Desktop Mapping with Personal Computers

R. Welch
Center for Remote Sensing and Mapping Science (CRMS), Department of Geography, University of Georgia, Athens, GA 30602

ABSTRACT: The Desktop Mapping System (DMS) is a low cost, powerful software package that facilitates image processing for photogrammetric, remote sensing, and GIS applications using off-the-shelf personal computers. Unique design features include the ability to conduct measurements from *monoscopic and stereoscopic* imagery in digital formats, and to undertake the compilation/revision of planimetric, thematic, and topographic map products. Terrain elevations can be derived from digital stereoscopic images by interactive procedures or fully automated stereocorrelation techniques. Accuracies of approximately ± 10 m in *X, Y,* and *Z*-terrain coordinates have been achieved with SPOT stereoimage data. The DMS also interfaces with computer-aided design (CAD) and geographic information system (GIS) software packages such as AutoCAD and ARC/INFO. It is anticipated that the DMS will make mapping oriented image processing and GIS technologies available to educators and scientists from diverse disciplines.

INTRODUCTION

DIGITAL IMAGE PROCESSING for use in remote sensing, photogrammetry, geographic information systems (GIS), and education has been constrained by the cost of hardware/software, complexity of available software packages, and limitations in hardware functionality and display technology. Over the last few years, for example, a number of personal computer (PC) software packages for image processing have been placed on the commercial market. However, only the more expensive packages (> $10,000) were oriented toward planimetric mapping and none provided the capability to derive terrain elevations from stereoimage data in digital formats or were truly compatible with existing GIS software. Consequently, a research project was initiated to develop a low cost, user friendly *mapping* software package for PCs with Intel 80286/80386 microprocessors. The following goals were established:

- Demonstrate the feasibility of using off-the-shelf PCs with *both monoscopic and stereoscopic* image data for planimetric, topographic, and thematic mapping tasks.
- Reduce the complexity of image processing and mapping tasks by featuring key operations in pull-down menus.
- Link raster image processing to vector mapping and GIS applications.
- Make mapping oriented image processing technologies available to educators and scientists concerned with problems in agriculture, cartography, ecology, forestry, geography, hydrology, etc.
- Provide a path for PC software developments that will eventually transfer remote sensing, photogrammetry, and GIS from highly specialized, costly technologies to a broad-based user community.

At the outset, three major problems were apparent: (1) the non-availability of digital image data in floppy disk formats; (2) the limitation imposed by 640 by 350 by 4-bit (16-color) enhanced graphic adapter (EGA) displays; and (3) the speed at which complex, notoriously slow mapping functions associated with geocoding, stereocorrelation, and three-dimensional (3-D) perspective view generation operate on large image data sets. Fortunately, the magnitude of these problems has been reduced by a combination of events. Satellite image data in floppy disk formats may be purchased from EOSAT and SPOT Image Corporation. Display technologies have evolved rapidly since the release of the IBM Professional Graphics Adapter (PGA, 640 by 480 by 256 colors) in 1984, and now include the Video Graphics Array (VGA, 640 by 480 by 16 colors) and enhancements and, most significantly, the IBM Display Adapter 8514/A (1024 by 768 by 256 colors) which is compatible with several 8514 class monitors. Of equal importance has been the release of PCs operating at clock speeds of 16 to 33 MHz, and the development of software designed to make use of efficient user interfaces (e.g., pull-down menus) and take advantage of display and speed enhancements. These advances in technology have enabled the development of the Desktop Mapping System (DMS)™ (Welch, 1987).

The DMS was first exhibited in Baltimore, Maryland at the 1987 ASPRS-ACSM conference, where major commercial exhibitors and government agencies were attracted by the ability to quickly derive contours and spot heights using both interactive and automated techniques on a PC. In November 1988, a short course *Desktop Mapping with SPOT Image Data*, was sponsored by the Center for Remote Sensing and Mapping Science (CRMS), University of Georgia, and SPOT Image Corporation. This short course revealed that many individuals having limited skills with PCs, no photogrammetric background, and only cursory experience with digital image processing could, with a few hours of practice, measure *X, Y,* and *Z* terrain coordinates to an accuracy of ± 10 m (± 1 pixel). This accuracy is comparable to that achieved by skilled photogrammetrists with analytical plotters or very sophisticated computer systems (Konecny *et al.*, 1987; Sharpe, 1988).

In this paper, an effort is made to describe those image processing functions of the DMS which allow the preparation of planimetric, thematic, and topographic map products using an off-the-shelf PC in an office environment. However, while attention is given to hardware requirements and to the speed and functionality of the DMS for rectification, vector-on-raster overlay, merging of multiresolution data, and thematic classification, emphasis is placed on those unique aspects of the DMS which facilitate topographic mapping, three-dimensional terrain representation from stereoscopic image data, and integration of image processing and GIS functions. Only recently have three-dimensional mapping and integrated image processing/GIS applications on a PC been given serious consideration.

HARDWARE CONSIDERATIONS

The selection of a PC for digital image processing applications should be based on cost, performance, and display technology. Today, complete computer systems which operate under MS-DOS and utilize 80286/80386 microprocessor technology can be purchased for $2,000 to $10,000. Typical machines include the IBM PS/2 series (Model 30-286 and higher); Compaq 286 and 386 series; Dell 220, 310, and 325; and many others.

Processing speed is critical for computer intensive tasks such as geocoding (i.e., rectifying), automatic stereocorrelation, and perspective view generation. An 80386 machine operating at a clock speed of 20 to 25 MHz (e.g., Compaq 386-20 and 386-25; Dell 310 and 325) will have a 2× to 3× advantage in processing time over an 80286 machine (e.g., IBM PS/2 Model 60) operating

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at 10 MHz – assuming the required (80387/80287) math co-processors operate at equivalent speeds. This advantage becomes significant when rectifying or deriving elevations for large data sets (Figure 1). In order to take full advantage of inherent processing speeds, disk caching and a disk access of less than 30 milliseconds are desirable.

Recent improvements in display technology have removed significant impediments to low cost image processing. Initial development of the DMS was undertaken on an IBM PC/AT Professional Graphics System (6 MHz) with 640K of RAM. This development platform was subsequently replaced by an IBM PS/2 Model 60 (10 MHz) with 8514/A adapter and 8514 display, permitting either 640 by 480 or 1024 by 786 pixel resolution in 256 colors (from a 256K color palette). At these resolutions, the pixels are square (1:1 aspect ratio) giving equal scale in both the x and y directions, and fine enough to ensure smooth vector representation - important considerations for both mapping and GIS applications.

For planimetric mapping and thematic classification, the standard 640 by 480 by 16 colors VGA display of most PCs will provide an excellent black-and-white rendition of single band digital images and a very usable three-band color image. For topographic mapping from a stereopair of digital images, an 8-bit display is required to ensure perception of a smooth, continuous surface and permit the display of vector overlays.

The 256 colors required for stereoimage display at 640 by 480 *or* 1024 by 786 resolution can be realized with the IBM Display Adapter 8514/A used in conjunction with any of a number of IBM 8514 compatible displays that have recently entered the market (Rosch, 1989). However, the 8514/A adapter is designed for the IBM PS/2 line of computers featuring microchannel architecture. To achieve comparable display resolution with PC/ATs and most 80386 based machines (e.g., Compaq, Dell), a third-party product such as the new Enertronics Research, Inc. Aurora 1024 board with full 8514 compatibility can be installed. A comparison of 4-bit and 8-bit black-and-white and color images is presented in Plate 1.

