Design and Implementation of a Photogrammetric Geo-Calculator in a Windows Environment

Rongxing Li

Abstract

The design and implementation aspects of a Geo-Calculator developed in a windows environment are described. Using this "soft" calculator, geometric entities such as coordinates, distances, differences of elevation, azimuths, areas, and profiles can be calculated through the measurement of objects appearing in stereo images. The Geo-Calculator is implemented as an individual system to provide convenient geo-functions. Thus, it can be adapted as a separate component for softcopy photogrammetry, digital mapping, and geographic information systems. Because the graphic user interface is designed to be user-friendly, no specific photogrammetric background is required when using the calculator.

Introduction

Although computers ranging from main frames to personal computers are available, mathematical calculators, which provide simple and handy mathematical functions, are still necessary in many cases of scientific and engineering applications. Recently, such math-calculators have been implemented in many desk-top software packages in a windows environments. Analogous to such "soft" math-calculators, the photogrammetric Geo-Calculator presented in this paper is implemented on a workstation or a personal computer and provides geo-functions such as the determination of object coordinates, distances, differences in elevation, areas, profiles, and other metrics by using digital stereo photographs and digital photogrammetry. Advantages of such a Geo-Calculator include, among others:

- Availability: these handy geo-functions may be used very often and can be accessed very rapidly;
- Graphic User Interface (GUI): it is designed as the panel of a calculator and does not require any special training to use;
- Independence: it is implemented as a separate unit in the windows environment and does not require any other photogrammetric systems to support it; and
- Flexibility: it can be accessed any time without terminating major processes.

The Geo-Calculator can be applied as a powerful tool where geometric information of objects from stereo photographs are to be generated. It can also be an important component in many complex systems such as softcopy photogrammetric systems, digital mapping and remote sensing systems, and geographic information systems (GIS). With the Geo-Calculator implemented in a windows environment, users can measure anything seen in the images in a very convenient and efficient manner. This paper presents results of the design and implementation of the Geo-Calculator and its applications.

Department of Geomatics Engineering, The University of Calgary, 2500 University Drive, NW, Calgary, Alberta T2N 1N4, Canada.

Functionality Design

The Geo-Calculator is designed and implemented in a windows environment. Therefore, it is also called a "soft calculator." It could be implemented as an independent calculator or as a component of a complex system. Figure 1 shows the design concept of the Geo-Calculator. Both digital image data and camera orientation parameters (if available) are input into the calculator through a Graphic User Interface (GUI). As such, the images are geo-referenced using the camera orientation parameters. The GUI is implemented using the panel of the calculator consisting of two parts: function buttons and text/graphics display. In addition, two stereo images are displayed in an image window of the Geo-Calculator where objects in images can be measured to support function buttons in the panel. A photogrammetric processing unit is used as a basis for all image measurements and photogrammetric calculations.

Currently, nine geo-functions have been implemented (Figure 2b):

Coordnt	- Measuring coordinates of a point in the object space,
Distance	- Measuring a spatial distance between two points,
DH	- Determining difference of elevation between two points,
Azimuth	- Determining azimuth of a line,
Area	- Calculating area of a polygon,
Profile	- Generating a profile of elevations,
Math-Cal.	- Activating Math-Calculator,
Clear	- Clearing the display area, and
Cancel	- Closing the Geo-Calculator.

According to the functions selected, necessary photogrammetric measurements have to be made using the stereo images displayed. Corresponding results are given in the display area, which could be in the format of either text or graphics. For calculating the (X, Y, Z) coordinates of a point, the image point in the left image has to be selected using a cursor. The system assists the user in finding the corresponding point in the right image. The point is then triangulated in object space photogrammetrically.

Functions of distance, difference in elevation, and azi-

Photogrammetric Engineering & Remote Sensing,
Vol. 62, No. 1, January 1996, pp. 85–88.

