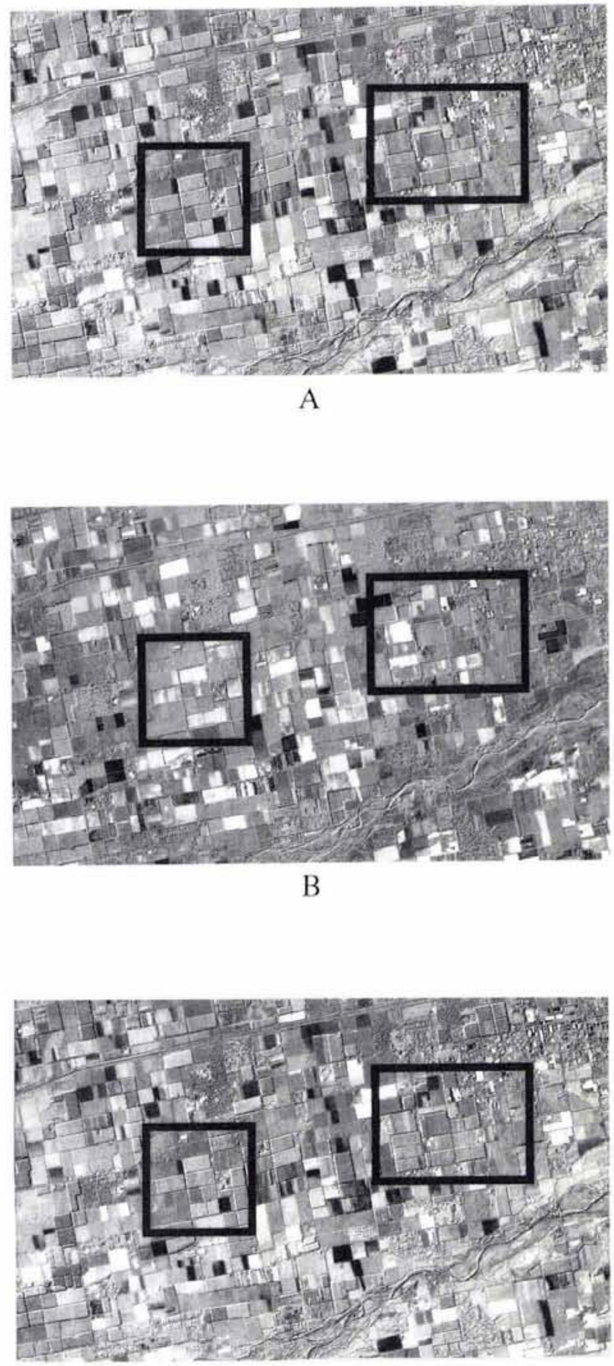

FIG. 3. Difference images generated by subtracting the PCA results from the (A) TM band 1 image; (B) TM band 4 image; and (C) TM band 5 image. These data had a 1 and 99 percent linear contrast stretch applied for visual presentation.

a textural file, at the TM 30-m resolution, to use as input with the TM bands for a spectral and spatial information classification procedure but is not an acceptable size for merging the spatial resolution information. The 7- by 7-pixel kernel size, just over twice the PAN versus TM sampling rate, generated good results. This kernel size was used in the Figures shown in this paper. The 11- by 11-pixel kernel size also generated acceptable results but started to add an edge enhancement effect based on the PAN data. Edge enhancements should be done after the data are merged, regardless of the method used to merge the information, because often edges are seen in one spectral band and not in another. If the PAN data are used to do edge enhancements during the merging procedure, only edges seen in the PAN spectral band will be enhanced, and edges seen in the near- and mid-infrared spectral bands will not be enhanced. An added advantage of using the HPF method instead of the HIS or PCA methods is that it extracts from the higher spatial resolution data only the local- or high-frequency detail. Therefore, if a low-

