An Evaluation of an Off-the-Shelf Digital Close-Range Photogrammetric Software Package

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Abstract

A series of digital close-range photogrammetric measurement tests with different non-metric images were carried out with the off-the-shelf digital close-range photogrammetric software package PhotoModeler Pro for two different test fields, to investigate the photogrammetric performance of the software, and also the strategies for different practical applications. The test results are generally promising. Theoretical discussions about some related concerns regarding possible improvements of this or other similar software are presented as well.

Introduction

Close-range photogrammetric software designers are faced with great opportunities as well as challenges in the current digital era, with the merging of photogrammetry with related computer technologies such as CAD, image processing, 3D modeling, and animation. Close-range photogrammetric software systems have been adopted in a vast range of non-photogrammetric fields as an attractive tool for geometrical information extraction and model construction.

A digital close-range photogrammetric software package named PhotoModeler® Pro (PM Pro), developed by EOS Systems Inc. in Canada, is a good example of finding its way to the current market. This low-cost and relatively low-accuracy package (Fraser, 1998) has been used by different users in non-photogrammetric environments worldwide and earned a promising reputation. In this paper, a series of practical tests of PM Pro for investigating its photogrammetric performance when dealing with non-metric images is presented. The tests were carried out with two different test fields with typically small and larger sizes, and three different types of non-metric images, including scanned hardcopy images and digital camera images. The optimum ways of using PM Pro for different practical applications with different types of images and objects as well as some discussions and suggestions regarding existing problems and possible further improvements are also presented.

Brief Overview of PhotoModeler

PhotoModeler Pro is a 32-bit windows program that runs on Windows 95+ and Windows NT 4.0+. It supports images larger than 16 MB (EOS, 1997). Among its other features, this package is characteristic in the multiple format input and output, including orthophoto output and 3D output with or without photo-texture, monoscopic photo-coordinate measuring to sub-pixel accuracy on a computer screen by simple marking; 3D object space measuring on a digital photograph or in a 3D view; help tools to assist image correlation of points, curved lines, and cylinders; different adjustment options and precision parameters; and effective help tools, including an animation tutorial movie with example projects and images. The latest version of PM Pro is 3.1b, upgraded in June 1999. The tests in this paper were performed mainly with version 3.0j, upgraded in October 1998. Changes caused by the latest upgrades are mentioned where necessary.

Test Fields and Image Acquisition

Two test fields constructed in the University of New Brunswick (Li, 1999) were adopted for the tests, one of a typically small size while the other of a typically larger size commonly seen. The small test field is a square metal plate of about 17 cm by 17 cm with 25 12-mm to 37-mm long bolts fixed vertically onto the plate plane (Figure 1). Thirty-six grid intersection points are engraved evenly on the plate to form 25 squares, and the 25 bolts are centered within each of the squares. Black lines, approximately 1 mm wide, are used to mark the grid intersection point positions and also the point positions on top of each bolt, to provide a good photographic contrast against the white background.

An Electronic Coordinate Determination System (ECDS), consisting of two one-second electronic theodolites (Kern E2) interfaced with an IBM PC computer, was used to determine the 3D object-space coordinates of the 61 target points marked on the plate (36 grid intersections plus 25 bolts) in an arbitrary 3D coordinate system. The precision (average standard deviation) of the resulting coordinates was 0.02 mm, 0.03 mm, and 0.02 mm in the *X*, *Y*, and *Z* directions, respectively.

The larger test field is a white wooden house located on the University of New Brunswick (UNB) campus. Four joining walls on the backside of the house were used as the test field (Figure 2). Forty-nine uniformly distributed point positions were marked with black paper targets 7 cm in diameter on the four walls. The four walls occupy a 3D range of approximately 7 m by 8 m in planimetry and 4 m in height. The 3D object space coordinates of the 49 points were determined to a precision of 0.7 mm, 0.6 mm, and 0.1 mm in the *X*, *Y*, and *Z* directions at the 95 percent confidence level by precise theodolite intersection with a five-station 3D geodetic adjustment.

For the photography of the metal plate, two sets of 100 percent overlapping convergent photographs with the same camera configuration were taken with an Olympus OM 10 35-mm film camera (with a 50-mm focal length lens) and a low-cost

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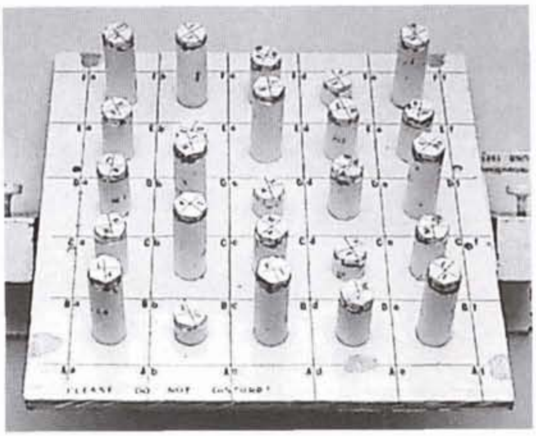

Figure 1. Small test field: metal plate with bolts.

