Digital Merging of Landsat TM and Digitized NHAP Data for 1:24,000-Scale Image Mapping

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ABSTRACT: Merging image data collected by different remote sensors is becoming an increasingly important component of digital processing as a user's ability to simultaneously analyze complementary information increases. In this study, two data sets with very different characteristics were digitally merged, and a single data set, which contains information from both sets, was generated.

Landsat Thematic Mapper (TM) data were selected for their spectral information, and a digitized panchromatic photograph collected as part of the National High Altitude Program (NHAP), with approximately 4-m resolution after being digitized, was used for the primary spatial information.

The Landsat TM data were digitally enlarged by 7× to produce an image having the same 4-m cell size as the NHAP data. The data were then smoothed with a 7 by 7 low-pass filter to eliminate the blocky pattern introduced by digital enlargement.

Five image control points and a second-order polynomial fit were used to combine the information from both data sets. The results were used to generate image products at scales up to 1:24,000. The objective of merging complementary spectral and spatial information from both data sets was successfully accomplished.

INTRODUCTION

IN RECENT YEARS, users of remotely sensed data have been exposed to a "data explosion." This is particularly true for data that are recorded in, or can be converted into, digital format for computer processing and analysis. Examples of digital data that are, or soon will be, available include Landsat multispectral scanner (MSS) and Thematic Mapper (TM) images; Seasat and Shuttle Imaging Radar (SIR-A and -B) images; Advanced Very High Resolution Radiometer (AVHRR) and other low-resolution images; and SPOT images.

Integrating or merging data sets collected by different remote sensors to fully utilize complementary information is becoming an increasingly important component of digital image processing. By digitally merging different data types, the user can take advantage of the unique characteristics of each particular data set. Several examples exist where data sets collected by different sensors at different times have been digitally merged for processing and analysis. Landsat MSS and radar image data collected by Seasat, the Shuttle Imaging Radar (SIR-A), and airborne systems have been successfully merged (Daily *et al.*, 1978; Daily *et al.*, 1979; Chavez *et al.*, 1983). Image data collected by the Landsat MSS and the return beam vidicon (RBV) systems were digitally combined to generate a product that had information from both sensors (Lauer and Todd, 1981).

Several other studies have been made of data sets digitally merged with different resolutions but collected by the same sensor. This includes the work done by Schowengerdt (1980), who worked with full-resolution and spatially compressed Landsat MSS data. He demonstrated the use of a high-resolution band to "sharpen" or edge-enhance lower resolution bands having the same approximate wavelength characteristics. Schowengerdt also combined Landsat MSS data at 80-m resolution and Heat Capacity Mapping Mission (HCMM) data having an approximate resolution of 600 m (1982).

The author has also done work in combining lower resolution images with one at a higher resolution. One study involved the digital merging of the 20-m SPOT simulator multispectral data with the 10-m panchromatic data (Chavez, 1984). Similar work with the SPOT simulator data was recently reported by Cliche *et al.* (1985).

The project's primary objective was to extract the spectral information from the Landsat TM and combine it with the spatial information from a data set having much higher spatial resolution. The project was also designed to ascertain the maximum scale at which such results could be printed for image mapping purposes. The Landsat TM data were selected for their spectral content. TM bands 5 and 7 have proven to provide unique data not available in either the Landsat MSS or SPOT simulator data (Chavez and Berlin, 1984; Crist, 1984; Crist and Cicone, 1984). The data set used for spatial information was a digitized panchromatic photograph

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collected by the National High-Altitude Photography (NHAP) Program.

Test Area and Data Characteristics

The area covered by the two data sets is approximately 30-km west of Washington D.C.; Dulles International Airport is shown near the center of the images (Figure 1). About 8 km to the east of Dulles is Reston, Virginia, where the U.S. Geological Survey has its national headquarters. The area is mostly rural and highly vegetated, with isolated pockets of small urban communities. There is some agricultural land (cropland and pasture), and the forest type is mixed deciduous.

The TM data were collected by Landsat-4 on 2 November 1982 (ID 4109-1149). The data were resampled to a pixel size of approximately 28.5 m, and there are seven spectral bands. In this study, the thermal infrared data, which have 120-m spatial resolution, were not used. The panchromatic NHAP photograph was taken in April 1980 at a scale of 1:80,000 (Antill, 1982; Bermel and Brew, 1984). The panchromatic image was recorded using a 0.1538-m (6-inch) focal-length camera with Kodak 2405 film from an altitude of approximately 12.3 km, and was digitized using an Optronics C100 scanner. The spot size of 50 μm used to digitize the NHAP photograph generated a pixel size of approximated 4 m. Figures 1a and 1b show band 4 of the TM data and the digitized NHAP image.