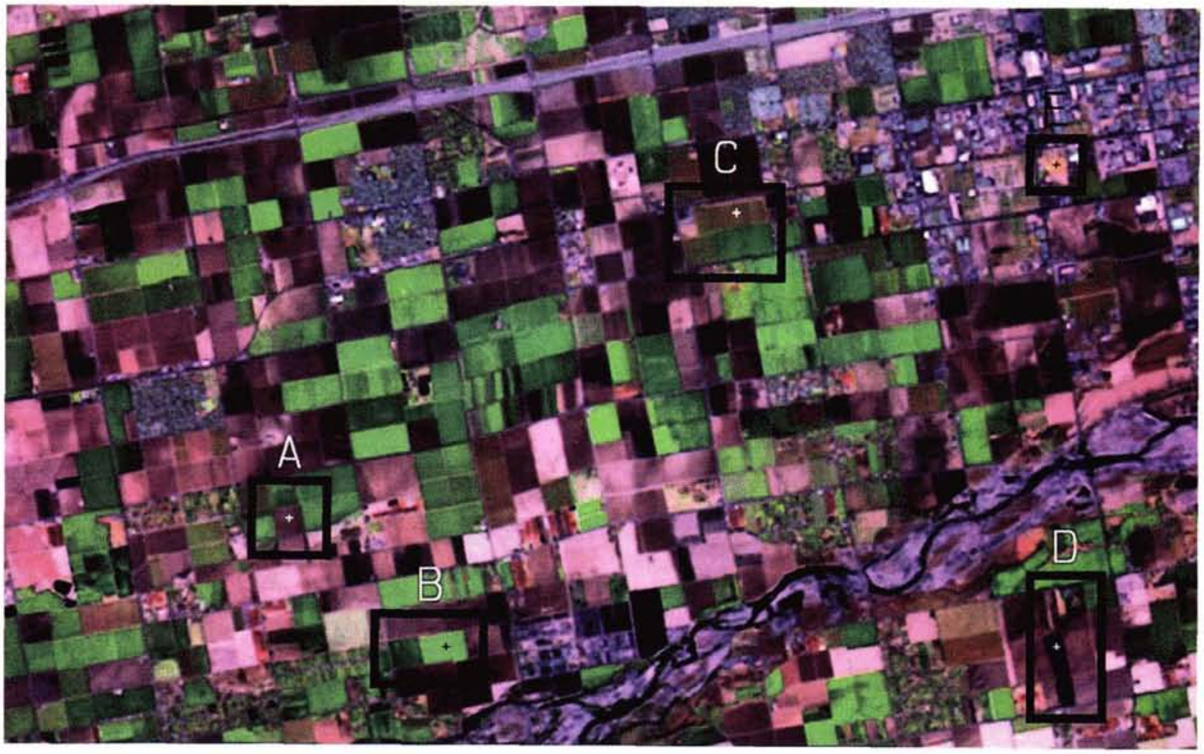

PLATE 1. Color composite made by using the original TM bands 1, 4, and 5 as blue, green, and red, respectively. This print should be used for the visual comparison with the HIS, PCA, and HPF color composites shown in Plates 2, 3, and 4. The rectangular windows (A, B, C, D, and E) are discussed in the graphical analysis section. This color composite has TM data only, and so the spatial resolution is 30 m; the color composites shown in Plates 2, 3, and 4 include the PAN data and so the spatial resolution is 10 m.

PLATE 2. Color composite made by using the HIS results of TM bands 1, 4, and 5 as blue, green, and red, respectively. This print should be compared with Plate 1 to identify where the spectral characteristics have been changed by the HIS method.