PLANIMETRIC MAPPING AND MAP REVISION

Most mapping and GIS operations require that the image data be referenced to a standard rectangular coordinate system such as the Universal Transverse Mercator (UTM) or State Plane systems in common use throughout the United States (Snyder, 1982). In order to obtain correspondence between the image and map coordinate systems, a minimum of four ground control points (GCPs) located in both coordinate systems are used to rectify the image (Figure 2).

Map coordinates for the GCPs may be entered from the keyboard or digitized directly from a reference map with the DMS. The image locations of GCPs are determined by using the mouse to precisely position the on-screen cursor on a 2× or 4× smoothed enlargement of the GCP image location, providing image coordinates to the nearest 0.5 or 0.25 pixel, respectively (Figure 2a). Determination of image coordinates to a fraction of a pixel governs the accuracy to which the image can be geocoded-an important consideration for GIS applications (Welch *et al.*, 1985).

A least-squares solution of polynomial equations is then implemented to yield correction coefficients and to determine a root-mean-square error (RMSE) indicating the fit between the image and ground locations of control points (Figure 2b). Normally, an RMSE value of ± 0.3 to ± 1.0 pixel units can be obtained with SPOT and Landsat images. Application of the correction coefficients on a pixel-by-pixel basis yields a geocoded product, resampled (with cubic convolution, bilinear, or nearest neighbor algorithms) to a pixel dimension of the users choice (Figures 2c and 2d). On an 80386 machine operating at 20 MHz, rectification (with cubic convolution resampling) proceeds at a rate of about *2500* pixels per second, producing a 512 by 480 geocoded image or map file in approximately 1.5 minutes (see Figure 1).

By definition, a geocoded image will register to digital planimetric map files. However, *this registration also can be achieved without resampling the image file*. With the DMS, the correction coefficients discussed above are automatically applied to vector files digitized from corresponding maps, thus ensuring their registration as overlays to the original, unmodified raster image. All image coordinates transformed by the coefficient file are stored on disk as ground or map coordinates, facilitating their use for mapping and GIS applications. The above procedures are efficient and eliminate the need for pixel-by-pixel rectification. They also provide the necessary mechanism for registering pc ARC/INFO, USGS Digital Line Graph (DLG), and AutoCAD files to the image data.

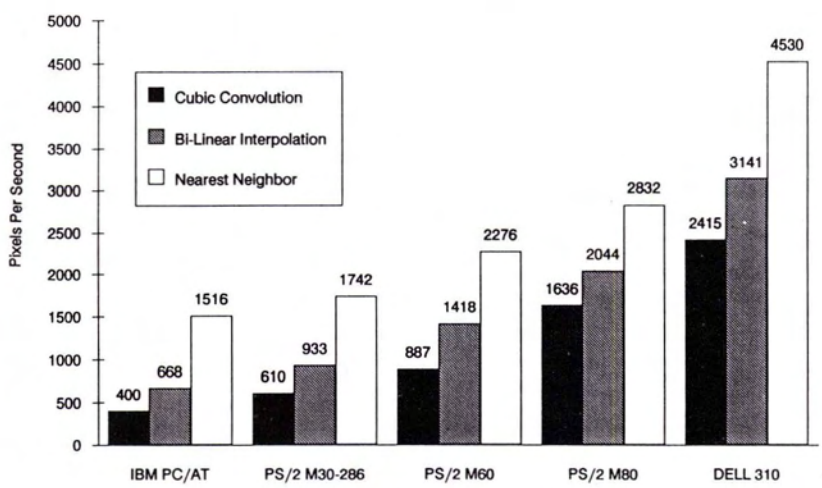


FIG. 1. DMS rectification rates on IBM PS/2 and Dell personal computers. All computers were equipped with factory installed hard disks and 80287 or 80387 math coprocessors. Processor speeds are 6 MHz (AT), 10 MHz (M30, M60), 16 MHz (M80), and 20 MHz (310).

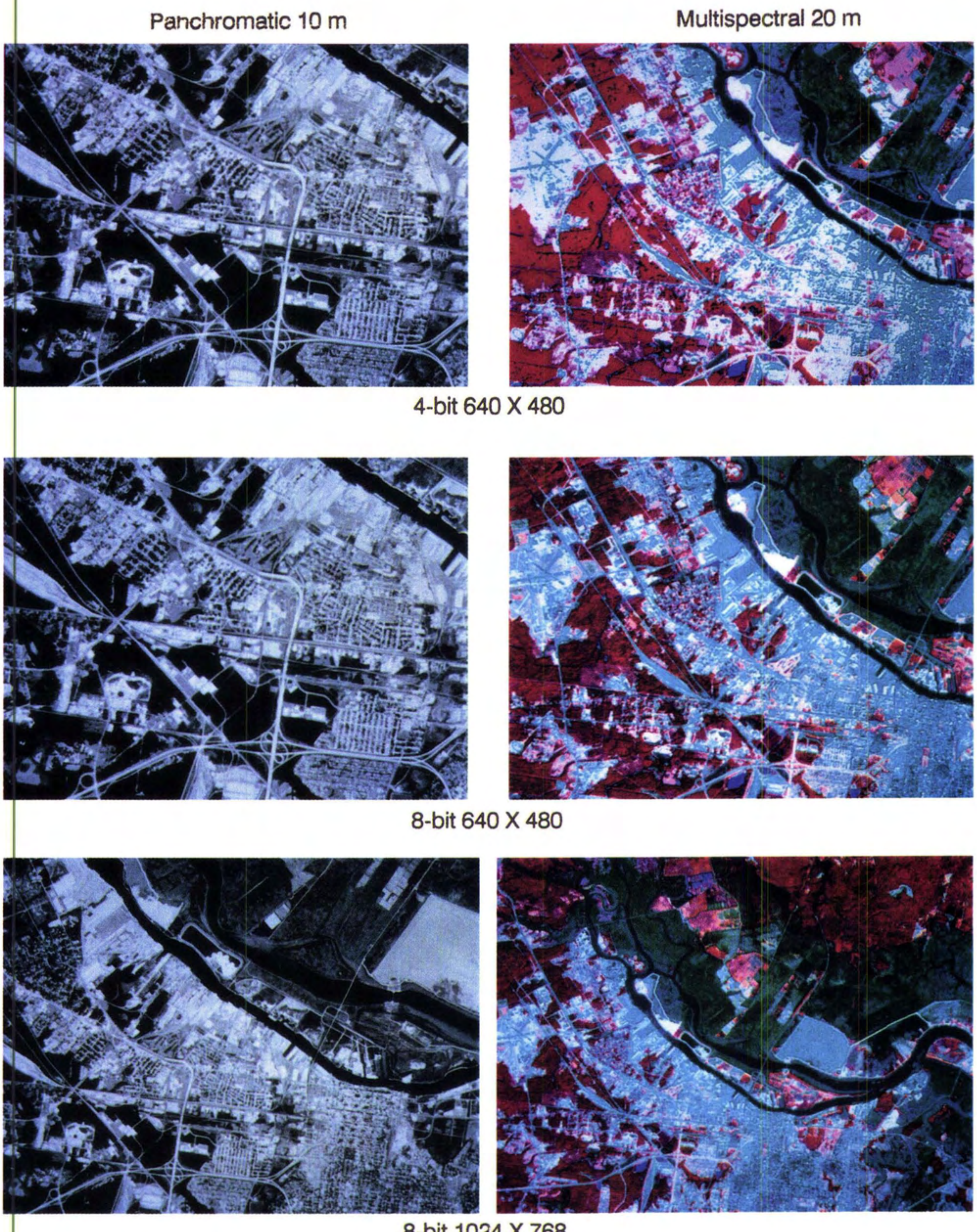
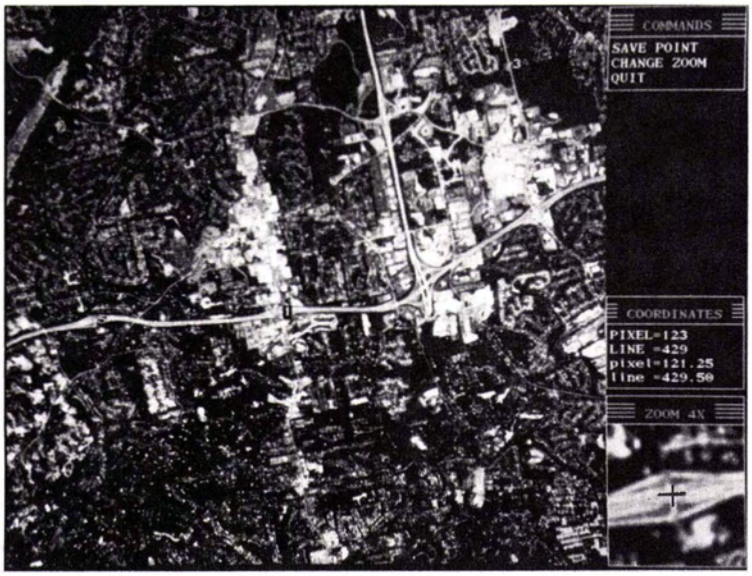


