PRACTICAL PAPER

A System for Large-Scale Image Mapping and GIS Data Collection

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Abstract

The Bonneville Power Administration (BPA) has been developing methods since the mid-1980s to better meet its growing need for up-to-date and accurate geographic data. These methods are currently used in the site design of BPA substations and for producing substation photomaps. High spatial accuracy is achieved by geometrically correcting digital images to conform to a digital terrain model (DTM), which is in the form of a triangular irregular network (TIN). Computer-assisted methods have also been developed for extracting linear feature data for subsequent use in a geographic information system (GIS). This practical paper addresses BPA methods, system design considerations, and the future migration to a system having an open architecture.

Introduction

The need for accurate up-to-date information is growing rapidly due to the increased use of computers for mapping and geographic analysis. This includes the need for both planimetric data and DTMs. At the same time, some new methods promise to be more expedient than traditional photogrammetric and ground surveys in meeting these needs. These include digitizing feature data from a digital orthophotograph (Parent, 1991), a method that has been receiving increased attention since the introduction of U.S. Geological Survey (USGS) orthophotoquads. Replacing the standard USGS 1:24,000-scale quadrangle maps (Skalet *et al.*, 1992), these orthophotographs provide valuable information for small-scale mapping and planning applications. However, their use in engineering applications will be limited due to their relatively low horizontal accuracy (10 metres), which results from basing geometric corrections on an existing digital elevation model (DEM) with a grid cell size of 30 metres.

At BPA, both engineering and planning applications are important. BPA is one of the U.S. Department of Energy's five power marketing agencies. BPA sells electrical power from 30 Federal dams and one nuclear power plant, has approximately 15,000 circuit miles of transmission lines, and markets power to some 130 Pacific Northwest utilities and 17 industrial customers. BPA not only designs, constructs, maintains, and operates its own transmission lines and substations, but has gained new responsibilities for regional planning, energy conservation, and fish and wildlife preservation, as a result of Federal legislation passed in 1980.

In supporting this mission, BPA has experienced a growing need for reliable geographic data. In the mid-1980s, BPA began to develop a system to provide these data in digital form and to integrate information from digitized large-scale aerial photographs with engineering data. This system is based on the software and hardware capabilities of an image processing system (IPS) acquired at that time.

If BPA were to start designing a similar system for image mapping and GIS data collection today, it would be different from the one described in this paper. Many new products have become commercially available, including low-cost scanners and output devices, geometric rectification software, and low-cost computers that provide improved processing efficiencies. But, most importantly, image processing has been evolving from systems that use specialized hardware to systems with open architectures. This makes it possible to develop software that is not dependent on a specific hardware-based system.

Current plans are to gradually replace BPA's IPS with one that has such an open architecture. To meet future workload requirements, this system will need to provide improved image mapping capabilities in addition to all the capabilities of BPA's present system.

System Design Considerations at BPA

In developing BPA's IPS, attention has been devoted to scanning, geometric distortion and its correction, adding a user coordinate system (UCS) to a digital image, compiling graphic elements, computer-assisted feature extraction, final products, image output, updating products, and future system design considerations. These issues are all covered in the discussion below. The summary and concluding remarks follow, and comments are interspersed throughout that reflect BPA's design philosophy.

Using BPA's current system, aerial photographs are warped to geodetic control to produce geometrically corrected images. Vector data are then written to the geometrically corrected image to produce a digital photomap, i.e., a map superimposed onto a digital image. Also, line-following algorithms are used to extract feature data in vector form from geometrically corrected images for subsequent GIS use.

Scanning

The achievable level of accuracy and detail, as well as initial system and production costs, depends heavily on the type of scanner. The use of low-cost desktop scanners is becoming more common (Carstensen and Campbell, 1991), while high-resolution scanners still cost at least $50,000 (Boniface, 1992). Perhaps more importantly, high-resolution images re-

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quire substantially more resources for processing and storing data. In selecting a scanner, it is important to look at both initial costs and the impact the scanner will have on product quality and production costs. These are all related to system specifications such as scanning rates, selectable picture element (pixel) sizes, maximum image format size, and point-digitizing capabilities.

BPA's present system was designed to meet the needs of many customers, including those requiring a high level of accuracy and detail. Present system capabilities include producing digital photomaps suitable for engineering site design, collecting accurate and up-to-date GIS data, and preparing legal exhibits. BPA has also demonstrated capabilities for map quality assurance/quality control (QA/QC). Errors are quickly detected by superimposing data in vector form over highly accurate digital images referenced to a state plane coordinate system. All of these applications require a scanner having a high resolution of 1,000 dots per inch (dpi) or more.

Some applications, such as reconnaissance engineering, small-scale GIS applications, and facility-access mapping, may not require high spatial accuracy. If these are the only applications being supported, a low-cost desktop scanner may be the best solution.

For applications requiring a high level of detail and accuracy, transparencies (not paper prints) of aerial photographs should be scanned with a precision digitizer. In a study performed by International Imaging Systems (I²S), "Tests indicated that transmissive scanning was essential to achieve quality imagery" (Boniface, 1992). While scanning a print produced a visually acceptable image, scanning transparencies provided more detail. It is important to note that photographic paper prints expand with an increase in humidity, and that this distortion is more substantial than that for photographic film (McKinney, 1980). This distortion due to humidity is both the most significant and most difficult to model, because it is neither linear nor uniform in direction. Paper length can vary by approximately 9 to 90 micrometres per 9-inch length for each percent change in the relative humidity.