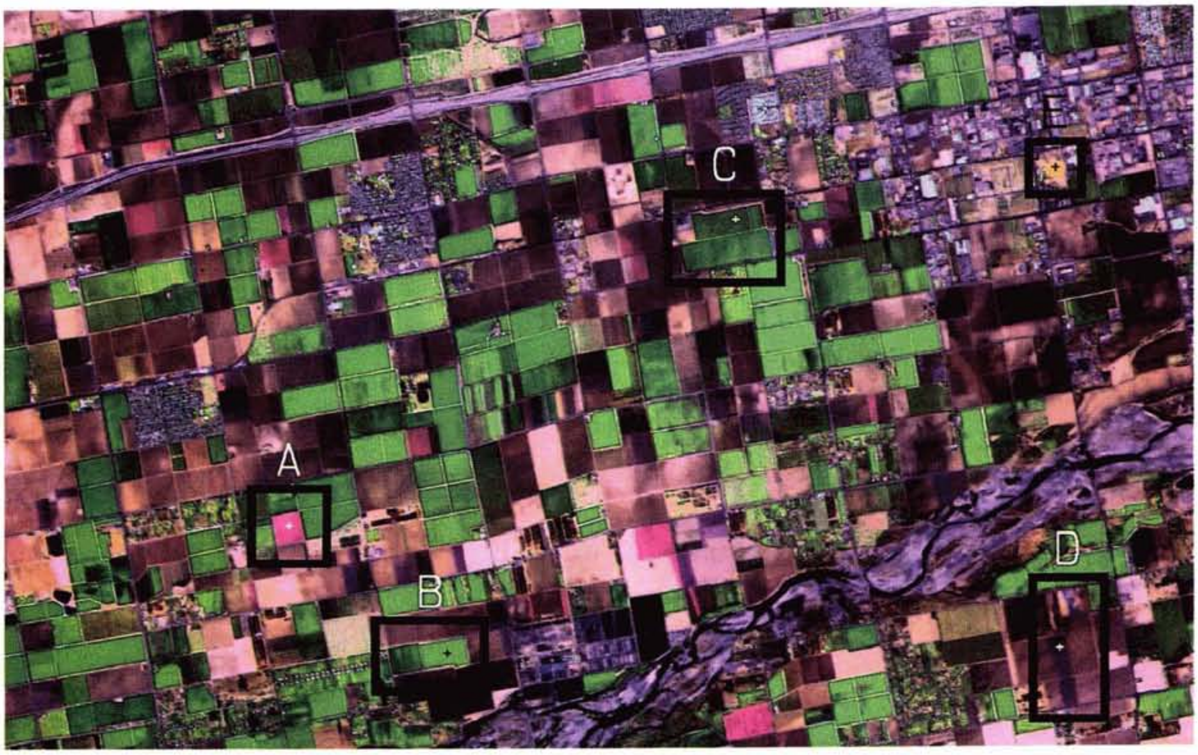

PLATE 3. Color composite made by using the PCA results of TM bands 1, 4, and 5 as blue, green, and red, respectively. This print should also be compared with Plate 1 to identify where the spectral characteristics have been changed by the PCA method.

PLATE 4. Color composite made by using the HPF results of TM bands 1, 4, and 5 as blue, green, and red, respectively. This print should be compared with Plate 1 to identify where the spectral characteristics have been changed by the HPF method.

frequency noise problem exists in the higher spatial resolution data set, such as the shading problem in the RBV data mentioned by Hayden *et al.* (1982) or often seen in digitized aerial photographs, the HPF merging procedure will automatically remove it.

CONCLUSIONS

The statistical, visual, and graphical analyses of the spectral characteristics of the data all indicate that the results generated

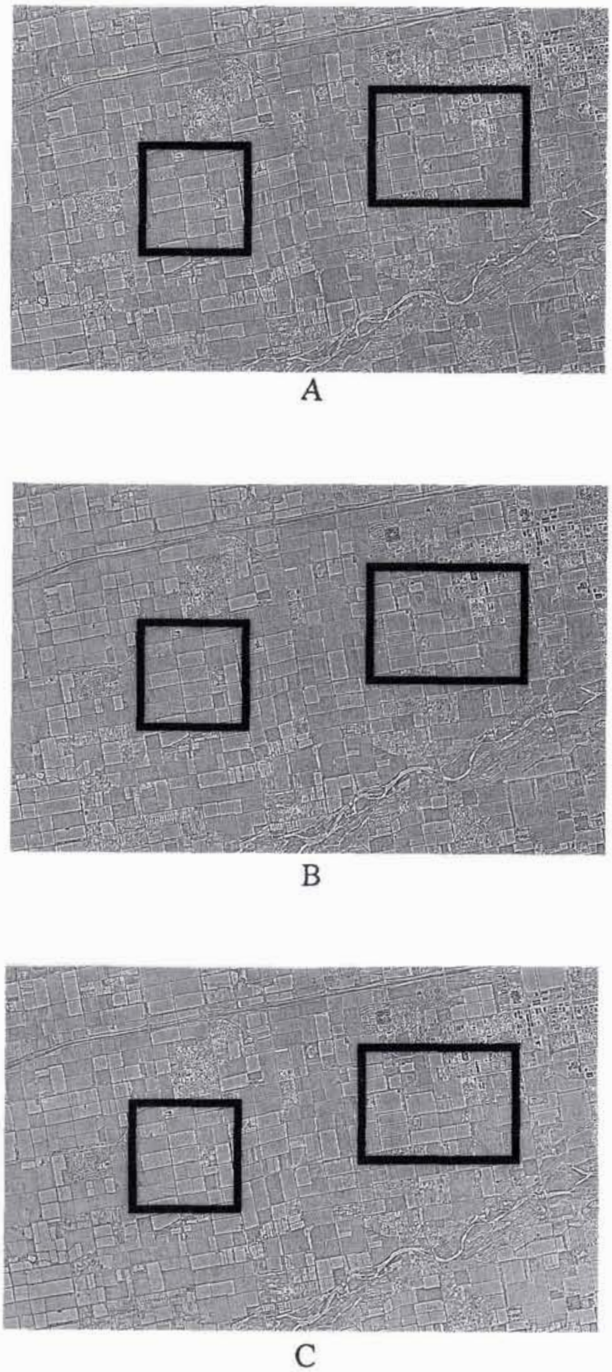

FIG. 4. Difference images generated by subtracting the HPF results from the (A) TM band 1 image; (B) TM band 4 image; and (C) TM band 5 image. These data had a 1 and 99 percent linear contrast stretch applied for visual presentation.