PLATE 1. Comparison of DMS 4-bit and 8-bit image displays of Savannah, Georgia. Original data are SPOT panchromatic (10-m) and multispectral (20-m) images.



(a)

#	True X	True Y	Est X	Est Y	Error
1	742302	3755318	742301	3755314	3.62
2	743768	3754825	743770	3754830	5.44
3	746056	3758086	746054	3758085	2.09
4	739820	3758716	739821	3758722	6.39
5	739751	3755660	739750	3755661	1.51
6	739603	3756592	739600	3756589	4.08
7	741072	3757857	741075	3757851	6.24
		RMSExy (0.46 pixels)			4.56

(b)

(c)

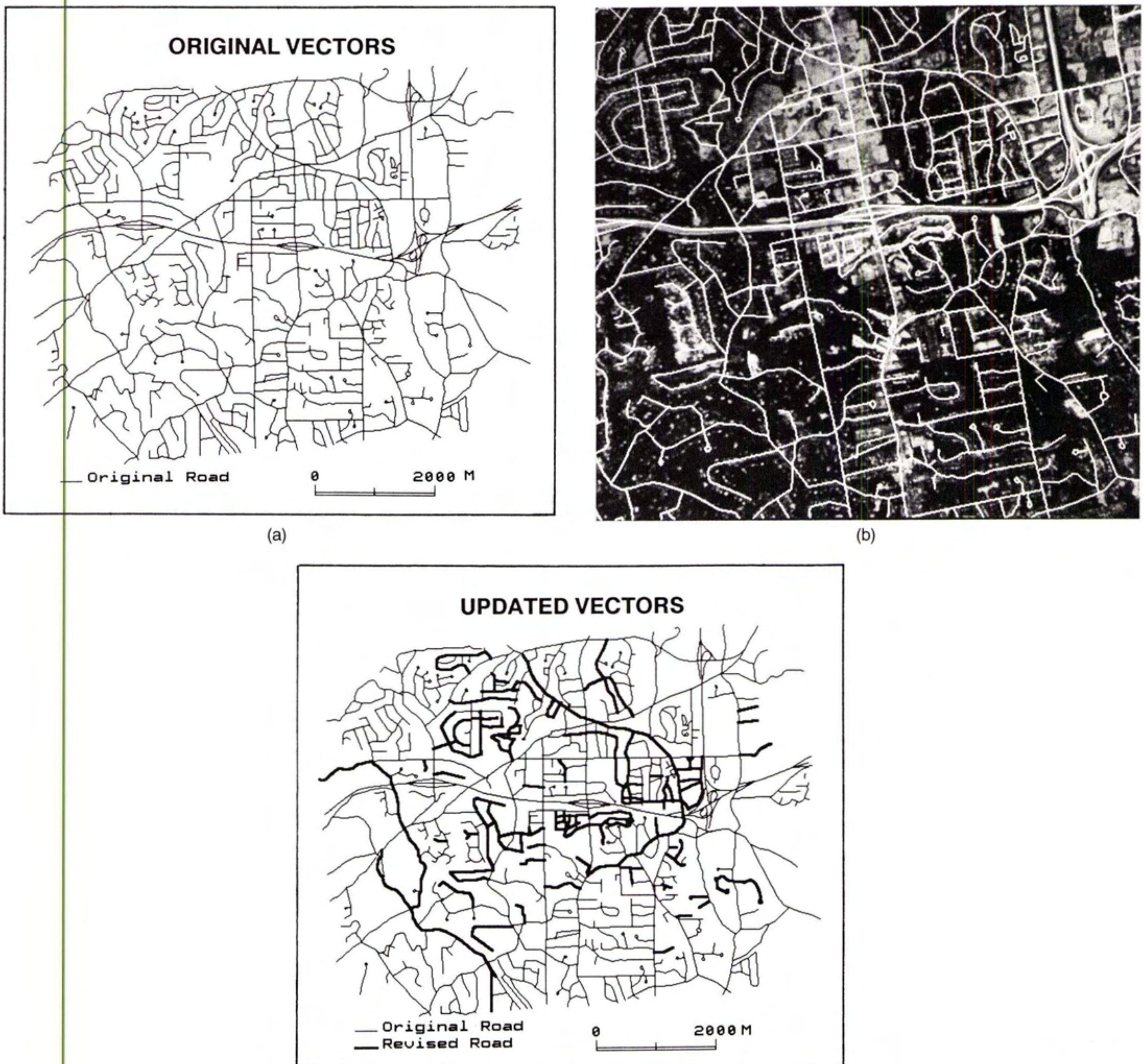
(d)

FIG. 2. Steps in geocoding satellite image data. (a) SPOT panchromatic image (10 m) of Atlanta, Georgia with annotated control points displayed. Note enlargement window for refinement of control point location; (b) computation of rectification coefficients and residual planimetric error; (c) area to be rectified (in box); (d) geocoded image at 8-m pixel resolution.