DIGITAL MERGING AND COMBINING TECHNIQUES

The actual combining of data from different sensors, or sources, involves two major and distinct steps. The first deals with the geometric registration of the data. The second step involves the merging of the data, or information, for digital or visual analysis.

There are several methods that can be used to geometrically register different data sets. The method used in this study differs slightly from most others in the way the two sets of data, with the extreme difference in spatial resolution (28 versus 4 m), are processed. It involves formatting the two data sets to approximately the same "pixel size"[1] before registration is performed. This was accomplished by digitally expanding the TM image data and creating pixels of 4-m size.

The Landsat TM data set was digitally expanded in both the x and y directions by a factor of seven using pixel duplication. Because digital enlargement by pixel duplication produces a blocky image, the results are smoothed using a low-pass filter having dimensions equal to the digital enlargement (Chavez *et al.*, 1984). This eliminates blocky patterns and allows images of different spatial resolutions to be digitally merged in a minimum amount of computer time. It also allows image products to be printed at larger-than-normal scales without seeing individual pixels (e.g., Landsat TM images at 1:50,000 to 1:25,000). Figure 2 shows a portion of Landsat TM band 4 before and after a 7× digital enlargement, and after a 7 by 7 smoothing filter has been applied to the enlarged image. Notice the blocky appearance of the digitally enlarged image, and how it has been reduced in the smoothed image. Also, note how the image quality has been retained at the 1:50,000 scale. This method has been successfully used before on Landsat MSS, TM, and SPOT simulator data (Chavez and Berlin, 1984; Chavez *et al.*, 1984).

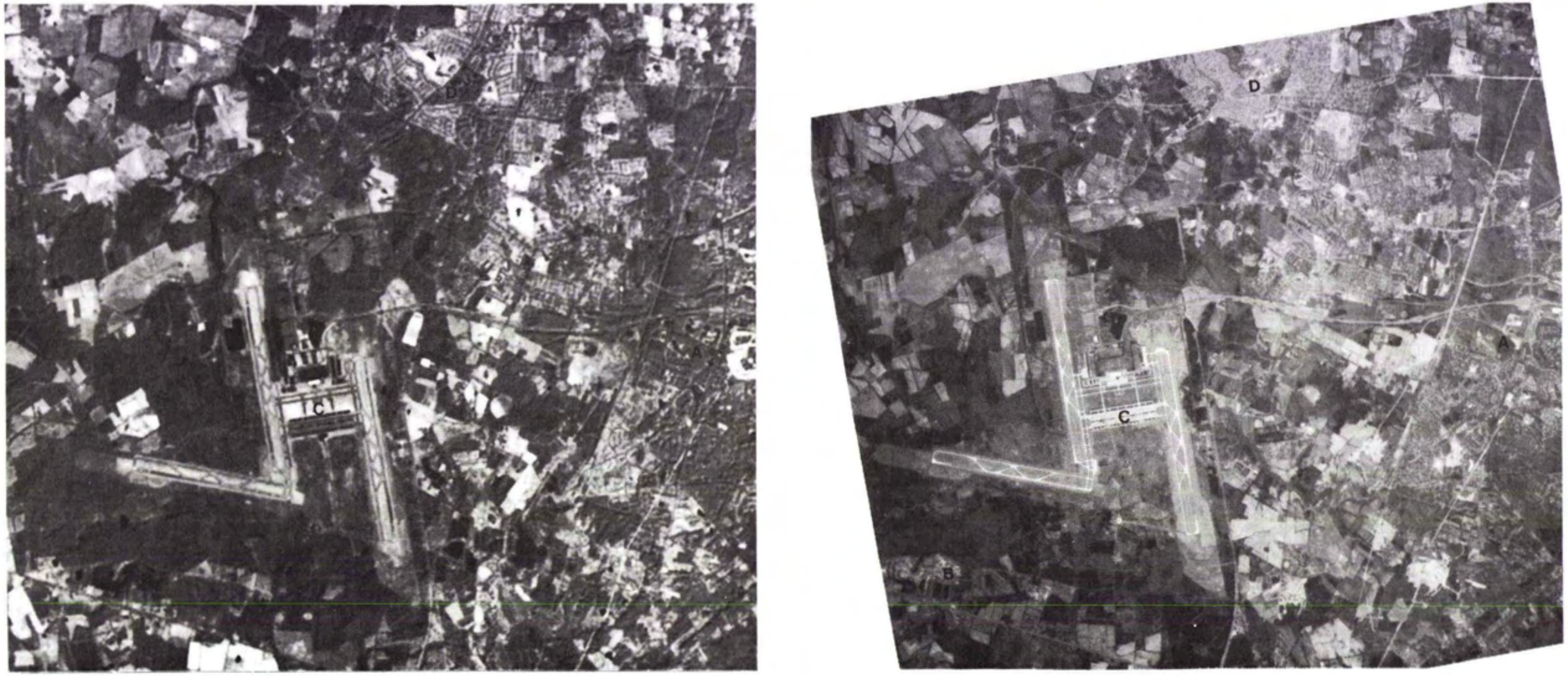
Once the Landsat TM image was digitally enlarged and smoothed, it became the "master," and geometric control points were selected to register to it the "slave," or the digitized aerial photograph. The TM image was selected as the master because its geometry, for such a small area, was acceptable without any further resampling. Also, this involved resampling only one band (the photograph) rather than the six TM bands. The number of image control points needed was small compared to most image-to-image registration projects. Tests were conducted using three, four, and five image control points with first- and second-order polynomial fits. The final results were generated using five image control points with the second-order polynomial fit. In this particular case, three and four control points were inadequate for generating acceptable registration results for the entire image (i.e., RMS errors of 2 to 4 pixels).

