A PORTABLE SOFTWARE SYSTEM FOR A DIGITAL PHOTOGRAMMETRIC STATION

P. Zatelli, PhD. student, Dept. of Civil and Enviromental Engeneering, University of Trento, via Mesiano 77, Trento, Italy.

Intercommission Working Group II/III

KEY WORDS: digital, plotter, software, object-space, image matching, portability, multiple images.

ABSTRACT

In this paper the design, the realization and the test of a photogrammetric system is presented. This system is built over a standard hardware platform using standard programming techniques to obtain a portable system. All the standard analytical plotter functions are assured and partially automated, such as image preprocessing, image orientation and determination of object space coordinates of single points and of points along linear features.

1. INTRODUCTION

This work is part of the digital photogrammetric research at the Photogrammetric Laboratory of the Department of Civil and Enviromental Engeneering of the University of Trento.
Interest's areas cover:

- digital sensors calibration and precision analysis of the close range photogrammetric techniques;
- monoscopic survey of plane objects for strain determination of laboratory samples;
- development of a digital photogrammetric plotter with the same functionality of a traditional photogrammetric plotter but with the automation of some of the tasks and a general ease of use.

In this paper the development and test of the digital photogrammetric plotter is presented.

2. DESIGN ELEMENTS OF THE SYSTEM

2.1 Functional design

The software component of the digital photogrammetric system must be suitable for:

- an efficient user-system interaction via a graphical user interface that provides images visualization, pointing of the interesting features and general controls of the system;
- image enhancement that makes possible the use of all the information in the images, making them more readable and increasing the meaning of the details;
- use of matching algorithms: these techniques perform digital image correlation, allowing the automation of some tasks and 3D point determination by monoscopic pointing;
- use of image orientation algorithms: this is necessary to obtain the functions of a stereoplotter (not only those of a comparator): the choosen algorithm is a global (relative + absolute) orientation performed in a single step by bundles adjustment;
- data base interface: the system can obtain images and other informations directly from existing databases, system output must be compatible with existing databases;

The following other tasks are not currently implemented but only designed for further developments:

- image trasformation: image normalization helps in DEM measurements and all the plotter functions;
- feature extraction: these operations are usually partially automated because of the difficulty in the formalization of the a priori knowledge of the operator about the objects in the images;
- results control: gross errors can be automatically recognized but the final quality judgment about the results must be always given by an operator.

Some of the digital photogrammetric systems actually make use of stereo vision, this solution requires dedicated hardware and trained operators.
In our system the operator observe one image at a time; the system itself substitutes the stereo vision by means of image correlation; the three main advantages are:

- no special hardware is required;
- no special training is required;
- the simultaneous use of several images is possible.

In the present version of the system there are no limits in the number of images for single points off-line plotting and image orientation, while up to three images can be used for on-line plotting with oriented images and monoscopic observation.
It must be remarked that the use of three images in the plotting operation make the system quite more precise and reliable than a system that uses two images only thank to the better redundancy. On the other hand a system that uses even more images would require a more complicated algorithm.

2.2 Internal design

The realized system essentially is a software package designed keeping in mind the functional requirements already explained and the further requirement of portability on different hardware platforms and the possibility of extensions. This is obtained by a modular design and the use of standards for coding. These standards are currently missing for image visualization and user interface, although the common orientation towards X-windows and Motif enviroments.

The use of a client/server architecture is another way to allow portability, this allows the use of the digital photogrammetric system even with huge photogrammetric data, relying on a central server.

The program is written in the ANSI C language to take advantage either of the flexibility of the C programming language and of the ANSI standardization.

The graphical interface, that realizes both image visualization and user interaction, uses the X-windows/Motif system, that is generally available on Unix system.

The software is divided into different modules for:

- image acquisition and preprocessing;
- user interaction (both input and output);
- numerical computation.

Each module has been tested as a separate program to evaluate both correctness and efficency.

3. OPERATIONS WITH THE SYSTEM

The operations with the system are divided into orientation and plotting.

The orientation is performed into three steps:

- the operator searchs for approximate homologous points in all the loaded images and for control points;
- the system refines the seach of the homologous points by a least square image matching;
- the global orientation is performed by bundles adjustment.