BPA has been using a Perkin-Elmer[1] Model 1010 microdensitometer (Micro-D) for nearly all its scanning. This precision instrument provides images of very high spatial and photometric quality, but it is not a fast device. For example, digitizing a 4096-pixel by 4096-line image of a 9- by 9-inch black-and-white photograph takes 2½ hours or longer.

Recently, BPA acquired the Vexcel VX3000 image digitizer, shown in Figure 1, to meet image mapping needs. Currently, it takes about 12½ minutes to scan a 4096- by 4096-pixel black-and-white photograph plus an additional 11 minutes to mosaic the image tiles scanned by the Vexcel CCD array and convert the image into Vexcel's band sequential format. Software updates are forthcoming that will improve digitizing times and provide concurrent formatting capabilities.

In the future, BPA plans to use the Vexcel for most image mapping applications, but plans to use the Micro-D for image classification applications. The Micro-D provides the uniform radiometric measurements needed for image classification by transporting each part of the image past the light path of a single photo-sensor.

[1]Various computer hardware and software products are referenced throughout this paper to reflect BPA methods. Reference to these products does not constitute an endorsement by the author or BPA over similar products on the market.

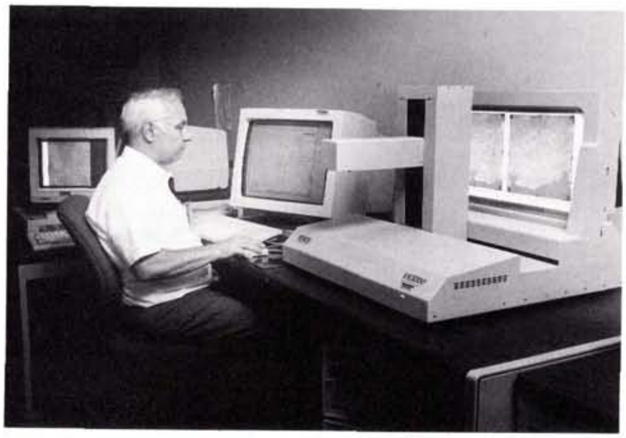

Figure 1. Vexcel VX3000 Image Digitizing Station.

Unlike desktop scanners, the Micro-D and Vexcel also provide point-digitizing capabilities. However, it is difficult to position the cursor accurately over the fiducial marks using the Micro-D. What's more, the operator must write down the x- and y-stage coordinates. With the Vexcel, the operator simply positions a cursor over the desired point as displayed on a monitor and pushes a mouse button to enter the coordinate data into a computer file.

The digitizing pixel size used in BPA work typically ranges from 25 to 50 micrometres. This pixel size is based on project parameters and available photography. Currently, BPA typically transfers an image with a scale of 1 or 2 feet per pixel to an Intergraph CAD Microstation for substation site engineering applications.

Geometric Distortion and Its Correction

The three primary sources of distortion in an aerial photograph are topography, camera tilt, and Earth curvature. To illustrate the magnitude of these distortions to GIS users and others, a BPA contractor tabulated distortions for photographic scales ranging from 1:6,000 to 1:80,000 (Veress and Ding, 1991). These tables show that a point of interest on a medium scale (1:24,000) photograph can be more than 400 metres off.

BPA work generally calls for photographic scales in the range of 1:6,000 to 1:24,000. Topography and camera tilt are typically the two most significant sources of distortion.

Distortions due to camera tilt and Earth curvature can be corrected by the image "warping" algorithms commonly used in image processing. These algorithms use a least-squares polynomial fit of the control-point data that relates the input pixel locations of these points to their output pixel locations. For example, a second-order polynomial of the following form might be used:

$$u = a_1 + b_1x + c_1y + c_1xy + e_1x^2 + f_1y^2$$
$$v = a_2 + b_2x + c_2y + c_2xy + e_2x^2 + f_2y^2$$

where x and y are input pixel coordinates, u and v are output pixel coordinates, and a through e are the least-squares coefficients.

These polynomials work satisfactorily for the geometric correction of high-altitude photography with a scale of 1:40,000 or smaller, as well as for satellite images. However,

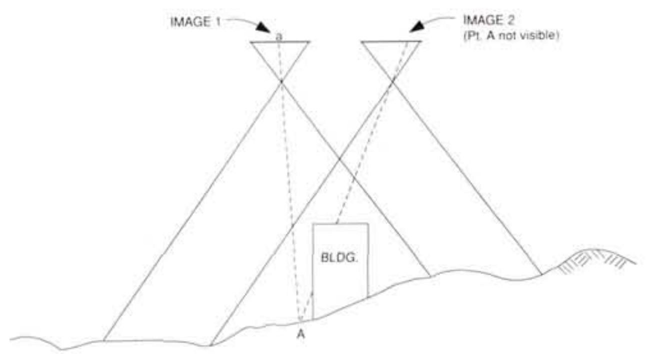

Figure 2. A problem encountered in stereo-correlation.

they do not accurately model the terrain of low altitude photographs having substantial relief.