Nearest-neighbor resampling was used on the photograph. A minimal amount of rotation and scaling had to be done because the TM image had been digitally enlarged to the same cell size. Visually the results were very acceptable, even with the extreme difference in spatial resolution between the two images. As mentioned earlier, this method has been used before but with data where the spatial resolution varied only by a factor of two or three (for example, MSS and SIR-A; TM and SPOT simulator; SPOT simulator 20- and 10-m data).

Once the data sets have been registered, the second step involves the actual merging or "combining" of the data for digital or visual analyses. The method used to combine the digital data can influence the type of information seen in the resultant product. For example, some digital combination techniques will enhance the high frequencies or the fine detail within the image, while others enhance the brightness/color of various cover types. Methods that can be used to combine the information from two registered data sets include adding, subtracting, or ratioing, pixel by pixel, the two data sets.

In an earlier study in which Landsat MSS and SIR-A images were combined, a correlation matrix of the

[1]The term "pixel size" is used rather than "pixel resolution" because it is not being implied that the digitally expanded TM data have 4-m resolution.



(a) (b)

FIG 1. (a) Landsat TM band 4 image of the study area after digital enlargement and smoothing. This represents the final TM data base at a scale of 1:80,000. This is an area which is approximately 30 km west of Washington D.C., and the labeled locations A, B, C, and D are (A) U.S. Geological Survey's national headquarters in Reston, Va.; (B) gravel pit and surrounding fields; (C) Dulles airport; (D) residential area. (Reduced to a scale of 1:135,000 for publication.) (b) Image of digitized NHAP panchromatic photograph with an approximate 4-m spatial resolution. The scale is 1:80,000. (Reduced to 1:135,000 for publication.)

combined images was used to identify, by the signs and/or absolute values of the correlation coefficients, which of the above methods to use for digital merging (Chavez *et al.*, 1983). For example, if the correlation coefficient between two images is negative, and the user is interested in color information, the data sets should be differenced or ratioed rather than summed.

The information from the two data sets can, at times, also be combined using principal-components analysis. A correlation matrix can again be used to decide which bands or images should be used as input to principal-components analysis. If the absolute value of the correlation coefficient between two images is small, they should probably not be used together for principal-components analysis because little, if any, mixing will occur between the uncorrelated data (for example, between Landsat and radar images). Selective principal-components analysis might be better in such cases (Chavez *et al.*, 1982; Chavez *et al.*, 1984).

Another method that can be used to merge information from geometrically registered data sets is band or image replacement. For example, instead of creating a color-composite image using TM bands 2, 3, and 4, TM bands 2, 3, and the digitized NHAP photograph can be used. However, this method may not generate acceptable results if the spatial resolution difference between the two data sets is large (as in this case) or if wavelength characteristics of the two data sets are very different. If the spatial resolution differs by only a factor of two or three and the spectral bands are similar, this method can generate acceptable results (Chavez, 1984).

RESULTS

The results generated from the geometrically registered and digitally combined TM and NHAP data are significant. Figure 3 shows a color-composite image of TM bands 2, 3, and 4 after digital enlargement and smoothing. Figure 4 shows the results of combining the TM data with the NHAP data by adding the two data sets on a pixel-by-pixel basis. The ground area is shown in these two figures at an approximate scale of 1:80,000. The results in Figure 4 should be compared with the individual TM and NHAP images shown in Figures 1 and 3. However, due to the spatial resolution of the combined data set, larger scales must be used to clearly see the improvement. Therefore, four sub-areas are shown in Figures 5, 6, and 7 at a scale of 1:24,000. The products shown are the digitized black-and-white NHAP photograph (Figure 5); the color composite of TM bands 2, 3, and 4 after digital enlargement and smoothing (Figure 6); and these two data sets digitally combined with pixel-by-pixel addition (TM2 + NHAP, TM3 + NHAP, and TM4 + NHAP) (Figure 7). These final products, which are enlargements of portions of the image shown in Figure 4, were contrast-stretched and color composited after digitally

