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Cartographic Potential of SPOT Image Data*

10-m Stereo data in digital formats will facilitate the integration of image processing and cartographic techniques.

Abstract: *The* SPOT *program will provide photogrammetrists and cartographers with the first systematic stereo satellite data in digital formats at spatial resolutions (10 m, 20 m) approaching those required for mapping tasks. Although these spatial resolutions are marginal for the compilation of planimetric detail, and estimated spot height accuracies of ±10 to ±20 m will likely be restricted to areas with adequate ground control, the* SPOT *data should permit the production of topographic maps of 1:50,000 to 1:250,000 scale with contour intervals of 40 to 50 m or greater. Mapping of remote areas will thus be facilitated. Image maps of 1:25,000 and 1:50,000 scale prepared from the 10- and 20-m data, respectively, should prove satisfactory for most users. Planimetric and thematic detail are most easily compiled by visual interpretation techniques from digitally enhanced image products in which the 20-m multispectral data have been merged with the 10-m panchromatic band. Comparative evaluations of land-use/cover maps prepared from* SPOT *simulation and Landsat Thematic Mapper (*TM*) and Thematic Mapper Simulator (*TMS*) data indicate a 15 to 20 percent improvement in classification accuracy at Level II/III using the* SPOT *simulation imagery. Because of its relatively high spatial resolution (10 m), the panchromatic band can be integrated with cartographic data bases in raster formats to facilitate the development of interactive map revision techniques.*

Introduction

In late 1985 the Système Probatoire d' Observation de la Terre (SPOT) satellite will be launched by the Ariane rocket from French Guiana. This satellite will carry two High Resolution Visible (HRV) line array sensor systems capable of producing monoscopic and stereoscopic coverage of the Earth (Chevrel *et al.*, 1981; Brachet, 1984). Significant aspects of the SPOT mission for cartographic applications include: (1) the recording of stereo image data at base-height ratios designed to ensure maximum heighting accuracies; and (2) the acquisition of 10-m data in a panchromatic mode or 20-m data in a multispectral mode.

Ducher (1980) and, more recently, Baudoin (1984) have examined the heighting potential of the SPOT data. Baudoin (1984) has reported that, by using an analytical stereoplotter with the 10-m data in film formats recorded at a base-height ratio of 1.0, it will be possible to determine spot heights to a root-mean-square error (RMSE) of approximately ±10 m. With digital stereocorrelation techniques it *may* prove possible to reduce the error to less than ±10 m. The above values represent accuracies of better than 1:80,000 of the satellite's altitude and, to be realized, will require image data of exceptionally good internal geometric fidelity. Because there is no provision for obtaining the precise position and attitude of the SPOT spacecraft or its sensors, it is likely that accuracies approaching the above values will only be achieved for areas in which ground control points can be recovered from existing large scale maps of good quality. At this time, it appears that SPOT stereo data will allow the compilation of experimental topographic maps of 1:50,000 to 1:250,000 scale with contour intervals of 40 to 50 m or greater.

The map information content of image data is directly related to spatial resolution. Previous studies (Welch, 1982a; Konecny *et al.*, 1982) reveal that the compilation of topographic maps of 1:50,000 scale or larger from satellite data to conventional stan-

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dards for accuracy and completeness will necessitate the use of image data acquired by sensors having an instantaneous-field-of-view (IFOV) of less than 5 m. Similarly, the preparation of planimetric and thematic maps of urban areas will require the use of image data with resolutions of 5 to 10 m (Welch, 1982b). For example, when the average size of urban land parcels for the United States and China—countries which represent extremes in urban population density and parcel size—are compared to the IFOV's of satellite sensor systems such as the Landsat Thematic Mapper (TM) (30 m) and the SPOT HRV (20 m, 10 m), it is evident that urban detail is of high spatial frequency relative to the sensor resolution (Figure 1).