Another possible solution is to use stereo-correlation methods to automatically generate a DEM, and to use this DEM to generate a digital orthophotograph (Keating and Boston, 1979; Konecny, 1979). However, a number of problems may be encountered in using this approach that require substantial editing (Norvelle, 1992b). For example, tree tops and buildings might be correlated, areas of uniform intensity may be encountered, and problems may occur where there are substantial differences in shape between corresponding parts of a stereo image (Norvelle, 1992a). Also, an area seen in one image of a stereo-pair may not appear in the other image, as depicted in Figure 2. These problems are more consequential when one tries to compile a high-accuracy DEM from large-scale photographs.

In BPA's present system, correlation problems are avoided by using stereo-plotter measurements at slope inflection points to form a triangular irregular network (TIN). Each triangle represents a planar surface and is represented by a first-order polynomial of the form

$$u = a_1 + b_1x + c_1y$$
$$v = a_2 + b_2x + c_2y$$

where x and y are the input pixel locations; u and v are the output pixel locations; and a, b, and c are the linear coefficients that provide an exact fit at the vertex locations.

This approach gives very good results if the control points are properly selected. Independent tests for various terrain conditions found the root-mean-squared (RMS) errors to be approximately 0.3 to 0.6 metres, as Table 1 shows (Veress and Ding, 1991). The photographic scale for these tests was 1:24,000, and the digitizing pixel size was 50 micrometres.

Table 1. Residual RMS Errors in Metres for Various Terrain Conditions (1:24,000-scale photography, 50-micrometre pixel size).

		x RMS error (m)	y RMS error (m)	z RMS error (m)
Flat	— Regular Triangles.	± 0.30	± 0.70	± 1.10
Rolling	— Regular Triangles.	± 0.21	± 0.09	± 0.49
Rolling	— Irregular Triangles.	± 0.21	± 0.09	± 0.21
Mountainous	— Irregular Triangles.	± 0.46	± 0.61	± 0.55

Figure 3 outlines BPA procedures for working with large-scale images digitized from aerial photographs. Major steps include digitizing the photograph, geometrically correcting the image, and compiling vector data.

The first step in geometrically correcting an image is to measure the fiducial marks using both a stereoplotter and the point measurement mode of the scanning system. Because only a section of the photograph is digitized for most BPA work, it is also necessary to define the origin of the digital image in the scanner's coordinate system, as depicted in Figure 4.

An affine transformation is used to transform stereoplotter photo-coordinates to input pixel locations. This linear transformation accommodates unequal scale factors in the x and y directions. This makes it possible to account for physical film distortions or differences in pixel spacings in the x and y directions of the scanning system.

Figure 5 shows how input image and output image locations for the control points are computed from stereoplotter measurements. In the affine transformation described above, stereoplotter photo-coordinates are used to compute the corresponding control point locations in input (pixel) space. Ground coordinates for the control points are obtained from parallax computations based on stereoplotter photo-coordinate measurements. From these ground coordinates, output pixel locations are obtained using the conformal transformation

$$u = \lambda x \cos\theta - \lambda y \sin\theta + c_u$$
$$v = -\lambda x \sin\theta - \lambda y \cos\theta + c_v$$

where

x and y are the control point ground coordinates;
u and v are the corresponding output (pixel) locations;
λ = the user specified scale factor;
θ = the user specified rotation angle;
c_u and c_v are user specified translations in the u and v directions; and
the signs for the y terms reflect that the y and v increase in opposite directions.

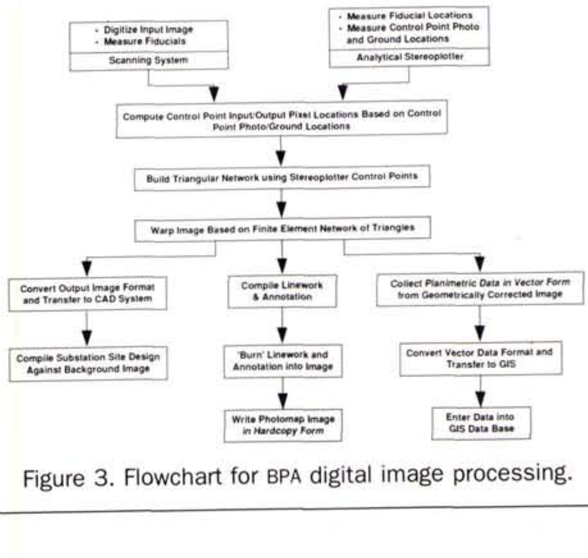

Figure 3. Flowchart for BPA digital image processing.