Map Compilation and Revision

Map compilation and revision from digital data sets require provision for overlay of existing vector files, enlargement or reduction of images, an ability to create vector files with attached attributes from raster image data, and a method for editing the vector files in digital format (Usery and Welch, 1989). In addition, because of the availability of digital image data at resolutions ranging from greater than 1000 m to less than 10 m recorded by a variety of electro-optical and electronic sensors (e.g., NOAA AVHRR; Landsat MSS, TM; SIR-B; SPOT HRV), it is important to be able to merge multisensor, multiresolution, multitemporal image files to create a composite image of improved resolution from which important map features can be extracted (Schowengerdt *et al.*, 1984; Chavez, 1986). With the DMS, image files are easily merged using an intensity-hue-saturation (IHS) algorithm (Welch and Ehlers, 1987).

The planimetric mapping capability of the DMS was used to revise a 1:12,000-scale utility map of a section of the Atlanta metropolitan area (Figure 3). A rectangular 6 by 5 km study area was defined on panchromatic and multispectral SPOT images



(c)

FIG. 3. Map revision with the DMS. (a) Vectors for Atlanta, Georgia digitized from existing map; (b) SPOT panchromatic image (10 m) with vector file as overlay; (c) revisions to vector file.

(Level 1B), and the panchromatic image rectified to the UTM coordinate system using GCPs digitized from USGS 1:24,000-scale topographic maps. In order to facilitate merging these data sets, the multispectral images were resampled to 10-m pixels using a cubic convolution algorithm.

The resampled multispectral images in combination with the SPOT panchromatic data were used to produce a composite IHS image of improved resolution suitable for revision tasks. Vectors digitized from the utility map (Figure 3a) were registered to the image using the overlay option of the DMS. New road features noted on the composite SPOT image were then added to the map file with the on-screen digitizing option (Figure 3b), and errors in the map file were revised (Figure 3c). Overall, the superior geometric quality of the SPOT images was noted and the 10-m resolution proved adequate to update the map file and correct for errors in street location and alignment.

THEMATIC MAPPING

The principles of thematic classification are well-documented (Jensen, 1986). With the DMS, a sequential approach to supervised classification is employed which permits automated classification procedures to be combined with interactive techniques, simulating a conventional photo-interpretation process. Classification is based on up to ten bands.

In practice, a pull-down menu defines the options and a legend for thematic classes is presented. Training sites are selected for a given class, statistics generated, and a parallelepiped classification implemented by color coding the image pixels. This procedure is then repeated for each class until complete. It is possible to interrupt the classification in order to rectify mistakes by "unclassifying" features. Also, if desired, the boundaries of troublesome areas can be outlined and known classes overwritten. The unclassify and overwrite options provide considerable flexibility and when properly used ensure a classification of high accuracy. For a 512 by 480 image and four bands, a complete classification cycle (outline training sets, select the class name, and classify) requires about 30 seconds on a PC operating at 20 MHz. If required, vectors may be overlaid on the classified image using the planimetric mapping option.

TOPOGRAPHIC MAPPING AND TERRAIN REPRESENTATION

The DMS-Stereographic Module is the *first* PC software package that permits the interactive measurement of Z-terrain coordinates (contouring and spot heights) from stereoimage data in digital formats, generation of digital elevation models (DEMs) by automated stereocorrelation, creation of perspective terrain models, and the development of orthoimages. These capabilities are discussed in the following paragraphs.

INTERACTIVE CONTOURING

In order to contour a stereopair, it is necessary to perceive the terrain in three-dimensions. This can be accomplished through the use of anaglyph, polarizing, binocular, or liquid crystal shutter display techniques that ensure the left and right eyes view only the corresponding images of the stereopair. With the DMS, an anaglyph display technique is normally employed, requiring the user to wear eyeglasses with red (left) and blue (right) lenses. Although an anaglyph display may be considered an "old" technique, it can be implemented on standard color monitors without the addition of expensive image memory boards or special attachments. The intensity and illumination fall-off problems that have plagued traditional photogrammetric instruments are not experienced with a computer monitor. Thus, it is feasible to undertake mapping operations in a normally lit room. By taking advantage of the digital enhancement capabilities of the DMS, it is possible to quickly produce images of optimal contrast for stereo viewing.

An alternative approach to the anaglyph display of stereoscopic images involves the use of the new liquid crystal shutter technology as represented by the Tektronix SGS 430 and 620 systems. These shutters are controlled by a Stereoscopic Graphic Adapter card mounted in the PC and produce circularly polarized images at a frequency of 120 Hz which are viewed through polarizing glasses. The liquid crystal shutter display provides a comfortable, high resolution viewing environment, well suited for the display of all types of panchromatic and multispectral image data, including non-topographic images recorded by scanning electron microscopes (SEMs) and X-ray machines. Although the addition of the liquid crystal shutter significantly increases the cost of the hardware components, this cost is insignificant compared to that of digital stereoplotters now beginning to enter the market (Cogan *et al.*, 1988).

In practice, the two images of the stereopair are rectified to a common datum and one or more reference elevation points are identified. These reference points are used to "calibrate" the stereomodel. Elevations are measured by means of a floating dot, in precisely the same manner as with a conventional analog or analytical stereoplotter. However, the Z-motion is controlled with the arrow keys on the computer keyboard and planimetric motion is implemented with the mouse. If desired, the stereoimage can be enlarged or reduced up to 5× (in about 10 seconds); however, enlarging the digital image beyond 2× does not seem to facilitate contouring or heighting. The ability to *reduce* the scale of the displayed image is very useful when viewing mountainous terrain at base-to-height (*B/H*) ratios approaching 1.0. In these instances parallax too large to be visually perceived is also reduced, enabling the observer to obtain a clear, three-dimensional image.

The precision and ultimately the accuracy to which Z-coordinates can be determined is controlled by (1) the *B/H* ratio of the stereopair, (2) the pixel resolution, and (3) the stereoscopic acuity of the user or the sensitivity of the correlation technique. With satellite imagery, geometric quality is excellent due to the inherent stability of the satellite and the systematic corrections introduced to the data. Image deformations, at least for subscene-size datasets on the order of 1024 by 1024 pixels or less, do not appear to be a significant problem. Thus, the computer intensive, sophisticated analytical photogrammetric restitution techniques employed with aerial photographs are not required to achieve acceptable measurement accuracies with Landsat or SPOT images.

The theory of deriving Z-coordinates from satellite images in digital format has been a subject of considerable discussion (Welch and Marko, 1981; Welch, 1985; Rodriguez *et al.*, 1988). With satellite sensor systems such as the pointable HRVs of SPOT, the general equation for determining the *difference* in elevation (Δh) between two points is

$$\Delta h = \frac{H \cdot \Delta p}{B} = \frac{\Delta p}{\tan \alpha_1 + \tan \alpha_2}$$

where $\frac{H}{B}$ = the inverse of the *B/H* ratio. It is computed from the incidence angles (α) noted in the SPOT header records for the two scenes forming the stereopair. The *B/H* ratio is equal to $\tan \alpha_1 + \tan \alpha_2$

Δp = the difference in parallax between the two points

The Δh values when added to the known Z-coordinate for a control point or reference point in a screen-sized area, yield absolute elevations (Z) referenced to mean sea level. That is, assuming no deformation in the stereoimage:

$$Z = Z_{ref} + \Delta h$$

where Z_{ref} = the Z-coordinate for a reference point of known elevation. The pixel resolution establishes the measurement threshold for Δp.