In this study, two major objectives were addressed: (1) a comparison of the suitability of SPOT and TM image data for mapping urban land use/cover; and (2) a preliminary assessment of the potential of SPOT image data for map revision when merged with conventional map sheets converted to raster formats. In order to meet these objectives within the approximate six-month period allowed for the studies, all analyses were conducted with TM Simulator (TMS) and real TM data recorded over Athens, Georgia in 1982, and SPOT simulation data acquired over Athens, Georgia and Chattanooga, Tennessee in July, 1983 as part of the SPOT IMAGE Corporation simulation campaign (SPOT IMAGE Corp., 1983; Saint and Weill, 1984). The parameters for these data acquisitions are summarized in Table 1, and comparative images are displayed in Figure 2.

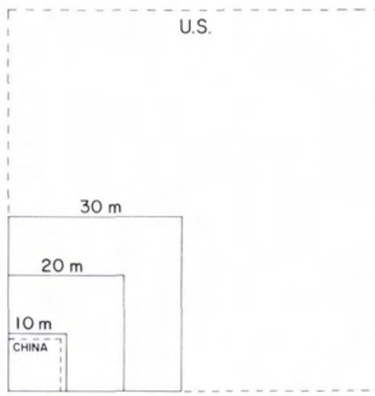

FIG. 1. A comparison of average size urban parcels (dashed line) in the United States and China with the IFOV's (solid lines) for the Landsat TM (30 m) and SPOT HRV (10 m) sensors clearly indicates the need for high resolution image data for urban mapping.

URBAN LAND-USE/COVER AND IMAGE MAPS

For this study, a total of 30 Level II and Level III land-use/cover classes (based on the USGS system) were identified for a 5.3- by 6.6-km study area centered on Athens, Georgia (Anderson *et al.*, 1976), and land-use maps were compiled from enhanced TM/TMS and SPOT images by a skilled image analyst using visual interpretation techniques (Figure 3). The wealth of Level III land-use information on the map prepared from the SPOT simulation data is readily apparent.

A comparison of the classification accuracies was undertaken using a systematic, stratified, unaligned sampling technique (Yeates, 1974; Matthews, 1984). This sampling technique required the iterative use of a sampling grid (180-m interval) and random number table to identify a total of 1080 sample points on a detailed 1:24,000-scale "ground truth" land-use/cover map of the Athens study area compiled from 1:40,000 and 1:80,000-scale color infrared aerial photographs recorded on the SPOT simulation and TMS missions. The sample points were also located on the maps prepared from the SPOT simulation and TM/TMS image data. At each point, the land-use/cover classes represented on the maps were noted and tabulated. Although this procedure is relatively easy to apply and ensures that all areas on the map are sampled, those classes occupying the largest areas are sampled more extensively.

Initial comparisons of the accuracies for all 30 classes revealed that the results were heavily biased by the inability to identify many of the Level III classes in the TM/TMS data set. Consequently, for the accuracy comparison, the classes were aggregated and redesignated to produce the 17 Level II/III classes underlined in Table 2. These classes could be identified to varying degrees on both data sets and included adequate samples to permit a representative evaluation of the land-use/cover maps.

In Figure 4, the classification accuracies achieved from the visual interpretation are compared for the Level II/III classes. An examination of this figure indicates that the higher resolution SPOT simulation data yield an average accuracy improvement of 15 to 20 percent for the urban classes (excluding class 142). Only for classes with distinct patterns (such as found in the industrial (13) and golf course (172) classes) did the TM/TMS and SPOT simulation data prove to be of comparable interpretability. If the land-use/cover class data are further aggregated to provide a Level II classification system, the overall accuracies for the urban classes are 83 and 67 percent, respectively, for the SPOT and TM/TMS data, confirming the advantage of the higher spatial resolution.

Attempts were made to classify the study site by supervised digital techniques using a maximum likelihood classifier. For Level II categories the resultant accuracies were about 50 to 55 percent for both the SPOT and TM/TMS data sets. These results are similar to those reported by Toll and Kennard (1984). Consequently, it would appear that the most efficient method for mapping the urban detail and land-use/cover to high accuracies is to apply visual interpretation techniques to digitally enhanced images.