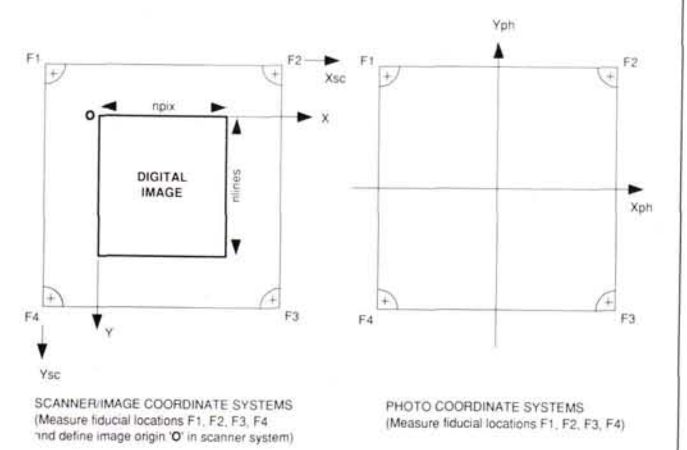

Figure 4. Registering a digital image to a photo-coordinate system.

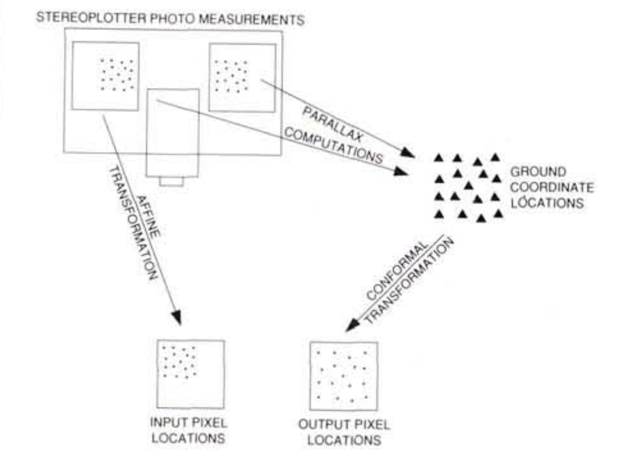

Figure 5. Computing control-point pixel locations.

A conformal transformation, unlike an affine transformation, preserves the shape of the ground control point configuration. Initial estimates for c_u and c_v are computed using a least-squares solution of a gravitational form of the above equations where

$$x_i' = x_i - x_g = x_i - \sum_{i=1}^{n} x_i /n,$$

$$y_i' = y_i - y_g = y_i - \sum_{i=1}^{n} y_i /n,$$

$$u_i' = u_i - u_g = u_i - \sum_{i=1}^{n} u_i/n, \text{ and}$$

$$v_i' = v_i - v_g = v_i - \sum_{i=1}^{n} v_i /n.$$

Results of this least-squares solution make it possible for the user to select transformation values that optimize the placement of the image in output (pixel) space.

Once the input and output pixel locations are determined for control points, a description of each triangle is needed. BPA initially used a classical TIN algorithm to form these triangles. Classical TIN algorithms, however, are based on geometry (Petrie and Kennie, 1987) and do not take elevation into account. This sometimes results in an incorrect solution. Figure 6 gives an example where an optimal angle criterion results in two triangles that truncate a ridge top, as the left half of the figure shows. The correct solution is shown in the right half of the figure.

Using current BPA methods, local four-point sets are first categorized according to one of the three configurations shown in Figure 7. Then, triangles are formed according to the rules in Table 2. The first five cases in Table 2 are different terrain cases for the four-sided polygon configuration, and the remaining two cases in Table 2 correspond to the other two configurations in Figure 7.

Figure 6 illustrates Case 1. The rule for this case is to join the high point to each of the three low points in forming the triangles, as shown in the right half of Figure 6.

After evaluating a four-point configuration and forming the appropriate set of triangles, a contiguous four-point configuration is evaluated. This process continues until the entire TIN is generated. If Case 4, i.e., an ambiguous case, is encountered, a five-point configuration is evaluated in order to resolve the conflict. If a fifth point is not found, the triangles are formed based on geometry and tagged as isolated triangles. This alerts the user that this case should be further assessed. The user can do that with the aid of a mirror stereoscope.

There are other possible ways to form the needed TINs. For example, a TIN could be formed at the same time control-point data are collected using BPA's recently acquired Zeiss P1 stereoplotter. The TIN would be superimposed on the analog stereo image viewed by the stereoplotter operator. A TIN could also be formed in a similar way using the Vexcel VX3000 image digitizer and an image processing workstation with stereoviewing capabilities. With either method, check measurements can be made inside each triangle at the time the control-point data are being collected to confirm the accuracy of the model.

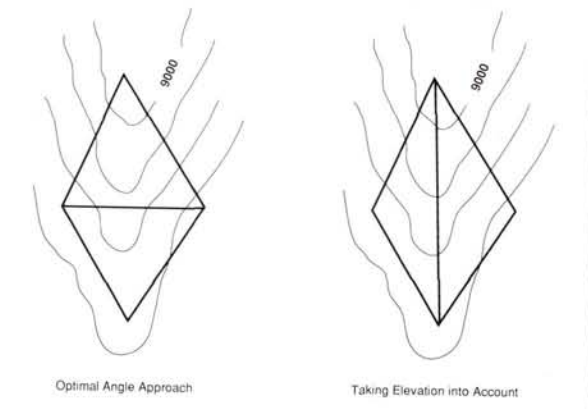

Figure 6. Forming Triangles.