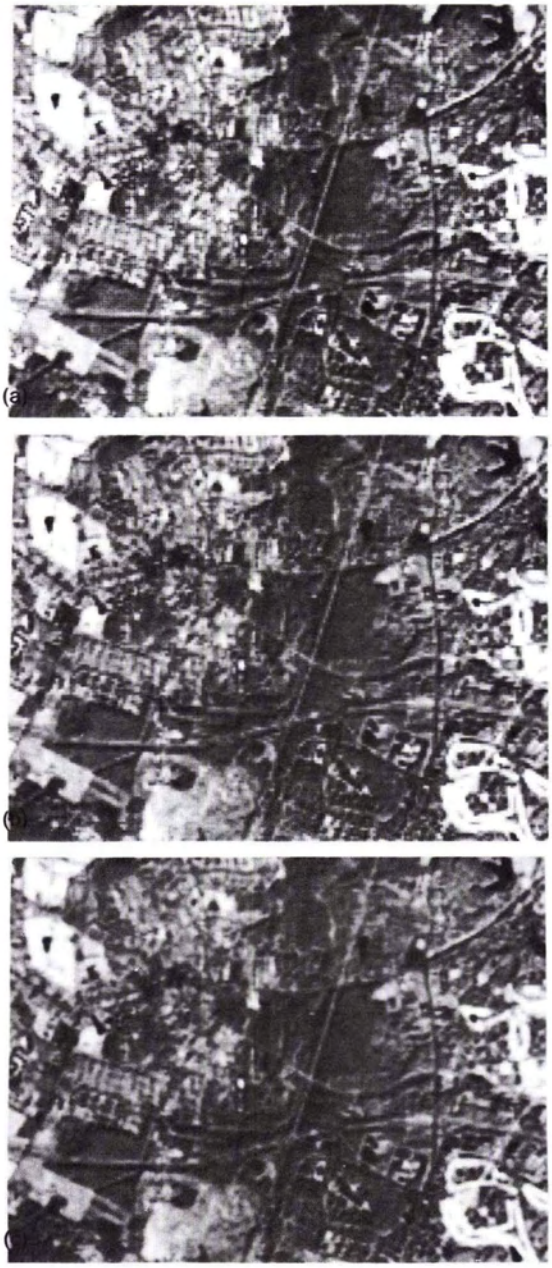


FIG 2. (a) Original Landsat TM band 4 data with an approximate pixel size of 28.5 metres of area A at a scale of 1:50,000 (reduced to a scale of 1:75,000 for publication). Note that the individual pixels can be seen and a screen pattern is present due to the non-ideal spacing between the pixels created by the hardcopy device (a mangnifying glass may be needed to see its effects). (b) Same image shown in Figure 2a but after the data have been digitally enlarged 7× in both directions (i.e., each pixel became 49 pixels). Note that the screen pattern is gone because the pixels are one-seventh as large. However, the duplication of pixels has made the image very blocky. (c) Same image shown in Figure 2b but with a 7 by 7 smoothing filter applied to the results. Note that the blocky pattern has been eliminated and individual pixels cannot be seen. This represents the final TM data as used in this project.

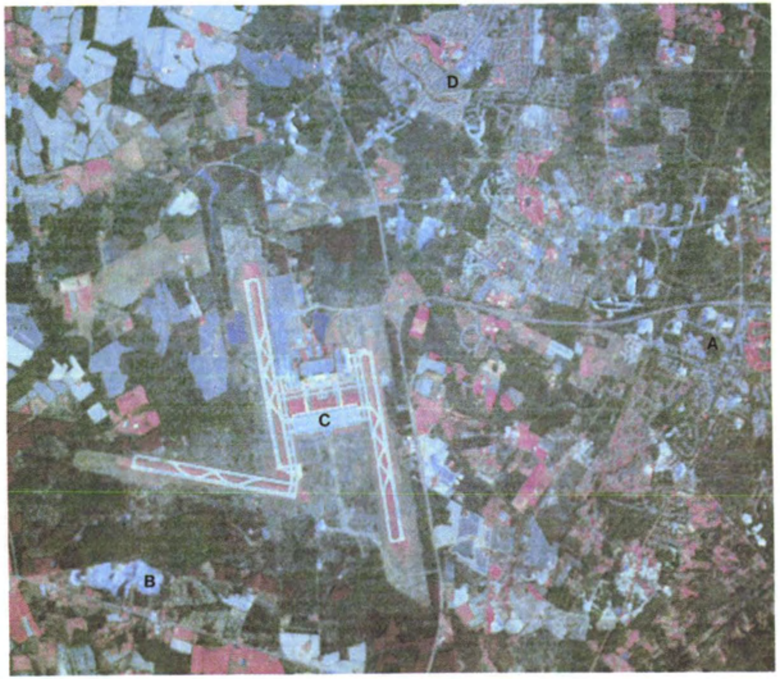


FIG 3. Landsat TM false color-composite made from bands 2, 3, and 4 after a 7 × enlargement and smoothed with a 7 by 7 low-pass filter. The scale of the image if 1:80,000. See Figure 1 for feature identification. (Reduced to a scale of 1:135,000 for publication.)