0099-1112/96/6201–85$3.00/0

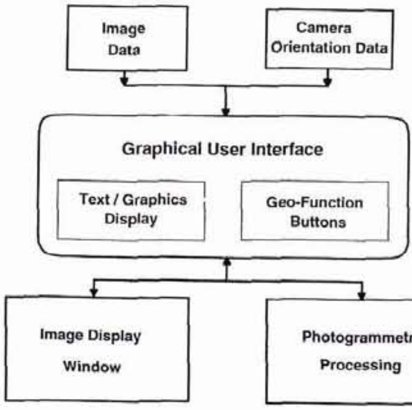

Figure 1. Design concept of the Geo-Calculator.

muth need two points. Therefore, values of these three functions can be calculated and displayed once two points are measured photogrammetrically. There is no hierarchy of button pressing required. For instance, if two points at two street intersections are measured for calculating the distance between the intersections, then the difference in elevation between the street intersections and azimuth of the street segment can be obtained by pressing DH and Azimuth buttons, respectively, without measuring the same points again. Area values are determined by measuring vertices of polygons in the images. A profile is first defined by choosing its two end points; once the number of profile points needed to be determined between the two end points is specified, the system selects and displays these points in the left image. The user has to determine the corresponding points in the right image. A graphical display of the elevation along the profile is shown in the display area after measuring.

Photogrammetric Processing

Most of the functions included are based on a photogrammetric model which transforms the measured image coordinates (x_1, y_1) in the left image and (x_2, y_2) in the right image of a point to three-dimensional coordinates (X, Y, Z) in the object space. The collinearlity equations for the left image (Wolf, 1983) are

$$x_1 = -f\frac{m'_{11}\ (X-X'_0)+m'_{12}\ (Y-Y'_0)+m'_{13}\ (Z-Z'_0)}{m'_{31}\ (X-X'_0)+m_{32}\ (Y-Y'_0)+m'_{33}\ (Z-Z'_0)}$$

$$y_1 = -f\frac{m'_{21}\ (X-X'_0)+m'_{22}\ (Y-Y'_0)+m'_{23}\ (Z-Z'_0)}{m'_{31}\ (X-X'_0)+m_{32}\ (Y-Y'_0)+m'_{33}\ (Z-Z'_0)} \quad (1)$$

where X'_0, Y'_0, Z'_0 are coordinates of the left perspective center in the object space; $(m'_{11}, m'_{12}, ..., m'_{33})$ are elements of the rotation matrix **M'** of the left image; and f denotes the focal length of the camera. The elements of the rotation matrix are functions of three rotation angles about three coordinate axes. These three rotation angles and the position of the perspective center are called external orientation parameters.

Equation 1 describes the relationship between the left image coordinates (x_1, y_1) of a point and its coordinates in the object space (X, Y, Z). Corresponding equations for the right image can also be established. This implies that, for any point in a stereo pair, there will be four collinearity equations. If external orientation parameters and the focal length are known and the image coordinates (x_1, y_1) and (x_2, y_2) for left and right images are measured, respectively, the coordinates (X, Y, Z) can be determined using a least-squares adjustment.

The orientation parameters can be calculated by measuring five or more image points appearing in the stereo image pair (Wolf, 1993), and then generating a photogrammetric model in a relative coordinate system. In order to determine scale, position, and orientation of the photogrammetric model in an absolute coordinate system, such as a state plane coordinate system, control points with known coordinates in both absolute and relative coordinate systems have to be available to determine an absolute orientation transformation. Recent advances in the Global Positioning System (GPS) and inertial navigation systems (INS), in both static and kinematic modes, have made it possible to perform camera orientations without or with reduced terrestrial control points. A direct determination of orientation parameters without ground control can be realized by using GPS data for perspective centers and INS for rotation angles (El-Sheimy and Schwarz, 1993; Li *et al.*, 1994).

The Geo-Calculator performs relative orientation in cases where ground control is not available. It gives measurements in the absolute coordinate systems if ground control points or GPS/INS data are provided.

Implementation Considerations

The Geo-Calculator is designed to be flexible and portable to different platforms. Therefore, a windows toolkit package with high level window functions, which can be embedded in the Motif and Microsoft Windows environments, was employed, and the Geo-Calculator presented can run on both UNIX and DOS operating systems. The GUI and basic functions of the system were developed using the C programming language.

Images are displayed in a separate window where the photogrammetric measurements take place. In principle, object space information is obtained through measurements of a pair of stereo images which form a stereo model. There are different ways to build stereo models, for example, by using polarized monitors with glasses, anaglyphic image displays with glasses, stereo mirror systems, or others. However, in this system corresponding image points are found with the help of epipolar lines in an interactive fashion, which does not require additional hardware and is easily adaptable to any application system.