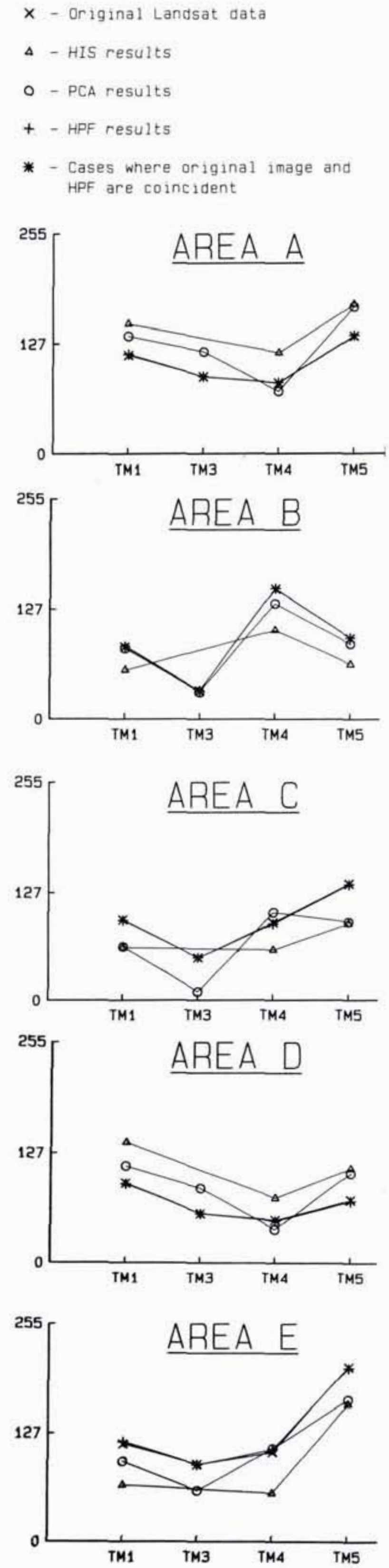

FIG 5. Plots generated from the average DNs of a 5- by 5-pixel kernel centered on the 9- by 9-pixel tic marks in the rectangular windows labeled A, B, C, D, and E in Plates 1, 2, 3, and 4. The average DNs for the original TM data and the HIS, PCA, and HPF results are plotted. The graphs do not include a TM band 3 value for the HIS results because this method can only handle three bands at a time.

with the HPF method are less distorted than the results generated by either the HIS or PCA methods. The PCA method distorted the spectral characteristics of the data less than the HIS method. This result is because the first principal component images are more correlated to the PAN image than are the intensity images.

The major advantage of the HPF method is that the spectral characteristics of the data are distorted the least. Other advantages are that the same PAN spatial filter output can be applied to all the bands, or any subset of the bands, and any low-frequency noise problems existing in the higher spatial resolution image will be automatically removed. The visual comparison indicates that the HPF method generates results with as good a spatial resolution as does the HIS method. The best kernel size was approximately twice the size of the ratio of the different spatial resolutions.

REFERENCES

Chavez, P. S., Jr., 1986. Digital merging of Landsat TM and digitized NHAP data for 1:24,000-scale image mapping: *Photogrammetric Engineering & Remote Sensing*, Vol. 52, No. 10, pp. 1637–1646.

Chavez, P. S., Jr., and J. Bowell, 1988. Comparison of the spectral information content of Landsat Thematic Mapper and SPOT for three different sites in the Phoenix, Arizona region: *Photogrammetric Engineering & Remote Sensing*, Vol. 54, No. 12, pp. 1699–1708.

Chavez, P. S., Jr. and A. Y. Kwarteng, 1989. Extracting spectral contrast in Landsat Thematic Mapper image data using selective principal component analysis: *Photogrammetric Engineering & Remote Sensing*, Vol. 55, No. 3, pp. 339–348.

Chavez, P. S., Jr., S. C. Guptill, and J. Bowell, 1984. Image processing techniques for Thematic Mapper Data: *Proceedings, 50th Annual ASP-ACSM Symposium*, American Society for Photogrammetry and Remote Sensing, Washington, D.C., pp. 728–743.

Haydn, R., G. W. Dalke, and J. Henkel, 1982. Application of the IHS color transform to the processing of multisensor data and image enhancement: *Proceedings, International Symposium on Remote Sensing of Arid and Semi-Arid Lands*, Cairo, Egypt, pp. 599–616.

Schowengerdt, R. A., 1980. Reconstruction of multispatial, multispectral image data using spatial frequency contents: *Photogrammetric Engineering & Remote Sensing*, Vol. 46, No. 10, pp. 1325–1334.

Thormodsgard, J. M., and J. W. Feuquay, 1987. Larger scale image mapping with SPOT: *Proceedings, SPOT-1 Utilization and Assessment Results*, Paris, France.

Welch, R., and W. Ehlers, 1987. Merging multiresolution SPOT HRV and Landsat TM data: *Photogrammetric Engineering & Remote Sensing*, Vol. 53, No. 3 pp. 301–303.

(Received 13 March 1990; accepted 11 June 1990; revised 18 June 1990)