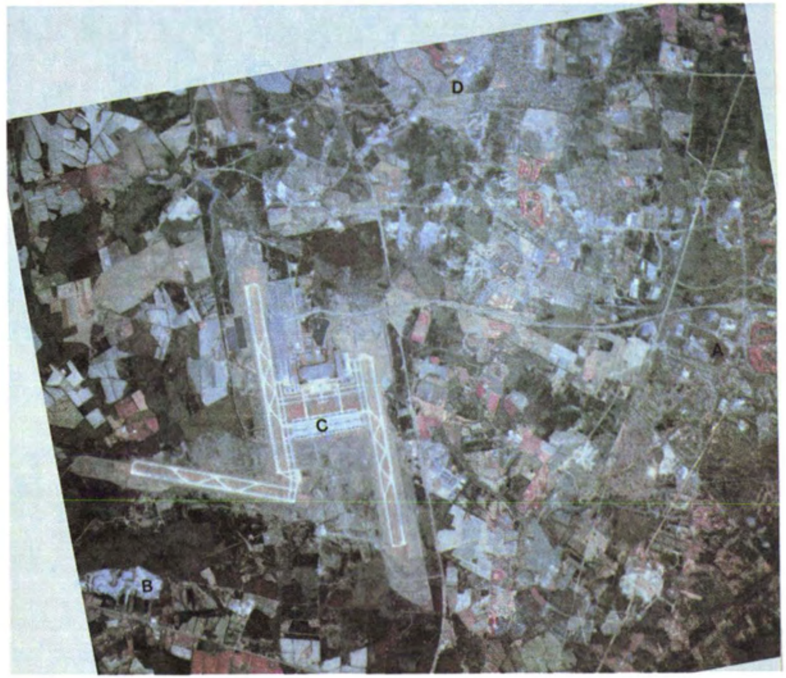


FIG 4. Landsat TM bands 2, 3, and 4 plus the NHAP photograph false color composite. This is the same product as Figure 3 but with the NHAP photograph added, pixel-by-pixel, to the TM data before compositing. The scale of the image is 1:80,000. See Figure 1 for feature identification. (Reduced to a scale of 1:135,000 for publication.)