After forming a TIN, BPA geometrically corrects the image by processing a series of 128-pixel by 128-line "pages" as depicted in Figure 8. Triangle sections that overlap each page are individually warped and mosaicked together. This process starts at the upper left-hand corner of the image and proceeds downward, column by column, until the entire image is geometrically correct.

At present, BPA uses an I²S Model 75 image processor with a full complement of image memory and a hardware warper to geometrically warp images as described above. The host computer is a Digital Equipment Corporation (DEC) VAX-8650. The hardware warper itself performs geometric corrections approximately 192 times faster than a VAX-11/780. Geometric correction of a 4096-pixel by 4096-line image with a TIN having 350 triangles takes approximately 3,800 seconds elapsed time and 280 seconds CPU time using the present Model 75/VAX-8650 configuration.

Registering the Image to a User Coordinate System (UCS)

The next step is to add a UCS to the image. This makes it possible for the user to measure the "x-y" position of any point in the image in geographic coordinates and to obtain length and area measurements. It also makes it possible to compile vector data such as lines, text, and symbols. Additionally, vector data from other systems such as CAD systems, geographic information systems, and stereoplotters can be combined or displayed with the image.

Two different types of coordinate systems are supported by I²S S600 software. The first is a linear system defined as

$$X_u = ax + b$$
$$Y_u = cy + d$$

and the second is a rigid system defined as

$$X_u = ax + by + c$$
$$Y_u = dx + ey + f$$

where X_u and Y_u are in UCS values. A rigid system allows images to be at any desired orientation, and a linear system is restricted to having north correspond to the y-axis of the image. BPA uses both types of systems. From a practical viewpoint, all data entry and UCS computations must be performed using double-precision numbers, or spatial accuracy will be compromised. Also, all image orientations need to be supported. If not, the image will first have to be rotated to correspond with a linear coordinate system prior to compiling or writing graphics overlay data, and then rotated back to the desired orientation to produce a photomap. This requires additional processing and may introduce "jaggies," i.e., stair-stepping of the raster line data. If raster line data must be rotated, a resampling algorithm that minimizes this effect should be used.

Compiling Graphic Elements

To generate a digital photomap on the IPS, the desired vector data are first collected and stored in special data structures called graphic elements. Current graphic elements include text, lines, circles, arcs, and symbols. These graphic elements contain location data as well as attributes such as line width, intensity, graphics color, text spacing, text slant angle, and orientation angle.

BPA has both I²S and in-house software for editing graphic elements and transferring graphic element data to or from other systems. This includes I²S software for transferring GIS data in Arc/Info form and BPA software for converting

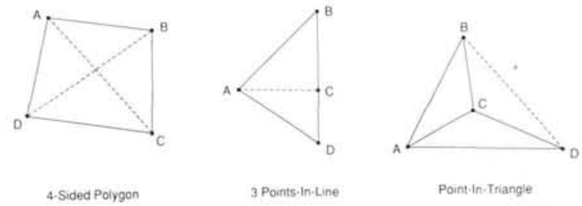

Figure 7. Four-point configurations evaluated in building a TIN.

'.DXF' data (i.e., AutoCAD's drawing interchange format) to BPA graph files.

BPA wrote its own graphics editing software to provide increased flexibility and improved interactive response. However, this development effort has proven to be very time-consuming (Pries *et al.*, 1990). For those contemplating a similar software project, we recommend considering the acquisition of commercially available software that meets all user needs.

Computer-Assisted Feature Extraction

Computer-assisted methods have also been developed to extract data for subsequent GIS use (Pries *et al.*, 1988; Schow-

TABLE 2. CASES AND RULES FOR EVALUATING LOCAL TIN CONFIGURATIONS.

Case	Description	Rule
1	All points within specified elevation range (Flat Case) or interpolated elevations at the diagonal intersection within a specified range (Even Slope Case).	Use shortest diagonal in forming triangles.
2	3 low points, 1 high point (e.g., Peak Case or 3 draw points and 1 high point).	Connect each low point to high point.
3	3 high points, 1 low point (e.g., Depression case or 3 ridge points and 1 low point).	Connect each high point to low point.
4	Two high points on one diagonal and 2 low points on the other diagonal (Ambiguous Case).	Add adjacent control point to form new 4-point configuration and resolve ambiguity.
5	1 low point and 1 high point on each diagonal (e.g., Ridge/Draw Case).	Connect high point to low point in forming triangles.
6	Three-Points-in-Line.	Join middle point of the 3 points on line to the point not in line with the other points.
7	Point-in-Triangle.	To form triangles, join center vertex to each of the three remaining vertices. If terrain case is 2, only include triangles that have high point as one of its vertices. If terrain case is 3, only include triangles that have low point as one of its vertices.