The procedure determines orientation parameters for each image and ground coordinates of the points with their standard deviations. It is possible to fix the reference system either using known ground points coordinates or setting proper constrains on the image orientation parameters. In this way it is possible to set an arbitrary reference system.

The actual plotting of points in the object space (i.e. the determination of object point coordinates) is carried out using a procedure that determines parameters in the object space by means of suitable observation equations described in the following paragraph. The operator chooses a point in the first image moving a cursor on the screen by the mouse and gives an approximate value for the elevation Z of the point. The system automatically gives the planimetric object space coordinates of the point and determines its height.

If the system is computing the coordinates of a linear set of points the operator follows the line on the first image: the system computes in real time the 3D ground point coordinates and records them with a fixed spatial interval.

The ground points coordinate determination is monoscopic in the choice of the points but tridimentional in the results: the operator selects points on one image and the system "sees" the other images to give the coordinates in the object space reference system. Obviously image orientation must be known at this stage.

All the system functions are controlled by the operator in two ways:

- with the preparation of input files;
- with the interaction during the system operations.

Input files are:

- a session description file, which contains all the default values for the parameters and the choices for the different options;
- a file containing approximate or actual (if available) orientation parameters for all the images;
- the image files.

A set of initial parameters is set up in the session description file, these include:

- input and output file names;
- least square matching parameters: dimensions of the local matching window, approximate values and constrains for the geometric and radiometric trasformation parameters;
- ground points coordinates determination parameters, such as approximate slope and object space discretization steps;
- image orientation parameters: minimum and maximum number of iterations and convergence test settings.

Each system operation records its results in a specific file that can be used as input for the following steps.

During system operations all user interactions are driven by an user-frendly interface; it's possible to change all the parameters' values at run time.

4. MATHEMATICAL MODELS AND COMPUTATIONAL PROCEDURES

4.1 General informations

The matamatical models used for the implementation of the system are partly very classical and well known and partly more innovative.

The least square image matching in the image space is now a standard procedure, and it will not be described here. It is used by the system to refine the coordinates of the homologous points before computing the orientation.

Bilinear finite elements are used to interpolate the image density (or gray values). The image gradient is evaluated by means of finite differences and interpolated in the same manner. This procedure is not based on an overall consistent model, but the results are acceptable for practical purpose and the procedure is very simple.

The equations for the final plotting are based on a direct definition of unknown parameters in the object space and will be described in the next point.

4.2 The equations of local image matching in the object space approach.

The object surface is locally approximated by a plane, therefore the parametric equation of the surface itself in the neighborhood of a point P is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_P + \begin{bmatrix} \Delta X \\ \Delta Y \\ \frac{\partial Z}{\partial X}\Delta X + \frac{\partial Z}{\partial Y}\Delta Y \end{bmatrix} \qquad (1)$$

where P is the considered point, $\frac{\partial Z}{\partial x}$ and $\frac{\partial Z}{\partial y}$ are the components of the gradient vector in the same point and ΔX, ΔY are the parameters that can be interpreted as local planimetric coordinates.

The variation of ΔX and ΔY within properly choosen intervals and with a certain incremental step define a set of gridded points around P.

For each of these points one or more observation equation can be written.

An indipendent equation can be written for each image in the form:

$$g_i(x_i, y_i) = G(X, Y) \qquad (2)$$

where

i = index of image ((1, 2) or (1, 2, 3) in our implementation);

x_i, y_i = image coordinates in the i^{th} image, related to (X, Y, Z) by the collinearity equation;

$G(X,Y)$ is the function that represent the gray value of the imaged surface (a very simplified radiometric model is considered here, in practice a linear radiometric trasformation has been implemented).

The first step for the practical use of the equation (2) is to eliminate the unknown function $G(X,Y)$.

We have, with two images:

$$g_1(x_1, y_1) = g_2(x_2, y_2) \qquad (3)$$

while for three images we can write

$$4g_1(x_1, y_1) - [g_2(x_2, y_2) + g_3(x_3, y_3)] = 0 \quad (4.b)$$

$$\sqrt{3}g_2(x_2, y_2) - \sqrt{3}g_3(x_3, y_3) = 0 \qquad (4.a)$$

that are observation equations with incorrelated known term of the same weight.