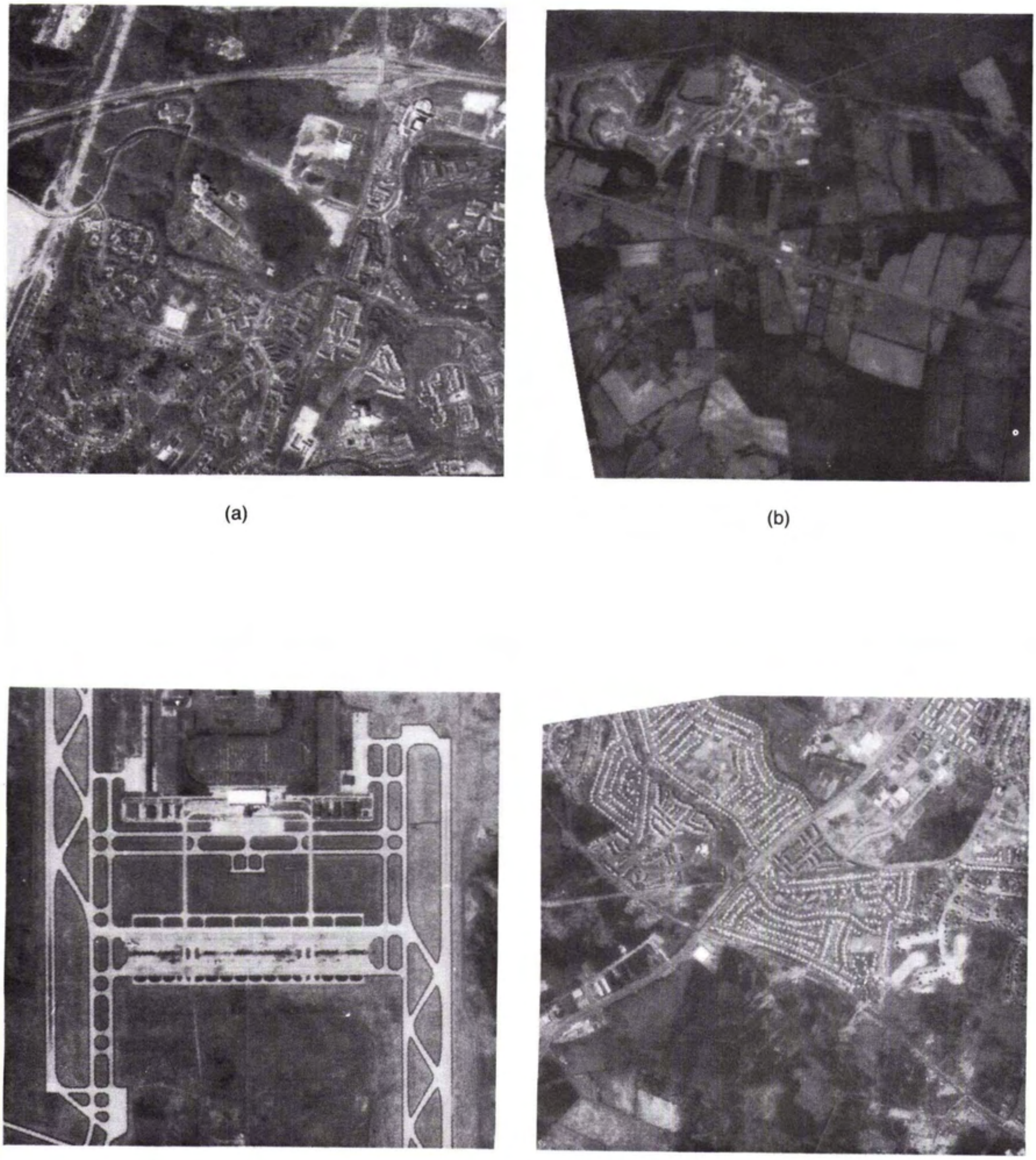
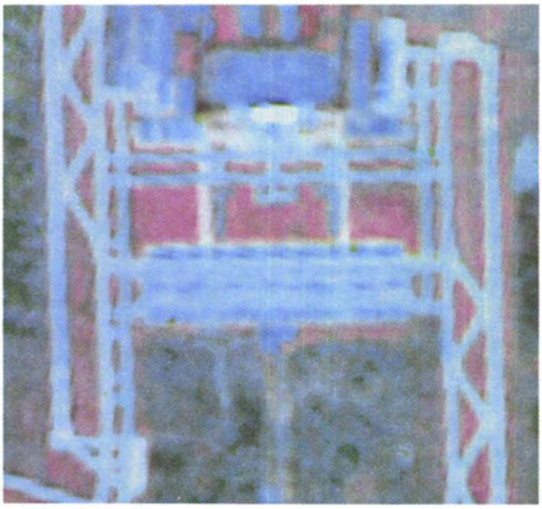


FIG 5. (a) Location A extracted from the digitized NHAP photograph shown in Figure 1b. The U.S. Geological Survey's national headquarters can be seen near the center. The image is shown here at a scale of 1:24,000 (reduced to 1:33,333 for publication). (b) Location B extracted from the digitized NHAP photograph shown in Figure 1b. The gravel pit and surrounding fields can easily be seen. The image scale is 1:24,000 (reduced to 1:33,333 for publication). (c) Location C extracted from the digitized NHAP photograph shown in Figure 1b. Dulles airport area can be seen. The image scale is 1:24,000 (reduced to 1:33,333 for publication). (d) Location D extracted from the digitized NHAP photograph shown in Figure 1b. The residential area can be seen at the top half of the image. The image scale is 1:24,000 (reduced to 1:33,333 for publication).

(a)

(b)



(c)

(d)

FIG 6. Location A extracted from Figure 3 which is the TM 2, 3, and 4 false color composite. The U.S. Geological Survey's national headquarters and a golf course can be seen. The image scale is 1:24,000 (reduced to 1:33,333 for publication). Location B extracted from Figure 3 which is the TM 2, 3, and 4 false color composite. The gravel pit and surrounding fields can be seen. The image scale is 1:24,000 (reduced to 1:33,333 for publication). Location C extracted from Figure 3 which is the TM 2, 3, and 4 false color composite. The Dulles airport area can be seen. The image scale is 1:24,000 (reduced to 1:33,333 for publication). Location D extracted from Figure 3 which is the TM 2, 3, and 4 false color composite. The residential area can be seen at the top half of the image. The image scale is 1:24,000 (reduced to 1:33,333 for publication).