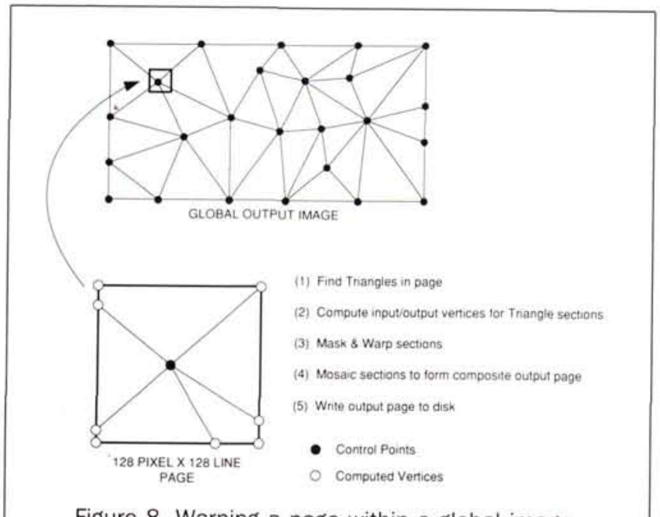

Figure 8. Warping a page within a global image.

engerdt and Pries, 1988). In these methods, the computer precisely follows a bright or dark linear feature based on a general path provided by the user. These methods work well even where the contrast of the feature being tracked and its background vary throughout the image.

The first step in the process is to select and display a section (or viewport) of a geometrically corrected image. The user then picks a starting point using the Model 75 cursor, as shown in Figure 9. Once this is done, the Model 75 displays a window at the starting location, and the window is segmented into feature and background pixels using an adaptive threshold, as Figure 10 shows. The system then computes and displays the two-dimensional (2D) centroid of the feature pixels. At the same time, the user updates the destination point with the Model 75 cursor. A new window is formed that overlaps the current window by a specified overlap amount in the direction of the destination point, and segmentation and 2D centroid computations are performed for the new window. This computer-assisted procedure continues until the user specifies an ending location. The final line is generalized using the Douglas-Puecker line-thinning algorithm (Monmonier, 1982). The user then chooses either to store the linear feature data directly into a graphics element or to edit its contents. The procedure is repeated for all linear feature elements in the viewport and for all viewports of interest in the image.

Recently, BPA has added edge-following capabilities to its linear feature tracking capabilities, and is currently developing a "user-interruptible" procedure for automatic feature tracking. In this "user-interruptible" process, the operator selects the position where feature tracking begins and the computer automatically follows a short segment of the feature. The operator then has the opportunity to reject this segment. If the segment is not rejected within a short time-interval, the same operation is repeated using the ending point for the segment as the starting point for the next segment. If the segment is rejected, the operator moves the Model 75 cursor to the ending point of a straight-line segment that will be used as the starting point for a new segment. At that time, the operator may either manually digitize the ending point for the next straight-line segment or resume the automatic tracking process. This process continues until the end of the feature has been reached.

Final Products

Final system products include geometrically rectified backdrop images, digital photomaps, planimetric feature data, and DTMs. The first two products are currently used for BPA substation projects, and an effort is now underway to incorporate demonstrated image mapping and feature-extraction methods into daily GIS work. A DTM in the form of a TIN is generated as a by-product for each geometrically corrected image, but the use of these DTMs has not yet extended to other applications. BPA first plans to develop QA/QC procedures for DTMs and then inform potential users of their availability.

Image Output

Until recently, BPA used the Micro-D's photowrite option for all photomap output, and writing the image took three hours or more. In searching for a faster output device, BPA found a substantial number of new commercial products for printing digital images. These included laser printers, color ink jet printers, thermal dye printers, thermal wax printers, and color electrostatic plotters.

In selecting a new image output device, it was important to consider specifications such as image format size, number of pixels (or dots) per inch, the number of intensity levels per dot, spatial accuracy, image output size, type of media, and media cost. The number of intensity levels per dot was found to be a most important specification. If a black and white printer has only two intensity levels per dot, some form of dithering (or halftoning) is required to represent additional intensity levels. Unless an ordered dithering process is used, the spatial resolution in image pixels per unit length is substantially reduced (Hill, 1990). BPA has written software that uses ordered dithering to print a black-and-white image using an electrostatic plotter. This provides the capability to print digital images having large pixel dimensions. This capability has been valuable in producing "check prints" of digital images, but does not provide the higher quality that can be achieved using continuous tone printers and film writers.

To meet its needs, BPA recently acquired the modified

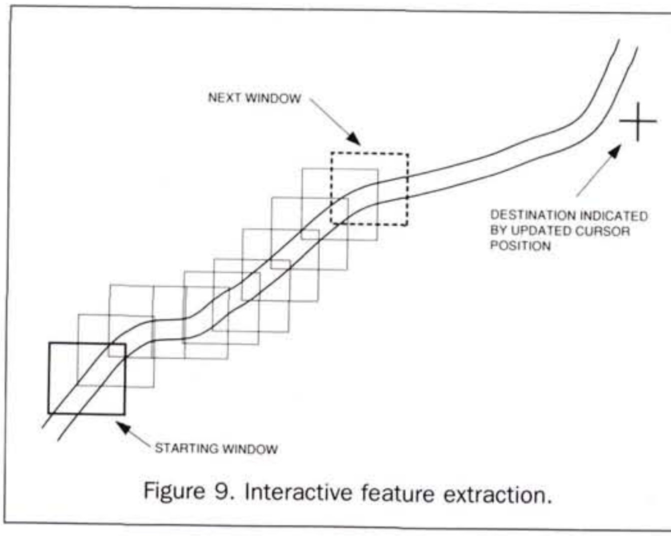

Figure 9. Interactive feature extraction.