Thus, for a stereopair of SPOT panchromatic images (10-m resolution) recorded at a *B/H* ratio of 1.0, a measurement error of ± 1 pixel will cause an equivalent error (± 10 m) in the Z-coordinate. Reduction of the *B/H* ratio will produce a proportionate increase in this error. Consequently, *B/H* ratios of about 1.0 are desirable for areas of flat to rolling terrain, whereas values of approximately 0.5 to 0.8 are better suited to mountainous regions where larger contour intervals are appropriate.

Tests of contouring and spot height accuracies with the DMS have produced excellent results. Terrain profiles developed from contours compiled with the DMS at a 50-m interval from SPOT panchromatic images (*B/H* = 0.57), and from a USGS topographic map (C.I. = 40 feet) of the same area, agreed to within ± 11 m and ± 15 m, respectively (Figure 4). Comparisons of elevations measured from SPOT panchromatic stereopairs having *B/H* ratios of 0.9 and 1.0 with elevations derived from topographic maps of 1:24,000- and 1:50,000-scale yielded $RMSE_z$ values of about ±10 m. As map errors are included in these figures, it is evident the PC/DMS combination does provide heighting capabilities approaching those obtained with sophisticated analytical plotters or computer systems which are an order of magnitude more

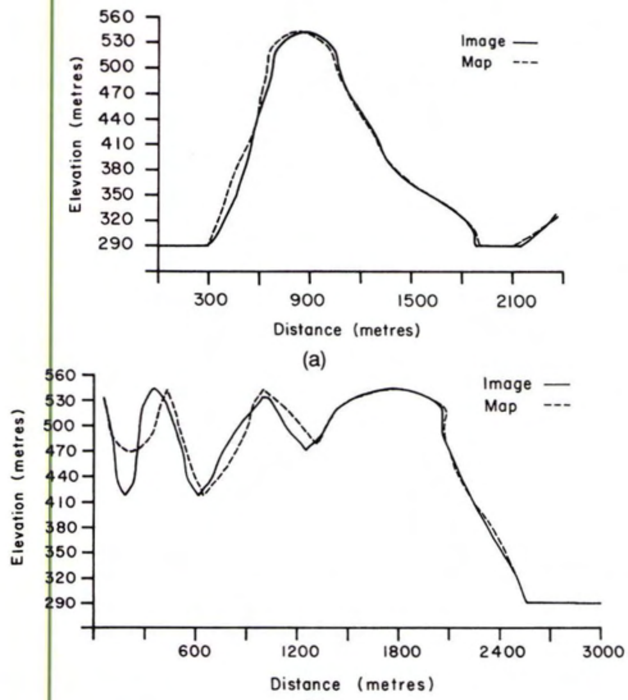


FIG. 4. Comparison of profiles derived from SPOT images with the DMS Stereographic Module and corresponding profiles taken from a USGS topographic map (C.I. = 40 feet). $RMSE_z$ values of ± 11 m and ± 15 m were obtained for profiles (a) and (b), respectively.

expensive (Gugan and Dowman, 1988). Of much greater significance, however, is the ability of the novice user to achieve acceptable measurement accuracies and to rapidly contour the terrain after only a few hours of practice.

The above approach also has been successfully used to develop contours from scanned aerial photographs (Figure 5). However, the tradeoffs between data volume, pixel resolution, measurement accuracy, and display resolution become a major problem when working from aerial photographic data in digital formats. For example, in order to capture the resolution of a stereopair of mapping photographs, it is necessary to scan them (or at least the stereomodel) at a pixel resolution of approximately 25 μm, creating a data set of about 85 Mbytes/photo or 68 Mbytes/stereomodel. With a stereopair of 1:80,000-scale aerial photographs scanned at 25-μm resolution (2 m on the ground), a 2- by 2-km patch of terrain will be visible on a 1024 by 1024 display. At 2-m resolution, heighting errors of about ± 3 to ± 5 m can be expected. Although the trend toward all digital photogrammetry is clear, it is equally evident that problems of data capture, storage, and display require attention.

STEREOCORRELATION

Stereocorrelation is a computational procedure utilized to automatically derive terrain elevations from digital images (Ackermann, 1984). When a stereopair of images rectified to a common datum are placed in register, the residual planimetric differences in the x-coordinates are assumed to result from relief displacement and can be determined by automatic correlation techniques (Ehlers and Welch, 1987). Differences in x-parallax may then be used to derive relative elevations or height differences, which when referenced to one or more GCPs of known elevation as described above, yield the absolute elevations required to form a DEM. The DEM is a fundamental requirement for the generation of contours, slopes, aspects, 3-D perspectives, and relief-corrected orthoimages. Recent experiments with stereoimages have confirmed the ability to achieve correlations to within ± 0.3 to ± 1.0 pixels (Rosenholm, 1986; Simard, 1988).

Stereocorrelation, however, is a *very* computer intensive task that until recently was viewed as suitable for only the most powerful minicomputer systems. With the DMS, stereocorrelation speeds of 30 to 60 pixels per second are routinely realized on a Dell 310 PC operating at 20 MHz (Figure 6). Thus, assuming the use of SPOT images of 10-m resolution, a grid of points at 50-m spacing can be computed for a 1024 by 1024 image in less than 25 minutes. Because stereocorrelation is undertaken as a batch

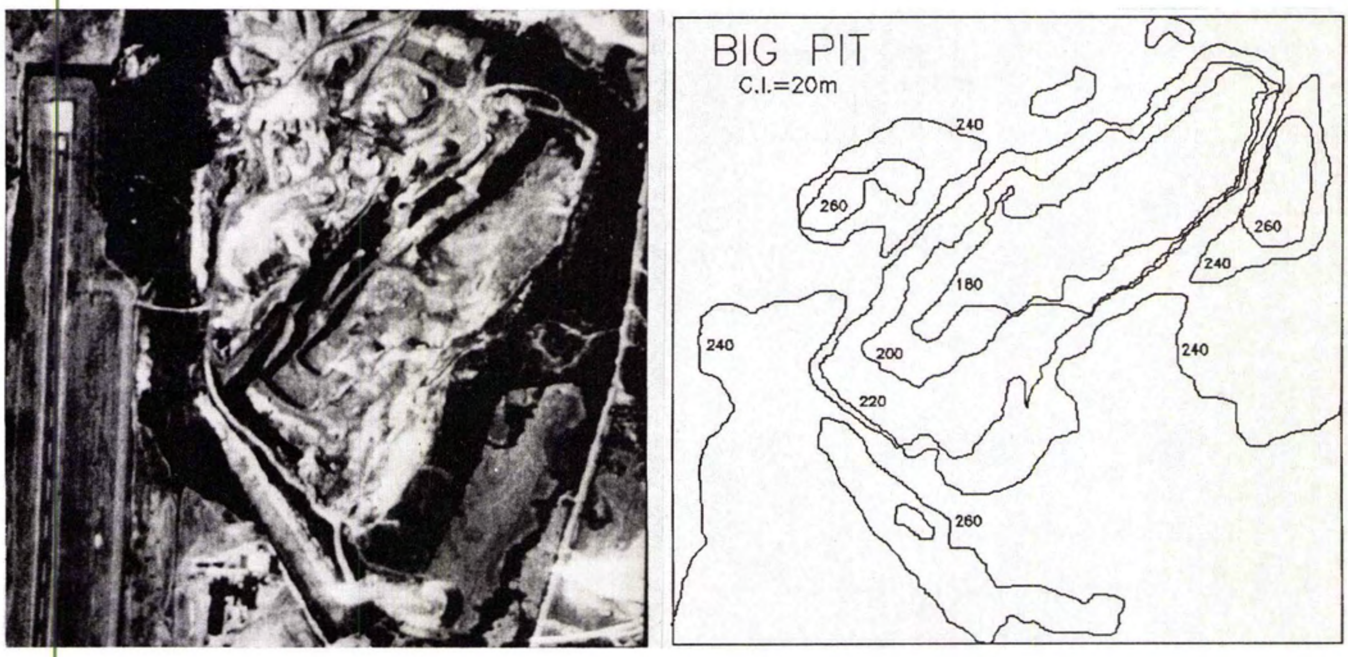


FIG. 5. (a) Section of an air photo digitized at 2.8 m pixel resolution, and (b) contours of a gravel pit (C.I. = 20 m) produced with the DMS.