These studies also permitted an empirical evaluation of suitable scales for image map products pre-

TABLE 1. SPOT SIMULATION, LANDSAT THEMATIC MAPPER SIMULATOR (TMS) AND LANDSAT-4 THEMATIC MAPPER (TM) DATA

Acquisition Parameters	SPOT Simulation	TMS	TM
Date Acquired	3 July 1983	15 October 1982	7 November 1982
Altitude	6,350 m	12,200 m	705 km
IFOV	7.9 m	30 m	30 m
Pixel	10 m, 20 m	30 m	28.5 m
Location	Athens, GA Chattanooga, TN	Athens, GA	Athens, GA

pared from the SPOT data. Prior experience has shown that Landsat MSS and TM data can be effectively displayed at 1:250,000 and 1:100,000 scale, respectively (USGS 1981; 1982; Colvocoresses, 1984). At these scales, there are approximately three Landsat IFOV's or pixels/mm which provide sufficient spatial frequency content for the unaided eye. If the same relationship is assumed to be acceptable for image maps prepared from SPOT data, the limiting scales are approximately 1:50,000 and 1:25,000 for the 20-m and 10-m data, respectively. Impressions gained through the interpretation and use of the SPOT simulation data indicate that image map products at 1:25,000 scale will prove acceptable to many users.