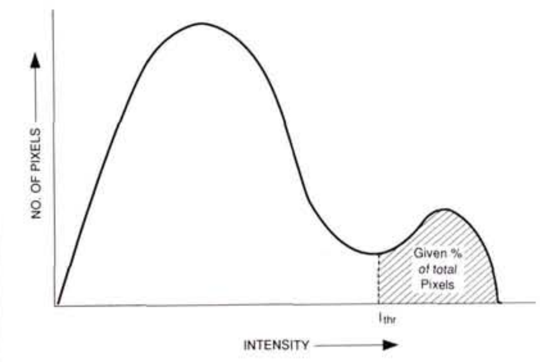

Figure 10. Segmentation using an adaptive threshold.

Raytheon TDU-1200 thermal printer shown in Figure 11. The Raytheon is a continuous tone printer that can write a photomap to paper, plasticized paper, or plastic transparency media in approximately 10 minutes. Output specifications are 300 dpi, and a maximum image width of 3,552 pixels. Modifications made by Raytheon for BPA include increasing the number of grey levels per dot from 32 to 256, and changing the rectangular pixel aspect-ratio to 1:1. The visual quality of the image printed with the Raytheon on plasticized paper closely resembles a photograph to the unaided eye, as Figure 12 shows.

BPA is currently using the Raytheon to produce photomaps for substation site design, facility planning documents, and environmental analysis. BPA has limited experience with the Raytheon at this time, and at present uses paper for preliminary copies and plasticized paper for final output.

Updating Products

An existing TIN can be used for geometric rectification if there have been no topographical changes since the last update. The mathematics for these computations are based on the collinearity equations (Keating and Boston, 1979; Konecny, 1979). A "direct form" of the collinearity equations can be written as

$$u = (w-w_o)\,\frac{m_{11}(x-x_o) + m_{21}\,(y-y_o) + m_{31}f}{m_{13}\,(x-x_o) + m_{23}\,(y-y_o) + m_{33}f} + u_o$$

$$v = (w-w_o)\,\frac{m_{12}\,(x-x_o) + m_{22}\,(y-y_o) + m_{32}f}{m_{13}\,(x-x_o) + m_{23}\,(y-y_o) + m_{33}f} + v_o$$

where

x and y are input pixel coordinates;
u and v are output pixel coordinates;
w is the ground elevation transformed into output space;
x_o, y_o, and z_o are camera station coordinates transformed into input pixel space;
u_o, v_o and w_o are camera station coordinates transformed into output pixel space;
the m terms are elements of the orientation matrix; and
f is the camera focal length.

Updating BPA photomaps or spatial data on the IPS will be accomplished by superimposing the old map in vector form onto an up-to-date image that has been geometrically corrected. Any changes can then be quickly detected and the appropriate graphic elements revised. Overall, updating will take substantially fewer resources than creating the first digital photomap or GIS data file(s) for a given area.

Efficiency Comparisons

A review of current BPA methods shows that efficiencies of using a TIN for image correction are significant. Most importantly, the stereoplotter operator needs to measure only a minimal number of control points to model the terrain accurately. Also, computations are minimized by using a finite element network of planar surfaces. Only four adds and four multiplies are needed for the geometric correction of one pixel. Using a gridded DEM and the collinearity equations requires 12 adds and 16 multiplies per pixel. For a 4,096-pixel image by 4,096-line image, approximately 134,000,000 computations are required using a TIN, as compared to approximately 470,000,000 computations using a gridded DEM. This comparison only addresses pixel-by-pixel geometric corrections. It does not include computations for interpolated elevations used in the DEM method or the computations needed to identify the triangle for a given pixel when using the TIN method.

Future System Design Considerations

BPA's current system is designed around I²S System 600 software and I²S Model 75 workstation capabilities. Even though all new software is written in the "C" language to improve portability, there is still a dependency on the special-purpose I²S Model 75 hardware. Many IPS software functions written by BPA call lower level I²S routines.

In the near future, BPA plans to acquire a modern workstation with the capabilities needed for rapid geometric rectification of image data, for automated and computer-assisted feature extraction, and for image correlation. BPA will also look at vendor software that provides improved performance, additional capabilities, and/or decreases program maintenance costs, without reducing present capabilities. In evalu-

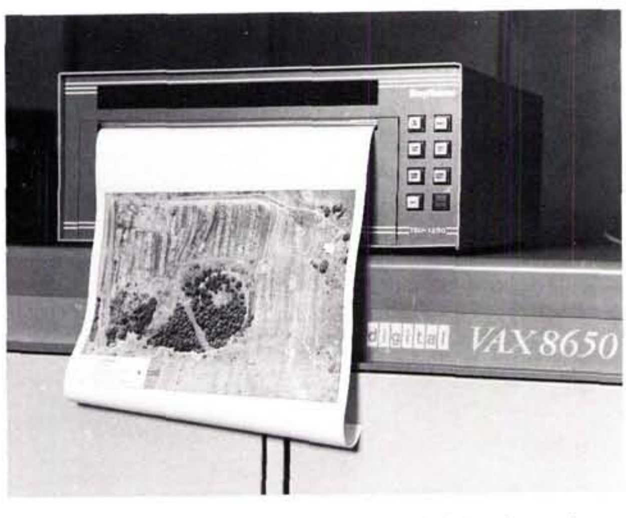

Figure 11. Raytheon TDU-1200 black-and-white thermal printer.

