A Microcomputer-Based General Photogrammetric System

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ABSTRACT: A digital photogrammetric system, called a videoplotter, has been developed to perform photogrammetric tasks with a minimum of cost and complexity. With a microcomputer and split-screen imagery for stereomodel display, the problems of anterior, relative, and absolute orientation are solved in a rigorous and efficient way. With the possibility of storing orientation files with image files, the system can be used without specific training in photogrammetry, in a way similar to the use of other menu-driven software packages. In its present state of development, stereomodel processing with the videoplotter includes on-line compilation; determination of object coordinates; point, line, and surface superimpositioning in different colors; map updating; and digital terrain model automatic (DTM) generation. Accuracy, a function of input pixel size, is on the order of 0.05 mm at photograph scale, in the experiments presented. The use of a 450- or 600-pixel/inch digitizing scanner, now available at low cost, instead of a 300-pixel/inch one, would lead to a proportional increase of accuracy.

INTRODUCTION

IN A RECENT AND COMPREHENSIVE REVIEW of design concepts of digital photogrammetric systems, Gruen (1989) points out that photogrammetry has now fully realized the potential of the new working tools. And, although he states that we are still "at an early stage of development," it is apparent from the review that development activities are very intense and go in many directions. All the systems presented, however, because of their complexity and cost, cannot be considered directly accessible to the general photogrammetric community. This leaves open a line of research and development that is important to address and to which was directed the concept behind the system described in Agnard *et al.* (1988). This paper even stated that, because of the outstanding advances in microcomputer and microcomputer-related technology, photogrammetry now had the potential to be directly accessible-for reasons of costs, ease of operations, and flexibility-to a lot of new users in engineering, forestry, agronomy, architecture, archaeology, police investigations, etc. The idea was that the hardware was already available in the form of low cost standard equipment. What was needed at this point was the development of software capable of making optimal use of this equipment so that the system would solve the standard photogrammetric problems in a user-friendly and efficient way and even perform tasks that were beyond the possibilities of conventional photogrammetric instrumention.

This paper is concerned with the description and evaluation of a system which represents an example of materialization of this concept. The system constitutes the expected evolution of the much more limited prototype presented in Agnard *et al.* (1988) which was called the "videoplotter."

CHARACTERISTICS AND OPERATIONAL ASPECTS

The hardware components of the new videoplotter have been kept simple and standard. They consist of

- a Model 60 IBM-PS/2 with 1 MByte of RAM, a 40 MByte hard disk, an 80286 microprocessor, and a standard VGA card;
- a Model 8513 IBM Color Monitor with high resolution of 640 by 480 pixels (4 bits) and low resolution of 320 by 200 (8 bits); and
- a mirror stereoscope mounted in front of the monitor to facilitate stereoscopic vision.

Using digitized stereo-images previously stored on the disk, the operations follow the usual steps of interior, relative, and absolute orientations.

To facilitate, speed up, and make more flexible the interior orientation, the program, at the beginning of operations, brings to the screen a rectangular figure, similar in shape to each digital image, on which appears a color window that can be quickly positioned, with a cursor, at the approximate locations of the n fiducial marks ($n \geq 2$). Each part of the image containing a fiducial mark is then automatically brought to the screen, and a pointing to each mark is executed with the measuring dot while its calibrated coordinates are entered as input. Displacement to any place in the two displayed images can be achieved, at the operator's choice, by a combination of movements

- of one or the other or both images, or
- of one or the other or both superimposed measuring marks.

Photograph coordinates are determined by applying the standard orthogonal transformation to the pixel coordinates measured at the scanning stage and stored as a two-dimensional matrix. The transformation parameters are determined by applying a least-squares adjustment to the linear system of equations employing the calibrated and the observed coordinates of the fiducial marks. A different type of transformation could of course be implemented to meet different situations or more sophisticated needs. As directed by the menu, the operator introduces the focal length during the interior orientation procedure. When this operation is completed, the left and right images, centered respectively on the left principal point and its conjugate, are displayed as represented on Figure 1.

A decision was made to proceed through the intermediate step of relative orientation instead of going directly to the bundle formation because the procedure was better suited to some specific applications such as, for instance, the one described in Gagnon *et al.* (1989), where the photographs are considered to be vertical and the scale is obtained directly from the known distance between the cameras.