MERGED DATA SETS FOR MAP REVISION

A use for SPOT data which has considerable po-

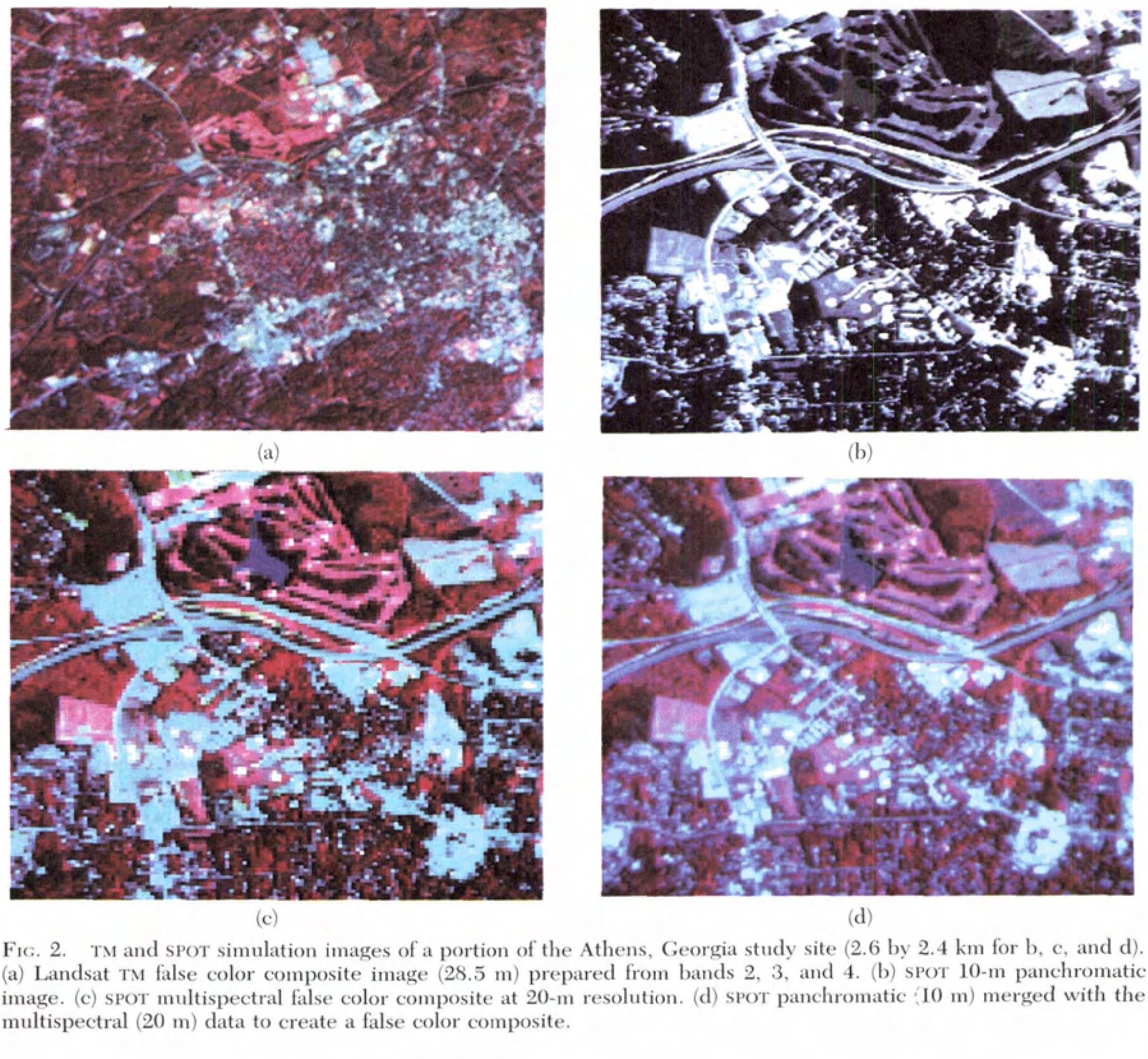

FIG. 2. TM and SPOT simulation images of a portion of the Athens, Georgia study site (2.6 by 2.4 km for b, c, and d). (a) Landsat TM false color composite image (28.5 m) prepared from bands 2, 3, and 4. (b) SPOT 10-m panchromatic image. (c) SPOT multispectral false color composite at 20-m resolution. (d) SPOT panchromatic (10 m) merged with the multispectral (20 m) data to create a false color composite.