These equations must be linearized and then they can be used in a standard least square adjustment.

There are two possible way for choosing the point to be plotted:

- fix X_P, Y_P; in this case Z_P and the components of the gradient are the unknowns.
- fix $(x_1, y_1)_P$: the point must be determined along the line of sight defined in this manner: again we have 1 degree of freedom for the position of the point and two more unknowns to model the slope.

All this unknowns are determined as solutions of the normal equations generated by the observation equation (3) or alternatively (4.a) and (4.b).

It must be remarked that the unknowns are implicitly contained in the (x_i, y_i) image coordinates by means of the collinearity equations and the parametric equation (1).

5. TESTS

The system has been tested both with simulated and real images.

5.1 Tests on simulated images

A specific program allow the simulation of images taking with a given color pattern, surface height and camera orientation. These tests allow an immediate checking of the results and the consequent judgment of the system working.

The grey function that describes the object pattern in the simulate images is:

$$g(x,y) = |X - X_0| + |Y - Y_0| + 20 \cdot sin(X) sin(Y) + 5 \qquad (5)$$

where (X, Y) are the planimetric ground point coordinates, (X_0, Y_0) are the coordinates of the centre of simmetry of the artificial pattern. The surface shape and the cameras' orientation are different in the various tests, however they are choosen so that images deformations are small and the overlapping is more than 60% in both directions.

In the main tests the object surface is a plane, with equations, in the different cases, $Z = 0$, $Z = 0.005 \cdot X + 0.005 \cdot Y$ and $Z = 0.03 \cdot X + 0.03 \cdot Y$.

Least square matching has given good results, as shown in the following table.

Test	Std Dev max	S. D. x max [pixel]	S. D. y max [pixel]
Slope 0	10^{-3}	$<10^{-3}$	$<10^{-3}$
Slope 0.005	$2 \cdot 10^{-3}$	0.007	0.007
Slope 0.03	$5\ 10^{-3}$	0.042	0.038

Table 1: least square matching results.

The higher values for the last two trial can be explained with the deformations of the images due to the slope.

The next step is images' orientation with bundle adjustment procedure, the reference system is fixed by constrains on the coordinates of the taking points of the first and the third images and on the ω angle of the second image.

The results of the orientation procedure are shown in the following table, the max error indicate the maximum error of the coordinates of the points on the images, that are known in the simulated tests.

• Test	σ_0^2 [pixels^2]	N. of iterations	Max error
Slope 0	$1.38\ 10^{-5}$	10	$1\ 10^{-5}$
Slope 0.005	$1.58\ 10^{-2}$	10	$1\ 10^{-2}$
Slope 0.03	$1.15\ 10^{-2}$	10	$2\ 10^{-2}$

Table 2: bundles adjustment results.

The determination of the ground point coordinates in the simulations lead to the following results ($\Delta Z = \hat{Z}$(estimated by the plotter)$-Z$(a priori known)):

Test	Max error ΔZ	mean ΔZ	$\sigma^2_{\Delta Z}$	mean formal Std Dev of Z
Slope 0	0.0	0.0	-	$<10^{-3}$
Slope 0.005	0.296	-0.004	0.0029	0.006
Slope 0.03	0.042	-0.003	0.0004	0.006

Table 3: plotting results.

5.2 Tests on real objects

In these tests only approximate orientation parameters and object shape are known.

Three images of a cilindrical object with radius of approximately 30 cm are taken by a CCD camera, as shown in the following scheme.

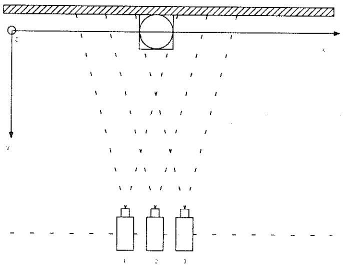

Figure 4: taking scheme

The digital images are obtained with a frame grabber with no special care for clock alignment and a resolution of 640x480 pixels.

Least square matching results are satisfactory, with a standard deviation of the adjustment among 10^{-3} and 5 10^{-3}, and standard deviation of the image coordinates x and y less than 0.110 e 0.085 pixel respectively.