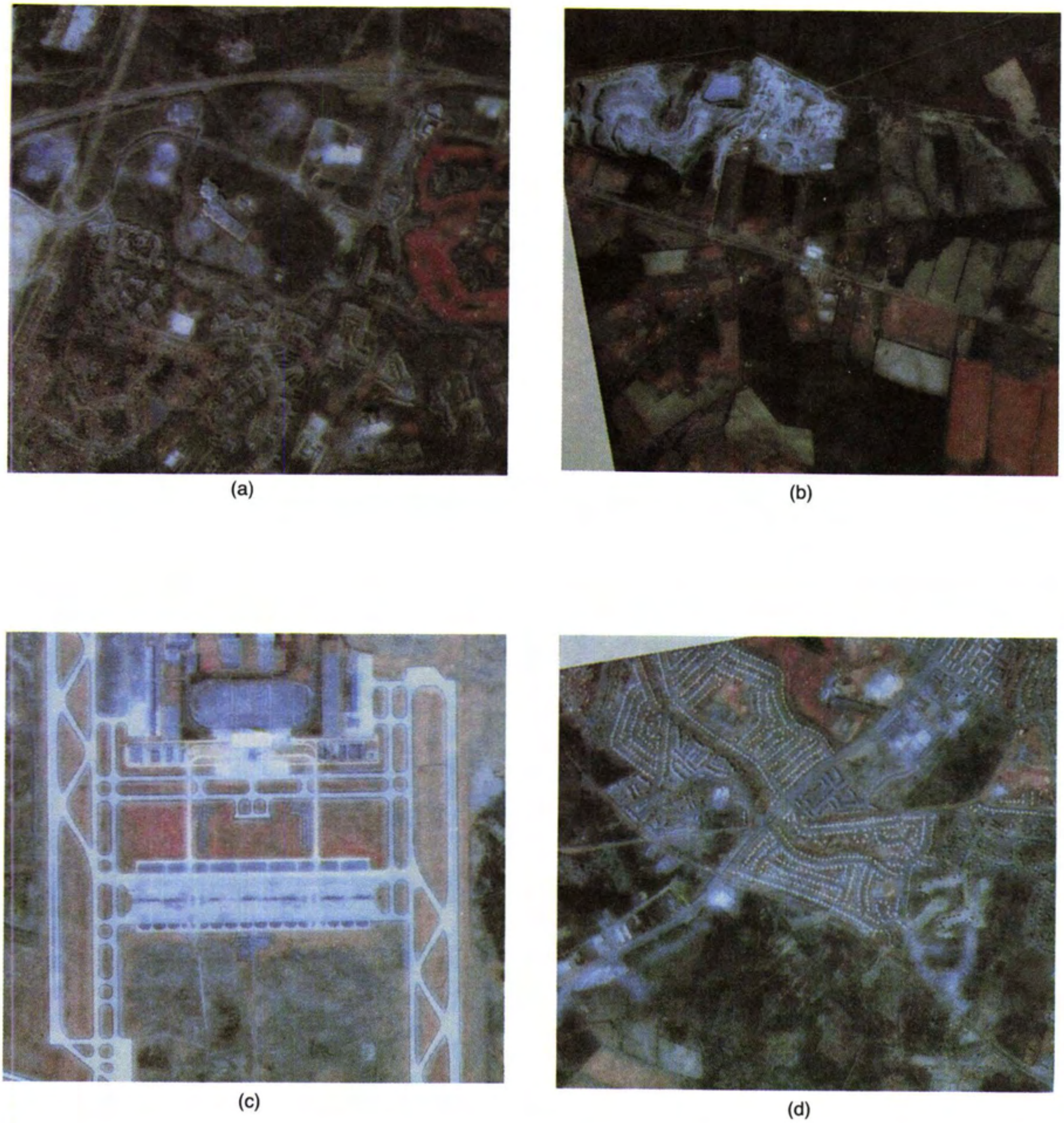


FIG 7. (a) Location A extracted from Figure 4, which is the false color composite made from TM bands 2, 3, and 4 with the NHAP photograph added to each of the bands pixel-by-pixel. Note both the color and spatial detail present on this image, which is shown at a scale of 1:24,000 (reduced to 1:33,333 for publication). (b) Location B extracted from Figure 4, which is the false color composite made from TM bands 2, 3, and 4 with the NHAP photograph added. Notice the detail, both color and spatial, present in the gravel pit and surrounding field. Image scale is 1:24,000 (reduced to 1:33,333 for publication). (c) Location 3 extracted from figure 4, which is the false color composite made from TM bands 2, 3, and 4 with the NHAP photograph added. Notice the added detail in the airport area (on the off the runway — scale 1:24,000, reduced to 1:33,333 for publication). (d) Location D extracted from Figure 4, which is the false color composite made from TM bands 2, 3, and 4 with the NHAP photograph added. Notice the detail within the residential area (scale 1:24,000, reduced to 1:33,333 for publication).

combining the two data sets. Notice that the color or spectral information from the TM data is present, as is the spatial information from the NHAP photograph. By comparing these products to the one shown in Figure 1 (with a magnifying glass), the reader can see that the primary objective of the project — the merging of two different data sets to obtain the best of both the spectral and spatial information — was accomplished.