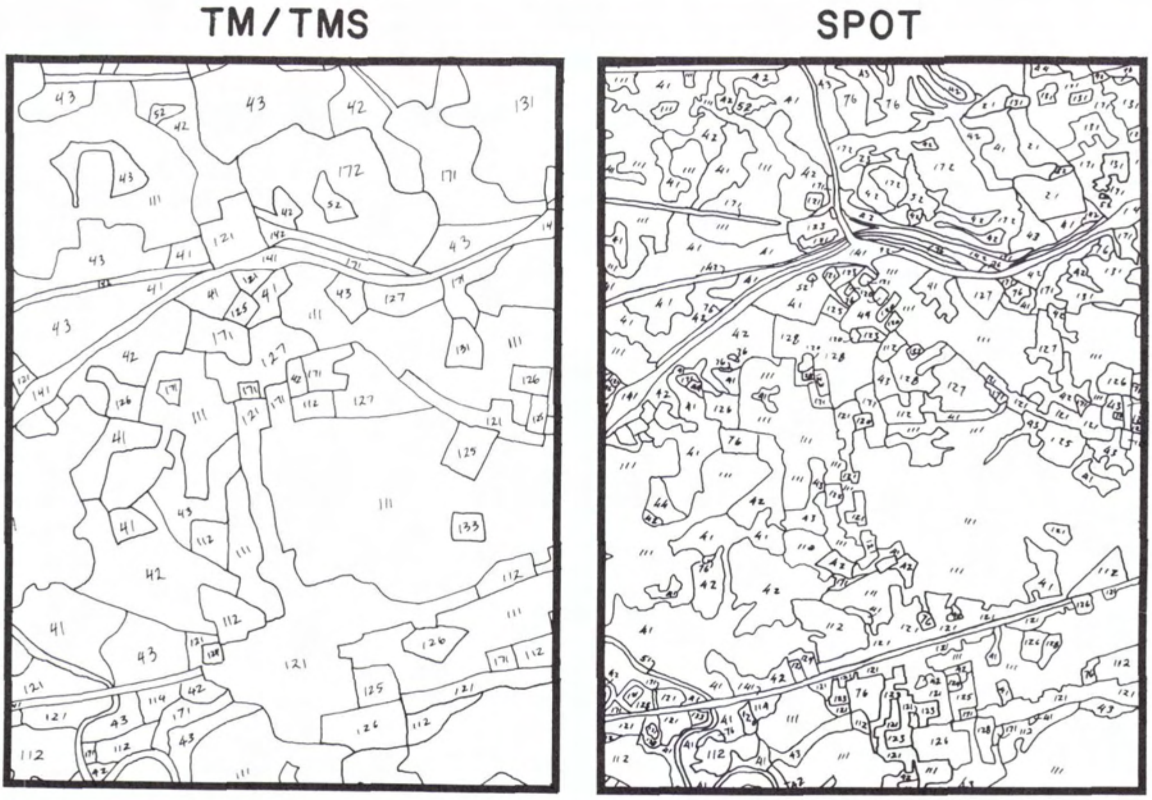

FIG. 3. Sections (3.3 by 4.4 km) of land-use/cover maps of the Athens study site prepared by visual interpretation techniques from TM/TMS and SPOT image data. The improved spatial resolution of the SPOT simulation data permits delineation of several classes of Level III detail.

tential for cartographic applications involves the integration of the high resolution panchromatic 10-m data with cartographic data bases to facilitate map revision. The procedure required to merge the image and map data sets involves several steps which are described below with reference to the Chattanooga, Tennessee study area (Figure 5; Welch, 1984).

A 5.1- by 4.8-km area common to both the existing U.S. Geological Survey 1:24,000 topographic quadrangle and to the SPOT simulation data was defined. The map area was then digitized with a video camera/frame grabber interfaced to an ERDAS 2400 interactive image processing system to provide a 512 pixel by 480 line by 8 bit image of 10-m pixels. Although the video camera/frame grabber approach limits the area which can be digitized at sufficient resolution for map revision tasks and degrades the quality of the map, only 1/30 of a second is required to capture the scene. Map areas of large physical dimension can be digitized in segments, which, in turn, can be mosaicked together with appropriate image processing routines. After the map has been digitized, control points are located in both the image (pixel, line) and map UTM coordinate systems, and the map image is rectified with the aid of a first order polynomial equation of the form:

$$\text{UTM} = a_1x + a_2y + a_3$$

where x and y are the pixel and line coordinates, respectively, of control points. As part of the rectification procedure, the pixels are reformatted to an exact uniform dimension (e.g., 10 m) and resampled to obtain appropriate gray values. This rectified map becomes the reference plane to which the digital SPOT image data can be registered.

The SPOT simulation data recorded by a Daedelus scanner mounted in a jet aircraft suffers from considerably greater geometric distortion than will be present in the real SPOT data. To fit the SPOT image to the map requires control or "tie" points common to both data sets. Registration is accomplished using first-order polynomials and the method of least squares to fit the SPOT image to the reference map image with the aid of tie points. For display screen-sized areas, this procedure can be iterated until the residual errors are reduced to less than ±1 data pixel.

The image processing system can then be used to display the map and SPOT image data sets in contrasting colors. In this example (Figure 5d), the map is displayed in blue and green, and the panchromatic 10-m SPOT simulation image in red. The pink

TABLE 2. LAND USE/COVER CLASSIFICATION SYSTEM USED FOR THE COMPARISON OF SPOT SIMULATION AND TM/TMS IMAGE DATA (AFTER ANDERSON *ET AL.*, 1976)

URBAN OR BUILT-UP (1)
- 11 Residential
  - 111 Single Family Housing
  - 112 Multiple Family Housing
- 12 Commercial and Services
  - 121 Commercial
  - 122 Institutional
- 13 Industrial
- 14 Transportation and Utilities
  - 141 Road, Highway, Railroad
  - 142 Utilities
- 17 Other Urban or Built-up Land
  - 171 Urban Grassland
  - 172 Golf Course