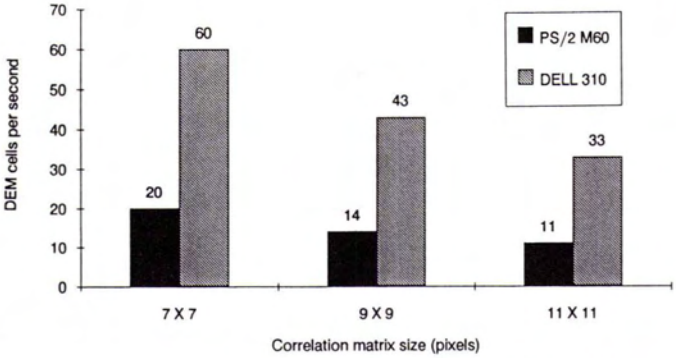


FIG. 6. Comparison of stereocorrelation rates for 80286 (IBM PS/2) and 80386 (Dell 310) computers.

job, the operator may, if desired, implement this task during off-peak hours. The completeness and accuracy of the DMS stereocorrelation will vary according to the selection of correlation matrix size, tonal and contrast similarities of the images forming the stereopair, terrain configuration, and *B/H* ratio. To date, completeness of correlation has averaged 80 percent or better and accuracies equivalent to ± 0.5 to ± 1.0 pixel are realized.

The DMS features a capability for interactively editing DEMs generated by the stereocorrelation option. A matrix of DEM "floating points" is superimposed on the stereoimage. The operator quickly scans the stereoimage, noting which points do not lie on the terrain surface. The elevations of these incorrectly correlated points may be adjusted with the mouse. Thus, the stereocorrelation editing option enables the user to take advantage of both automatic and interactive heighting capabilities.

PERSPECTIVE VIEWS

The ability to create a perspective view of the terrain and to drape digital numbers (DNs) or color values of the pixels on the perspective is of considerable interest to foresters, geographers, geologists, planners, and military intelligence specialists (Plate 2). Major drawbacks to generating terrain perspectives, however, include the volume of data to be manipulated, the time required to generate a display of adequate resolution, and the difficulty in establishing optimum vertical exaggeration, viewing angle, and azimuth. With the DMS, these problems are addressed by initially generating a coarse resolution wire frame or draped perspective at a cell size defined by the user. This coarse perspective is then rotated and tilted, and the vertical exaggeration is adjusted. Once the viewing parameters have been determined for the coarse resolution perspective, cell size is reduced to yield a high resolution perspective display. In this way, time consuming iterations of the display are reduced or eliminated. Comparisons of the rates at which fishnet perspectives (with and without hidden lines removed) can be generated on different hardware configurations are presented in Figure 7. It is interesting to note that direct comparisons for displaying the same DEM data sets as fishnet perspectives using the ARC/INFO TIN module operating on a Prime 2250 *minicomputer* and the DMS on a Dell 310 *PC*, show an approximate 20× speed advantage for the DMS/PC combination. Provided the DEM cell size corresponds to the image pixel dimension, the speeds at which draped perspectives are created will roughly correspond to those for the hidden lines removed column of Figure 7.

ORTHOIMAGES

Satellite images, like aerial photographs, suffer from displacement caused by terrain relief. The magnitude of relief displacement increases outward from the nadir and with pointable sensors, such as the SPOT HRVs oriented to ± 27 degrees east or west of the orbit track, relief displacements of greater than 50 pixels can occur in mountainous terrain, preventing the registration of planimetric and topographic features. In order to correct for relief displacements and ensure feature registration, terrain elevations must be known (Swann *et al.*, 1988).

With the DMS, a regular grid of terrain elevations can be derived directly by implementing on the PC the automated stereocorrelation option (or indirectly by first contouring the terrain or measuring the heights of the grid locations). Because the parallax at each pixel is known, the relief displacement relative to one image of the stereopair can be calculated and offsets introduced in the *x*-direction to place the pixels in their correct planimetric positions. The elevations required to generate the offsets also may be imported from USGS or DMA digital terrain data. Thus, it is possible to create orthoimages and image maps

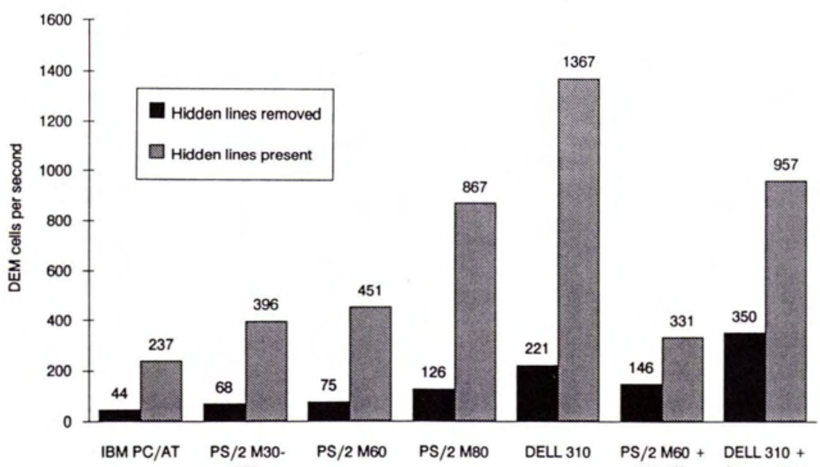


FIG. 7. Comparison of DMS rates (in DEM cells per second) for generation of perspective views with and without hidden lines removed. These rates include both calculation and display time. Except as noted, all computers were equipped with 80287 or 80387 math coprocessors and VGA boards.