The relative orientation phase is accelerated by the fact that the software provides easy and fast movement to any part of the stereomodel. In the upper right corner of the screen, as is shown on Figure 1, two small rectangles represent the stereomodel and the black cursors, represent the position in the stereomodel of the displayed images. In order to have another part displayed, the white cursors are moved by a mouse to that part. Depressing a button then brings the black cursors to the same position and brings to the screen the images of that part. From there the measuring marks are moved to the desired conjugate points, by combining either mark or image displacements. Mark movement is usually preferred: it is independent from roam

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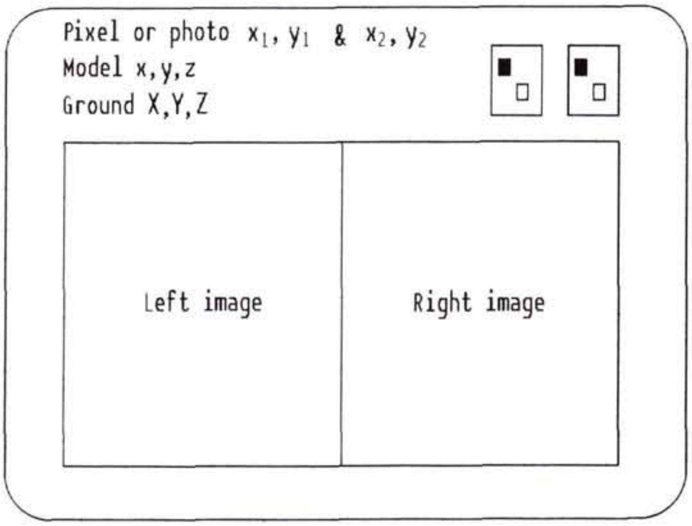

FIG. 1. View of the screen.

speed and probably seems more natural because it gives the impression of moving over the terrain instead of seeing the terrain move.

The relative orientation is solved for by least squares using the coplanarity condition, and a printout of the following is produced for analysis: the values of the orientation elements, the residuals y-parallaxes at the relative orientation points, and the standard y-parallax, at photograph scale. Once the relative orientation is solved, the measuring marks become locked to the respective conjugate points, so that the model is preserved in all displacement of the dots and/or of the images.

The ground or object coordinates $\mathbf{X}$ are computed from the model coordinates $\mathbf{x}$ by application of the similarity transformation

$$\mathbf{X} = \mathbf{k}\cdot\mathbf{M}\cdot\mathbf{x} + \mathbf{X}^{\circ} \tag{1}$$

The scale factor k, the orthogonal matrix $\mathbf{M}$, and the vector of translations $\mathbf{X}^{\circ}$ are determined by least squares using the coordinates of the control points. The solution is based on the Space-M formulation, as described in Blais (1979). The seven independent unknowns of Equation 1 are computed by application of its following linearized form in an iterative way:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a & b & -c \\ -b & a & -d \\ c & d & a \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} e \\ f \\ g \end{bmatrix} \tag{2}$$

Each iterative yields a new set of parameters $a, b, \ldots, g$, which are used to obtain improved values of k, $\mathbf{M}$, and $\mathbf{X}^{\circ}$ (no more than three iterations are sufficient to reach convergence). When the absolute orientation is completed, the system provides a listing of the control points, with their coordinates and discrepancies, and with the mean error in X, Y, and Z.

At the end of each of the three orientation steps, the operator has the possibility of storing the orientation observations or elements in a file attached to the image files, so that a given stereomodel needs to be oriented only once. For a subsequent use of the stereomodel, a menu-driven recall of these files will execute automatically the orientations, so that model processing can be started immediately. In the present state of development of the system, model processing includes

- on-line compilation, by linking the microcomputer to a cartographic plotter;
- determination of X, Y, Z coordinates in the object or terrain system. As shown on Figure 1, photograph, model, and terrain coordinates are continuously displayed at the top of the screen;
- point, line, and surface superimpositioning in different colors. As mentioned by Gruen (1989), this feature is useful for completeness checking. It is also used for map updating, data bank construction, and image analysis. In the color superimpositioning of surfaces, the relative densities of the covered images are preserved in the overlay, in the low-resolution option of the software, so that stereoscopic vision is maintained even inside the colored area; in the high-resolution option, the colors are flat (this limitation would disappear with the use of a card of the IBM-8514 type).
- DTM automatic generation. The stereomodel is scanned along lines parallel to the model x-axis, and terrain coordinates are computed at regular intervals on these lines. Each new DTM point is materialized on the screen by a green point superimposed on its conjugate corresponding points, which helps checking and keeping track of the operation as it proceeds. The point of best correlation is given by the maximum value of the following equation:

$$k = \frac{(\Sigma a_{ij}\cdot b_{ij})^2}{\Sigma a_{ij}^2 \cdot \Sigma b_{ij}^2} \tag{3}$$

where a_{ij} represents the grey value of pixel ij in the master (left) window and b_{ij}, the grey value of pixel ij in the slave (right) window. More sophisticated formulas have been tested but have not provided significantly better results. The result is subjected to three rejection tests:

- if k is smaller than a preset value,
- if a big jump in elevation is immediately followed by a similar jump in the other direction, and
- if the highest correlation comes from the extreme points of the slave (right) window.

When the computation cannot provide an adequate result, for instance, in the case of cliffs, high walls, or important shadows, a red point is displayed instead of a green one, as an editing tool, and a buzzer informs the operator.

SYSTEM PERFORMANCE

The last two features go beyond the possibilities of standard stereoplotters, conventional or analytic. The same applies in a certain way also to the second feature when considering the above-described possibility of going very fast to any point in the stereomodel, without having to take into account roaming speed, that characteristic contributing, in fact, to improving all the operations. The possibility of recalling and using the orientation files means that the system can be used without prior knowledge or background in photogrammetry, in a way that is similar to the use of other menu-driven software packages.

As the formulation of the different steps of operations rests on well-established mathematical concepts, and as pixel-size observations are easily performed on the type of screen used, the accuracy of the output is essentially ruled by the resolution of the input, which, in the experiments related to the development and testing of the system, has been generated by an HP Scan-Jet Digitizer, at a resolution of 300 pixels/inch, or 0.08 mm, in 16 shades of grey. Effectively, as the following results below indicate, the accuracy of the output is of the same order as the quality of the input. These results give a good indication of the present accuracy of the system; they were obtained using 1:6000-scale photography of the Canadian Research Council's test area of Sudbury, Ontario. The photography is 23 by 23 cm in format, taken with a 15 Uag objective Wild camera and has been digitized from paper positives. The model chosen contained 19 well-distributed X-Y-Z control points, known to the nearest 1 cm and materialized by 30- by 30-cm targets. Nine points were used as control points and ten as check points. The RMS, in metres, in X, Y, Z, was,

for control points:	0.23	0.32	0.08
for check points:	0.25	0.51	0.22

From these we get the following RMS, in mm, at photograph scale

for control points:	0.04	0.05	0.01
for check points:	0.04	0.09	0.04

With the same model, a standard y-parallax of 0.02 mm, at photograph scale, has resulted for the relative orientation, computed with ten well-distributed points, which agrees with results obtained with other models processed in a similar way. This result, in addition to the ones given above, is in accordance with the accuracy that can be expected from the input pixel size. For this reason, the scanner has only been calibrated for scale differences between its x and y axes, and the fiducial marks have been measured on the paper positives. The eventual use of a smaller-sized input pixel will, of course, require more sophisticated processing, in order to take advantage of the increased potential of accuracy. A substantial increase is already possible, considering the fact that low-price scanners are now available on the market, with resolutions of up to 600 pixels/inch instead of the resolution of 300 pixels/inch on which the above results are based. Another improvement will come with the possibility of digitizing the images with low-price color scanners. Interesting applications could be considered, in large-scale forest inventories, for instance, with a spread of intensity levels of colors sufficient to obtain displays that will appear reasonably smooth to the eye (Gonzalez and Wintz, 1987).

CONCLUSION

The systems described by Gruen *et al.* (1987) or Cogan *et al.* (1988), or the systems now being developed by Helava & Associates or Matra, have the possibilities of being very efficient and yielding very sophisticated and accurate results. Yet, as they are quite complex and costly, they are not readily accessible to users who, on the other hand, would be satisfied by the type of operations and the kind of results that the system described here can provide. This system meets the desirable requirements of flexibility, simplicity, and adaptability mentioned by El-Hakim (1985), at a hardware cost of under $5000, and much less if the user already has a suitable microcomputer at his disposal. Because of that, the category of potential users is vast: it includes not only those interested in the usual surveying and mapping applications but also a lot of new users, in remote sensing, forestry, agriculture, architecture, etc., who will most probably be able to see and develop numerous applications with this type of soft-copy photogrammetry.

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