AGRICULTURAL LAND (2)
- 21 Cropland and Pasture

FOREST LAND (4)
- 41 Deciduous Forest Land
- 42 Evergreen Forest Land
- 43 Deciduous and Evergreen Forest Land
- 44 Scrub and Woodland

WATER (5)
- 51 Rivers, Streams, and Ponds

WETLANDS (6)
- 61 Forested Wetland

BARREN LAND (7)
- 76 Barren Transitional Areas

and light red areas in the composite image indicate sections of the map where changes have occurred. Areas of change can be delineated in an interactive mode with the aid of a cursor, joystick, or light pen. The coordinates are recorded on disk and may be used to create an update file which can be merged with the original map data set to implement the revision (Usery and Welch, 1984). Work is currently underway to develop efficient techniques of feature extraction from multisource data sets.

CONCLUSION

Studies to date indicate that the 10-m and 20-m data anticipated from SPOT will allow a variety of map products to be produced. Although the spatial resolution may prove to be a limiting factor, the SPOT data will permit the compilation of topographic maps of 1:50,000 to 1:250,000 scale for areas where limited map coverage currently exists. To ensure that the planimetric detail extracted from the images exceeds 75 to 80 percent of the features normally depicted on such maps, it will be desirable to use manual interpretation techniques in conjunction with digitally enhanced stereo pairs for which 10-m panchromatic and 20-m multispectral data have been merged. In areas where well-defined ground control points are already available, it may be possible to realize spot height accuracies of ±10 to ±20 m using analytical plotters or stereocorrelation techniques. These spot height values are compatible with accuracy standards for contour intervals of approximately 40 to 60 m.

Analytical techniques should also enable the development of digital elevation models (DEM's) that can be used to generate ortho-images or to rectify data recorded by other sensor systems (e.g., synthetic aperture radars). When integrated with cartographic databases containing conventional map sheets converted to raster formats, the SPOT data should permit the development of interactive map revision procedures based on image processing techniques. From evaluations of Landsat digital image data and inspections of SPOT IMAGE products, it appears that the SPOT 10-m and 20-m data will be of sufficient quality for the reproduction of image maps of approximately 1:25,000 and 1:50,000 scale, respectively.

The high spatial frequency of urban detail facilitates comparative evaluations of the potential of Landsat TM and SPOT HRV sensor data for the compilation of thematic maps depicting Level II/III land-use/cover classes. Accuracy assessments of sample map products prepared for the Athens, Georgia area indicate that, by using digitally enhanced SPOT image products, classification accuracies in excess of 80 percent can be realized for selected Level II/III urban classes, whereas accuracies of 65 to 70 percent are more typical for maps produced from the 30-m (28.5-m pixel) TM/TMS data. Attempts to classify urban land-use/cover by digital techniques have not been successful, indicating that visual analyses of digitally enhanced image products may prove more useful for thematic mapping tasks.

In summary, the SPOT program will provide cartographers with the first systematic stereo satellite data in digital formats at spatial resolutions compatible with mapping requirements. Thus, photogrammetrists, cartographers, and specialists in image processing and computer graphics should see significant opportunities to integrate their skills and develop new mapping techniques and/or products.

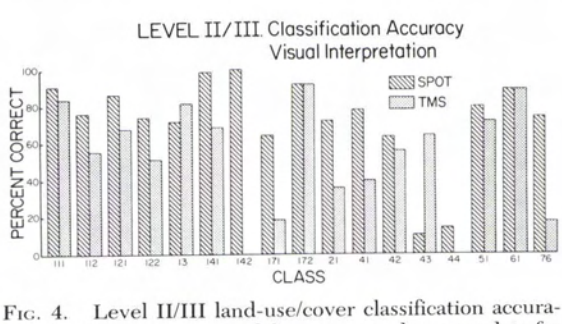

FIG. 4. Level II/III land-use/cover classification accuracies for the maps prepared from SPOT and TM/TMS data for the Athens study site.