Once the data sets have been geometrically registered to each other, different types of composite images can be generated by either using a different method to merge them digitally (e.g., subtracting) or by combining the NHAP data with different TM bands (e.g., TM3, 4, 5). The image shown in Figure 8 was made by subtracting, pixel-by-pixel, the NHAP data from TM bands 2, 3, and 4.

CONCLUSIONS

Two very different data sets have been merged and several methods used to extract the best information component from each (i.e., spectral and spatial). The high spatial resolution of the merged data set allowed image products to be generated at scales up to 1:24,000. The spectral resolution allowed several color composites to be made showing the area as it appears in several different parts of the spectrum.

The integration of data sets collected by different sensors to fully utilize complementary information is becoming an increasingly important and widely used technique. However, due to the large amount of data that can be generated, care must be taken to merge only data sets that will complement each other and produce new information. From the results generated in this and previous projects, two data sets that will complement each other are Landsat TM and SPOT 10-m panchromatic data, when the latter becomes available. The Landsat TM is preferred over the 20-m multispectral SPOT data because of the information in TM bands 5 and 7. Also, three of the TM bands are highly correlated to the three 20-m SPOT bands are little, if any, spectral information would be gained by merging these two data sets. In order to reduce the amount of data in

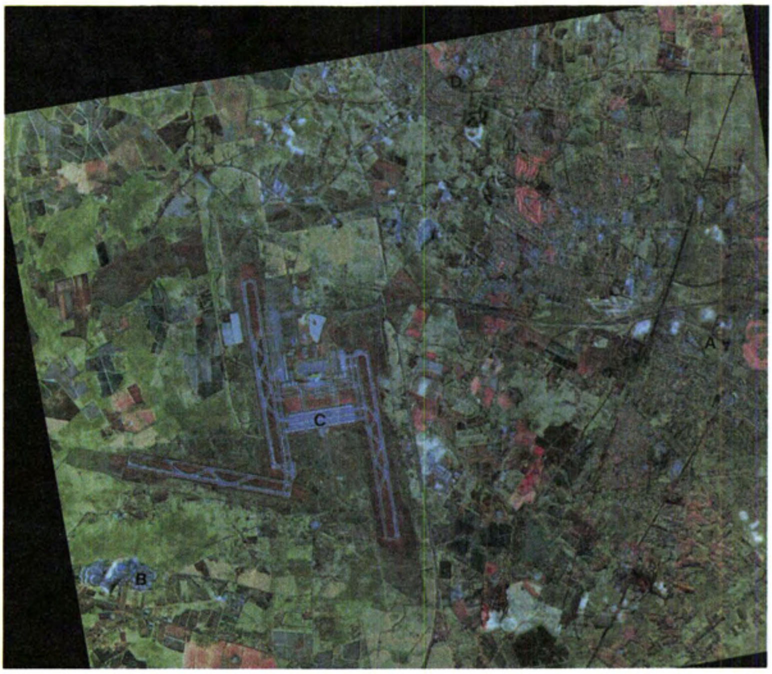


FIG 8. Landsat TM bands 2, 3, and 4 minus the NHAP photograph color composite. The NHAP photograph was subtracted, pixel-by-pixel, from the TM data before compositing. This shows one of the advantages of merging the high resolution data with the TM data. Different methods can be used to incorporate the spectral information (i.e., difference instead of sum; or new TM band combinations, such as TM 3, 4, and 5 can be used). The scale of the image is 1:80,000 (reduced to 1:135,000 for publication), and locations A, B, C, and D are labeled on the image for comparison with Figure 4.

Figure 4.

the merged data set, the user may want to merge only a subset of the TM bands to the SPOT 10-m data. This is because a very high correlation usually exists between the visible bands (TM 1, 2, and 3) and between the IR bands (TM 5 and 7). An example of data sets that might be used to extract a maximum amount of information and keep the number of bands or data volume to a minimum is to merge Landsat TM bands, 2, 4, and 5 with the 10-m panchromatic SPOT band.

The results presented here, along with new ones currently being generated — Landsat TM and Large Format Camera data collected by the space shuttle — will hopefully help support the idea of having multispectral data with low spatial resolution (30- to 80-m) collected simultaneously with one or two higher spatial resolution (5- to 10-m) monochromatic band(s). This will reduce the volume of data that needs to be collected and stored, and allow a data set to be generated which has both high spectral and spatial resolution.

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Erratum

Plates 1 and 2 on page 542 of the article, "Use of Multitemporal Spectral Profiles in Agricultural Land-Cover Classification," in the April 1986 issue of *PE&RS* were switched.