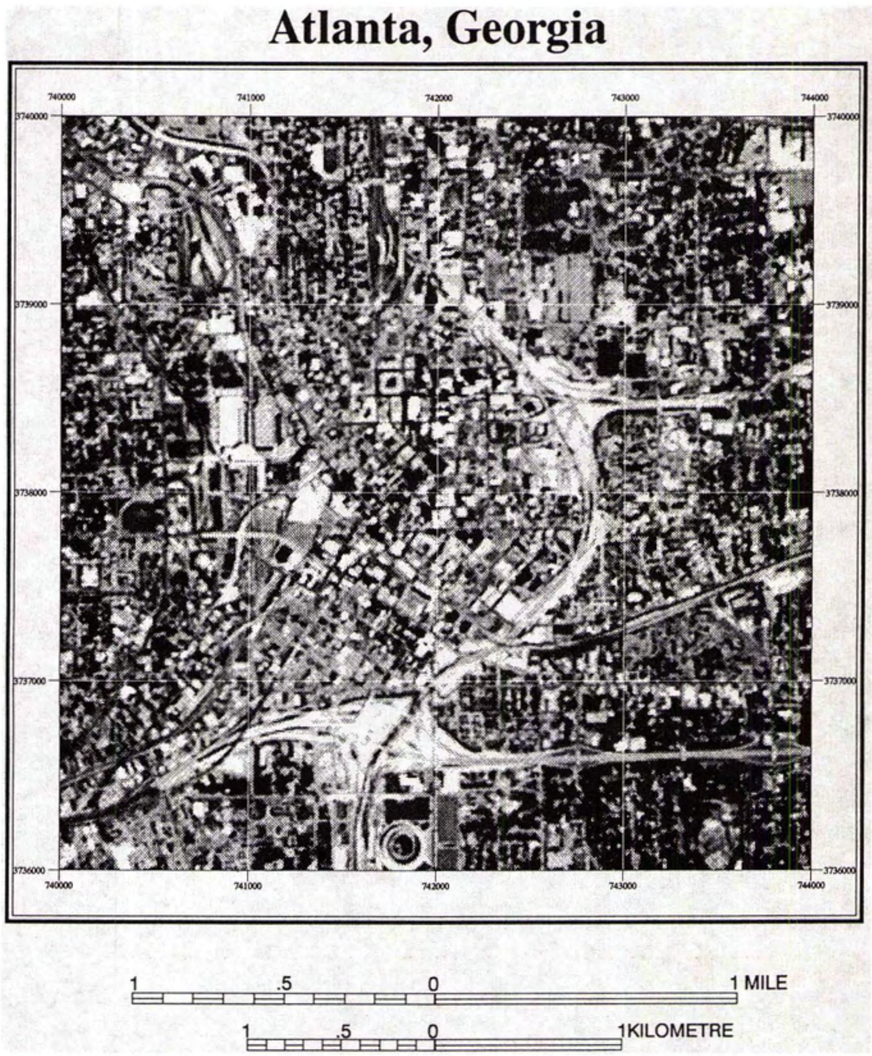


FIG. 8. Orthoimage generated with the DMS and SPOT panchromatic (10-m) data of Atlanta, Georgia.

of even the most rugged terrain that can serve as the reference layer for a GIS database (Figure 8).

INTERFACE BETWEEN IMAGE PROCESSING AND GIS

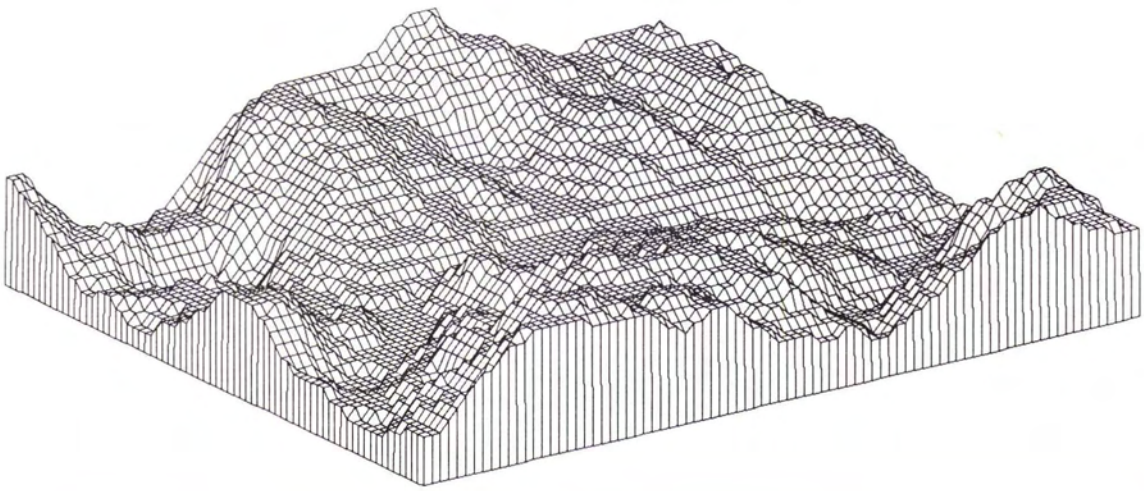
Today, emphasis is being placed on registering vector USGS Digital Line Graph, Bureau of Census TIGER, and GIS data files (e.g., ARC/INFO) with raster images for update or analysis. For such applications, the ability to read different data formats is important, as is the ability to place the vector files in exact registration with the image data. In this context, the DMS may be employed to create vector files that can be utilized with the ESRI ARC/INFO package resident on the same computer. Also, ARC/INFO files can be transported into the DMS environment for registration with digital image data (Welch, 1988). An example of the use of these capabilities to identify potential sites for small shopping centers in an urban/suburban setting is presented here.

A road net for the city of Athens, Georgia was digitized in vector format from USGS 1:24,000-scale topographic maps using the CAPTURE option within DMS. Because the topographic maps were about 15 years old, it was necessary to update the Athens vector file from a SPOT panchromatic image using the previously described revision techniques. A DMS conversion utility was then employed to transform the updated vector file to ARC/INFO format.

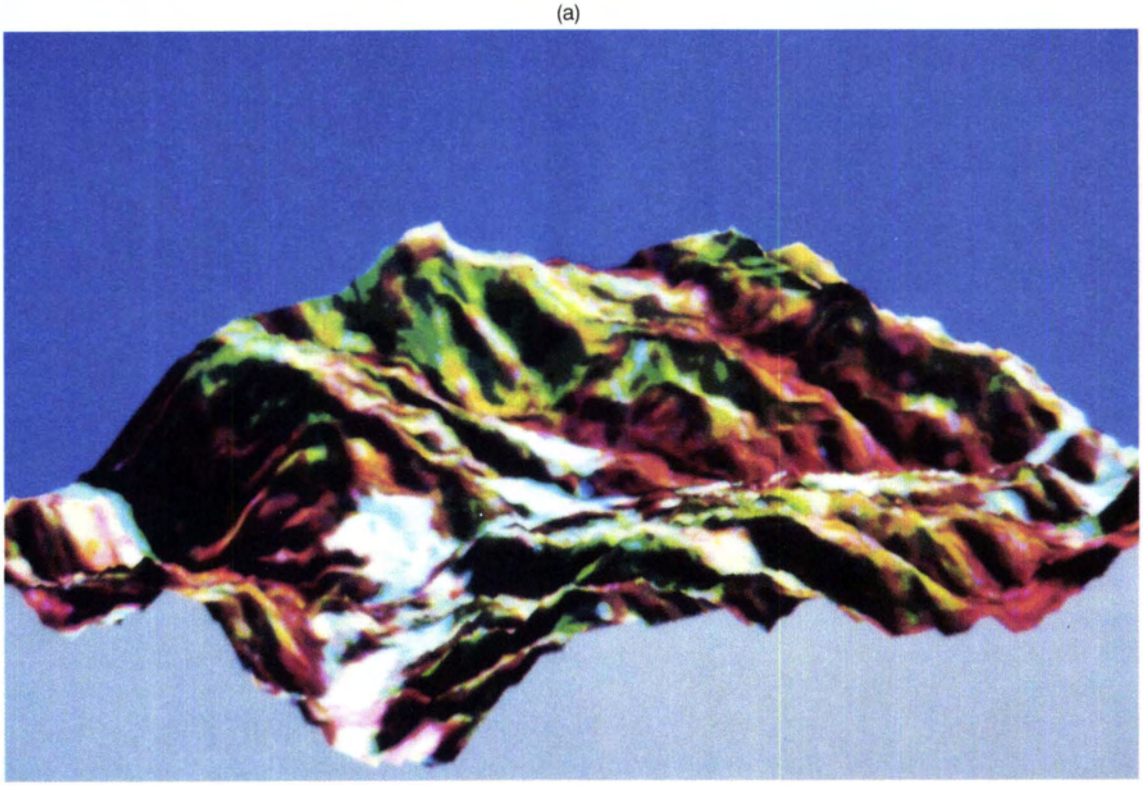
Within pc ARC/INFO – accessed by a few keystrokes – a coverage for the Athens road net was produced using the GENERATE command. Additional tasks undertaken with pc ARC/INFO included building the topology, adding attribute information, conducting a buffer analysis along major roads to create a 200-m wide zone within which shopping centers potentially could be located, and composing maps with ARCPLOT (Figures 9a and 9b). The UNGENERATE command was then employed to create an ASCII file of buffer coordinates which could be used within the DMS to overlay the buffers on the image data (Figure 9c). Once the buffers were superimposed on this image, it was possible to select and outline potential shopping center sites with the planimetric mapping option of the DMS. Of course, if required, other GIS coverages related to zoning, land prices, population density, market areas, and travel time also can be transferred from ARC/INFO to the DMS for registration with the image data.