Images orientation is performed setting a conventional reference system fixing all the orientation parameters of the first image and the X_0 coordinate of the third. The procedure is performed with a standard deviation of 0.102 [pixel] and 10 iterations.

In this test a "ground truth" is not avilable to check the real precision of the procedure. To evaluate the results, besides a first qualitative judgment of the plot of the obtained points as shown in the image below, a parametric model of the surface has been built.

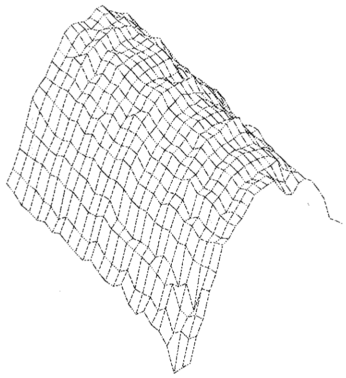

Figure 5: obtained surface.

Assuming that the plotted points belong to a cylindrical surface it is possible to esimate in a least square procedure the five parameters that describe the cylinder's size and its position in space.

It is now possible to estimate the distance of each point from the surface. This value can be considered the error of the determination of that point. For the points in the tests this error has a mean of 0.147 mm and a standard deviation of 5.056 mm, the number of points is 518.

6. CONCLUSIONS

The system that has been described can be considered a prototype of a complete digital photogrammetric system. Several test of different digital photogrammetric techniques, not described in this paper, have been carried out to select those suitable for real applications. The development of the user interface is carried out thinking of a real production enviroment, giving the user a simple, consistent and standard interface, as well as default values for most of the required parameters.

The simulated tests show the functionality of the system; the real test shows the precision of the overall procedure that, taking into account the quality of the images, can be considered satisfactory. A further step in the development of the system will be the integration of the digital sensor calibration techniques, currently under study at our laboratory.

7. SELECTED BIBLIOGRAPHY

1. Papers about researchs developed in the same department and related to the present work:

Benciolini, B. 1990. The Observation Equations of Digital Phototgrammetry. Proceedings of the ISPRS Intercommission WG 3/6 Tutorial: Mathematical Aspects of Data Analysis, Rhodes, Greece.

Benciolini, B., Sguerso, D., 1996. Digital image matching in photogrammetry. Bollettino di Geodesia e Scienze Affini, anno LV, n. 2, pp.178-190.

Zatelli, P., 1994. Progetto, realizzazione e sperimentazione di un sistema fotogrammetrico digitale. Bollettino della SIFET, n. 3, pp. 135-154.

Zatelli, P., 1996. A special purpose monoscopic digital plotter. In print.

2. Papers on digital photogrammetry seen when preparing the present work:

Abertz, J., König, G., 1991. The advanced Digital Stereophotogrammetric System of the TU Berlin, in: Ebner H., Fritsch D., Heipke C. (eds.), Digital Photogrammetric Systems, Wichmann, Karlsruhe.

Ackermann, F., 1984. Digital image correlation: performance and potential application in photogrammetry. Photogrammetric record, 11(64): 429-439.

Dowman, L., 1991. Design of digital Photogrammetric Workstations, in: Ebner H., Fritsch D., Heipke C. (eds.), Digital Photogrammetric Systems, Wichmann, Karlsruhe.

Forstner, W.,1982, On the Geometric precision of Digital Correlation. International Archives of Photogrammetry and Remote sensing, 24-III, pp. 176-189.

Forstner W.,1984. Quality Assessment of Object Location and Point Transfert Using Digital Image Correlation Techniques. International Archives of Photogrammetry and Remote sensing, 25-III, pp. 197-219.

Gruen, A., Baltsavias, E.P., 1988. Geometrically constrained multiphoto matching. Photogrammetric Engineering and Remote Sensing, 54(5): 633-641.

Gruen, A., Baltsavias, E.P., 1988. Geometrically Constrained Multifoto Matching. Photogrammetry Engineering and Remote Sensing, 54-5, pp.663-641

Helava, U.V., 1988, On system concepts for digital automation. Photogrammetria, 43(2):57-71.