According to Equation 1, for any point in the object space, its image coordinates (x_1, y_1) and (x_2, y_2) in two images have to be measured. In this system, the operator defines the image point in the left image by a mouse activated cursor, and then the image coordinates (x_1, y_1) are taken. According to camera orientation parameters, epipolar lines of this point are calculated and displayed on two images to assist the operator in finding the corresponding image point in the right image (see Figure 2a). The epipolar geometry ensures that the corresponding image point has to be along the epipolar line in the right image if the orientation parameters are of high accuracy (Wolf, 1983). A zooming function with factors of 2, 4, and 8 is provided for precise positioning of the measuring cursor using the right mouse button. Once the image coordinates (x_2, y_2) in the right image are measured, the coordinates in the object space (X, Y, Z) can be calculated using Equation 1.

In many cases, only relative entities such as distance/size, difference of elevation, area, and others are needed. Thus, the image pair may only be oriented relatively and with their scale adjusted without an absolute orientation in the ground coordinate system. This is implemented by setting an option in the data input. If the camera orientation parameters are not available, the system allows choosing six pairs of corresponding image points in order to calculate the

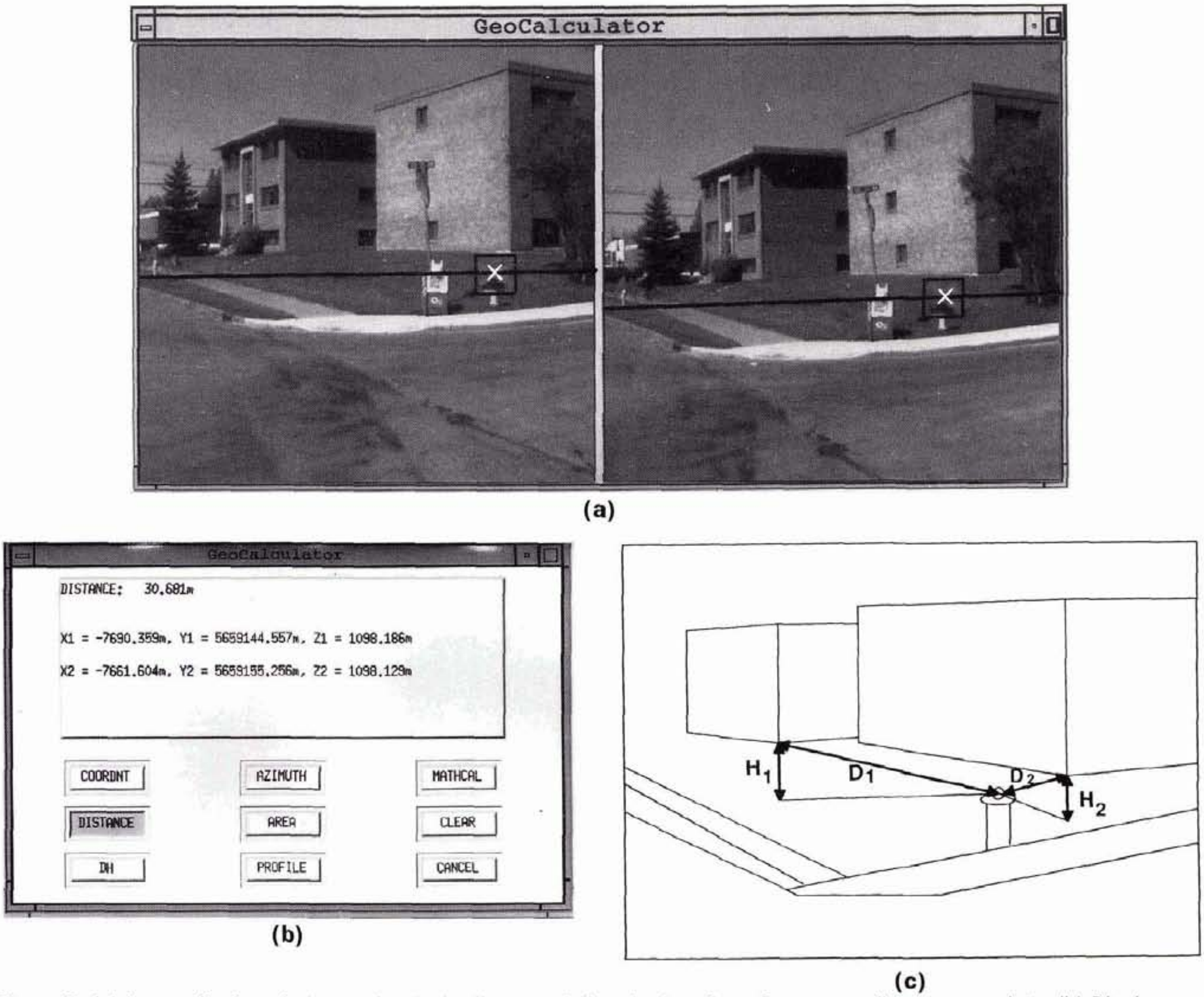

Figure 2. (a) Image display window and epipolar lines assisting the location of corresponding image points. (b) Display area and geo-function buttons. (c) Measuring distances D_1 and D_2 and differences of elevation H_1 and H_2.

relative orientation parameters. This last option is especially helpful, for example, in the situation where underwater images are used to estimate the average size of a fish school, because there is usually a lack of ground control in the underwater environment.

Example

The Geo-Calculator has been implemented on a personal computer in the Microsoft Windows environment and on a SUN SPARC II workstation in the X-Motif Window environment.