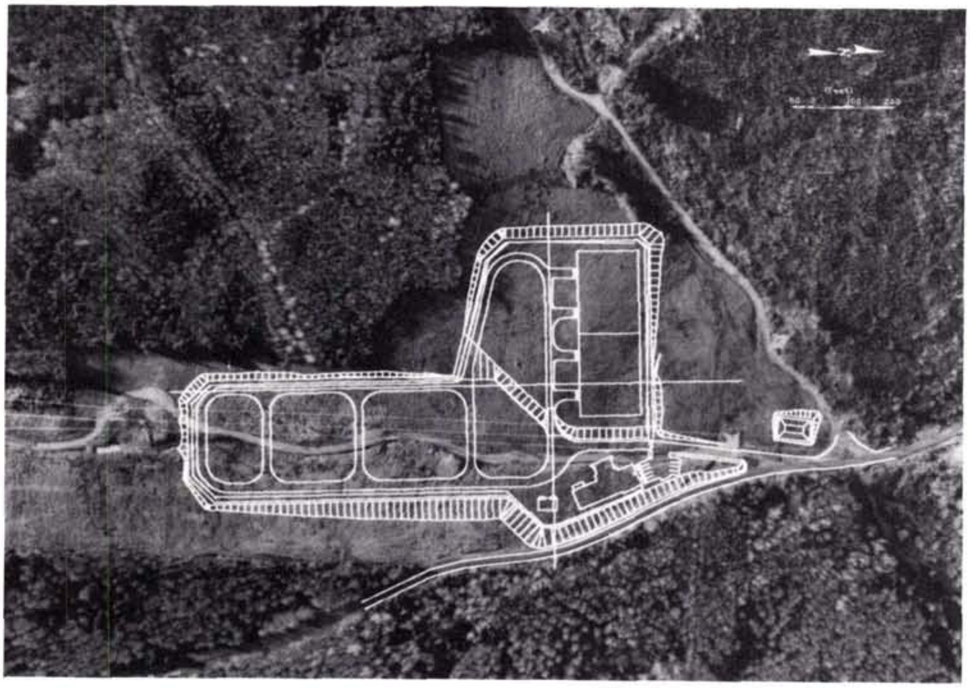

Figure 12. Sample Raytheon TDU-1200 output, 2400 pixels by 1700 lines.

ating the various Unix workstations and personal computer (PC) systems that are commercially available, a number of considerations need to be made. These include initial system and peripheral costs, interfaces to BPA's GIS and CAD systems, CPU throughput, available software, and available peripheral interfaces (to scanners, digitizers, etc.).

The new workstation may include a color stereo monitor. Because the Vexcel VX3000 image digitizer can be controlled from any Unix system running X-Windows, it may be possible to use the new workstation in conjunction with the Vexcel to make parallax measurements. The Vexcel has a 254-mm by 508-mm digitizing surface, a scanning resolution that ranges from 150 to 3000 dpi, 256 intensity levels per dot for each band, and an interface that allows the user to interactively view and select the image area to be digitized. This offers some interesting possibilities for applying softcopy photogrammetric techniques. This system will be capable of making accurate measurements of small, high-resolution sections of an image without the need to archive large image files. These new system capabilities will make it possible to check and upgrade DTMs and provide the tools to interactively work with three-dimensional (3D) image data.

Presently, BPA is pursuing ways to increase automation. More automation is being introduced in IPS feature tracking, and vendor software for image correlation is being researched. Also, feature extraction and image correlation might be combined into a single operation, as suggested in the concluding remarks of another *PE&RS* paper (Hellava, 1988).

Summary and Concluding Remarks

In summary, BPA has developed methods for rectifying large-scale aerial photographs in digital form based upon stereoplotter measurements. The resulting images are currently used to generate highly accurate digital photomaps and may also be used in the extraction of feature data using BPA computer-assisted line-following methods. Single aerial photographs are scanned for these applications and geometrically corrected using a TIN. This approach minimizes labor, data storage, and computational requirements.

In the near future, BPA plans to migrate from a hardware-based system to one having an open architecture. Acquisition of a new system may include new software for stereo-correlation and a color stereo monitor. If acquired, stereo-correlation software might first be used for small-scale mapping applications and later used to acquire TIN data for large-scale mapping applications.

BPA also plans to continue integrating its various geographic and mapping systems. Perhaps the ultimate development will be an expert system that provides image processing and photogrammetry capabilities to those performing GIS and CAD work. This type of system will make it possible for an engineer or planner to acquire photogrammetric measurements, allow the end-user to work interactively with 3D image data, and reduce the risk of omitting relevant data from a project's database. Although this type of system is not likely to emerge in the near future, continued development in areas like those addressed in this paper should bring us closer to meeting that objective.

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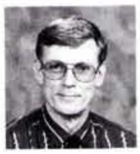

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