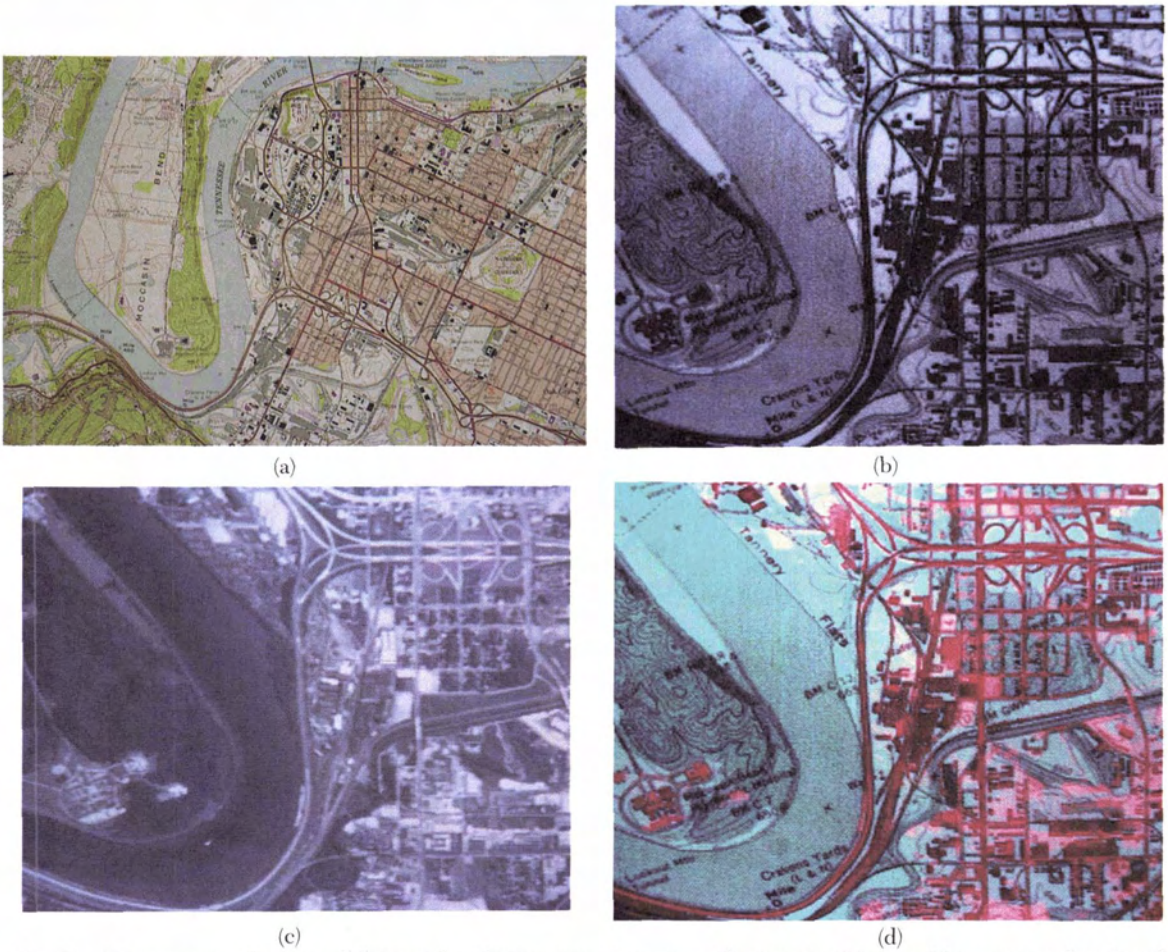

FIG. 5. Components of a merged data set for Chattanooga, Tennessee. The topographic map (a) is converted to digital format (b) and registered with the SPOT panchromatic data (c) to create a color composite (d) in which the map is displayed on the RGB monitor in blue and green and the more recent SPOT data are displayed in red. Areas which have changed since the map was constructed appear as pink or light red.

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