A pair of stereo images (see Figure 2a) was taken using a CCD camera in a residential area. Control points were measured by conventional survey methods. Relative and absolute orientation parameters were determined by a bundle adjustment using measured image coordinates and ground coordinates of the control points (Cosandier and Chapman, 1992). The image pair and the orientation parameters were input to the Geo-Calculator for photogrammetric measuring.

Objects appearing in the image pair can be measured by employing functions of the Geo-Calculator (see Figure 2b). For example, height and footprints of buildings, height of the trees, positions of the road sign and the stop sign, width of the sidewalk, azimuth of the street, elevation profile of streets, and others can easily be calculated by pressing corresponding buttons and measuring image points in the image window. An interesting application would be the measurement of distances and differences of elevation between a fire hydrant and two buildings D_1, D_2, H_1, and H_2 (Figure 2c). This information could be used to estimate how fast the water from the fire hydrant can be used to reach the buildings in emergency cases. A zooming factor would be selected and the "Distance" button pressed (see Figures 2a and 2b); then, by placing the cursor at the top of the fire hydrant, image coordinates in the two images would be taken for this point. Subsequently, image coordinates of appropriate points of the closer building (e.g., a building corner) are measured. Internally, the Geo-Calculator would calculate the ground coordinates of the fire hydrant and the building corner. Then, the distance D_1, which is a function of the ground coordinates of these two points, would be determined. Also, by pressing the "*DH*" button, the difference of elevation, H_1, between the fire hydrant and the building could be calculated without measuring the same image points again. This is because the difference of elevation is also a well-defined function of ground coordinates of the same photogrammetrically triangulated

Table 1. Comparison between Distances Conventionally Surveyed and Those Measured Photogrammetrically Using the Geo-Calculator.

Point No.	1	2	3	4	5	6	7	8
Distance (m)	14.93	17.41	19.27	22.12	25.38	28.17	31.92	45.74
Difference (m)	0.19	0.02	0.27	0.26	0.87	0.74	0.95	1.04

points in object space. Distance D_2 and elevation difference H_2 would be determined in a similar way.