CONCLUSION

The increased emphasis on the integration of image processing, photogrammetry, remote sensing, and GIS technologies



(a)



(b)

PLATE 2. (a) Wireframe perspective of DEM generated by automatic stereocorrelation from SPOT image data of north Georgia, and (b) multispectral Landsat TM image draped on the wireframe perspective.

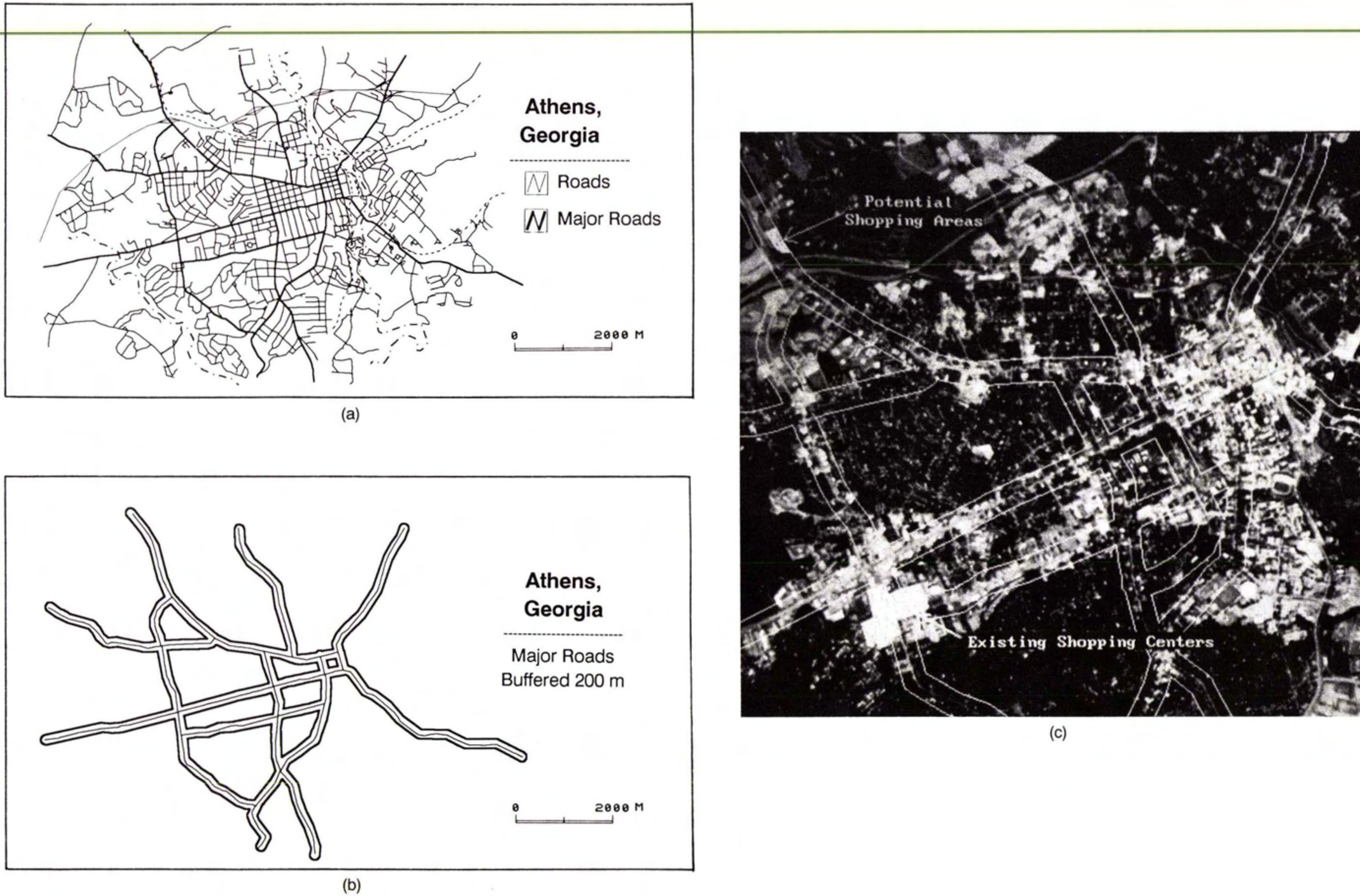


FIG. 9. (a) Road map of Athens, Georgia created with pc ARC/INFO; (b) major roads buffered to indicate potential areas for the location of shopping centers; (c) buffers superimposed on a DMS display of the SPOT panchromatic image (10 m) with existing and potential shopping center locations noted.

mirrors the growing demand for image and map data in digital formats. In this context, the DMS has been optimized to allow complex mapping tasks such as rectification, merging of multiresolution image data, interfacing raster image processing and vector GIS functions, thematic classification, and, particularly, the development of three-dimensional topographic data sets and orthoimages to be undertaken on off-the-shelf PCs in an office environment. Significantly, subpixel measurement accuracies in *X*, *Y*, and *Z* can be achieved by persons having only a few hours of training and little or no previous experience in photogrammetry and digital image processing. Results from investigations with SPOT stereodata, for example, have yielded RMSE values of $\pm$ 10 m and better depending on the quality and *B/H* ratio of the images. Computer intensive tasks such as rectification, automated stereocorrelation, and perspective view generation can be accomplished on 80386 PCs at speeds exceeding those realized on larger minicomputer systems.

It is anticipated that the continued evolution of PC and mapping software technology, coupled with low maintenance costs, will result in the transfer of many image processing, mapping, and GIS tasks from a specialized service industry to a broad-based user community. The DMS and similar software packages will facilitate this trend.

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