The accuracy of the calculated parameters depends on a number of factors, such as quality of cameras, the photogrammetric model, control points, and geometric configuration formed by camera positions and objects. In addition, the range between cameras and the object to be measured plays an important role. If the object is too close to the camera, it cannot be projected onto the image clearly because of the optical limit of the camera; if a large object is far from the camera, it would be represented just by few pixels in the image and further, small features of the object cannot be located in the object space accurately. It is expected that, to some extent, the measuring accuracy may decrease as the distance between the camera and the object increases. A test was accomplished to examine this relationship. On the site depicted by Figure 2a, distances from the left camera to objects at varying ranges were measured both by conventional surveying methods and photogrammetrically using the Geo-Calculator. Distances measured by these two methods were compared. In Table 1, absolute values of the distance differences in metres are listed according to point number and distance from the left camera in metres. A diagram using the same data set illustrates the relationship between the measurement error and distance (Figure 3). Note that distance differences can be controlled within 26 cm for objects located 22 m from the camera or closer. Because distances measured by the surveying method can be considered as being accurate, the distance differences are mainly due to photogrammetric triangulation, and increase as the distance from the camera increases. One of the major error sources is the small camera baseline (1.854 m) which is restricted by the hardware configuration of the data acquisition system. The larger measuring errors of far objects are partly caused by lower resolution which is a function of the distance between the camera and the object. Considering lower resolution at a far distance from the camera, a one-pixel location error in the image would cause a large error in the object space. To improve the measuring accuracy, the hardware configuration should be modified so that a wider baseline will enhance the photogrammetric triangulation accuracy; higher resolution CCD cameras will provide higher resolution for far objects; definition of objects in the image space should be carried out at a subpixel level; and, finally, in addition to a pair of stereo images forming a small intersection angle at the far object feature, a third image which covers the same target object and gives a better intersection angle should be used to increase the photogrammetric triangulation accuracy.

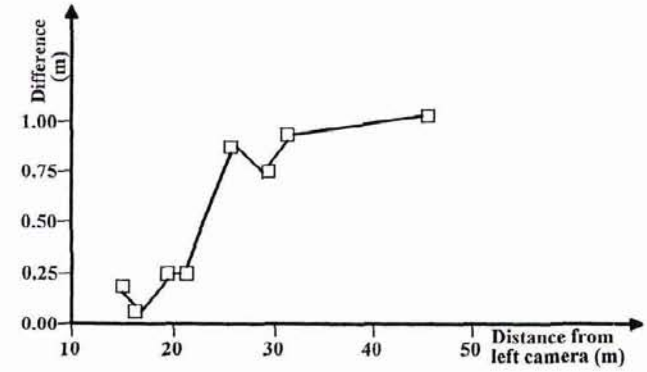

Figure 3. Diagram illustrating difference of distances measured conventionally and photogrammetrically using the Geo-Calculator.

Conclusion

The Geo-Calculator provides convenient geo-functions that can be implemented easily in various computer environments. This soft calculator can be integrated into systems such as softcopy photogrammetric systems, mapping systems, and GIS. One of the major advantages of this independent Geo-Calculator is that simple geometric entities of objects appearing in the image pair can be measured without going through the entire procedures of main application systems. Such unnecessary processing can be very complicated and require additional computational time to perform unrelated operations included in the main application systems. Designed in this manner, the Geo-Calculator is very user-friendly. No specific photogrammetric background is required to use the calculator.

Further efforts will be made in automating the measuring procedures by integrating digital image matching techniques without significant computational overhead (Li, 1992). Additional functions may be added for other interesting applications.

Acknowledgments

The research was supported by research grants from the Natural Sciences and Engineering Research Council of Canada (NSERC), The University of Calgary, and GEOFIT Inc., Laval. Comments from Dr. M.A. Chapman and programming efforts made by my graduate student team are greatly appreciated. Suggestions and comments from reviewers were constructive and appreciated.

References

Cosandier, D., and M.A. Chapman, 1992. High Precision Target Location for Industrial Metrology, *Proceedings of SPIE OE/Technology*, Boston.

El-Sheimy, N., and K.-P. Schwarz, 1993. Kinematic Positioning in Three Dimensions Using CCD Technology, *Proceedings of VNIS'93*, pp. 472-475.

Li, R., 1992. Building Octree Representations of 3D Objects in CAD/CAM by Digital Image Matching Techniques, *Photogrammetric Engineering & Remote Sensing*, 58(12):1685-1691.

———, 1993. 3D GIS: A Simple Extension in the Third Dimension? Proceedings of ACSM/ASPRS 93, pp. 218-227.

Li, R., K.-P. Schwarz, M. A. Chapman, and M. Gravel, 1994. Integrate GPS and Related Technologies for Rapid GIS Data Acquisition, *GIS World*, (4):41-43.

Wolf, P.R., 1983. *Elements of Photogrammetry*, McGraw-Hill Publishing Company.

(Received 29 November 1993; revised 9 December 1994)