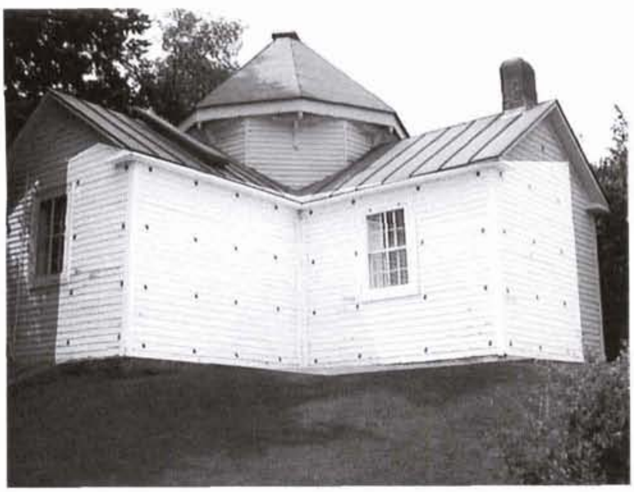

Figure 2. Large test field: wooden house with target points (from Li (1999, p. 123)).

Kodak DC-50 digital camera (lens $f = 7 \sim 21$ mm), respectively. Each set included three photographs. The object distances were approximately 0.6 m. Indoor laboratory lighting was adopted to provide a uniform illumination. The measurements with theodolite and the photography were accomplished in the same summer afternoon to minimize the effects of temperature change; this is important when middle to high accuracy is expected.

The photography of the wooden house was performed with another low-cost digital camera, the Fujix DS-100 (lens $f = 8 \sim 24$ mm). Five convergent photographs were taken with the object distances ranging from 7 to 10 meters. Natural daylight was adopted as photographic illumination.

The hardcopy images of the plate taken with the Olympus camera were scanned from Kodak Elite 400 diapositive color slides into digital images with a Nikon scanner. The scanning resolution was 59 dpmm (dots per millimeter), and the final resolution for the output images was 101.7 P/mm (pixels per millimeter), resulting in a 9.8- by 9.8-μm pixel size. The format of the scanned image was chosen to be 1.325 cm by 1.000 cm, which led to a change of the scanned image scale from the original film. The effect of a change in scale is discussed elsewhere in the paper.

The objects were photographed such that the test field covered as much as possible of the available format, in order to obtain large photo scales for all photos, which is important for good accuracy. Furthermore, image distortions needed to be handled effectively, especially for non-metric images. The capabilities of the software for compensating for the image distortions were to be investigated with such images.

All of these photographs had been taken on different earlier occasions for other projects in the Department of Geodesy and Geomatics Engineering at UNB. They were selected and adopted for this project for the purposes of avoiding duplicating work and for testing the applicability of PM Pro to the existing photographs, which is not uncommon in close-range photogrammetric applications, especially for applications with non-metric images.

Test Results

Software Requirement for Control Points

For processing non-metric images taken with non-calibrated cameras, the test results showed that PM Pro requires no less than eight 3D control points for one adjustment project, with no less than seven control points imaged and measured on each photograph.

Accuracies Obtainable

From over 40 different adjustment tests with PM Pro, the best accuracies obtained with practically the maximum numbers of well distributed control points for the two test fields and three types of non-metric images are listed in Table 1 (28 control points and 33 check points were used and kept the same in the two cases of the small test field, and 27 control points and 22 check points were used in the large test field case). The accuracies in Table 1 are acceptable for many practical applications.

Strategies for Practical Applications

Optimum Numbers of Control Points

The accuracy of an adjustment result generally improves with an increase in the number of control points used in the adjustment, but the improvement becomes insignificant when the number of control points is increased beyond a certain level. For different adjustment models and conditions, the optimum number of control points allowing for a proper trade-off between accuracy and reasonable cost for control are different and need to be determined by practical tests. The optimum number of well distributed control points for non-metric images taken with non-calibrated cameras and processed with PM Pro, according to the tests, is 9 to 12 points for digital camera images and 20 to 25 points for scanned hardcopy images. To use as many as 20 plus control points is, however, not feasible in many practical cases.

Figure 3 illustrates the change of the object space check point 3D root-mean-square (RMS) values with the increase in well distributed control points for the metal plate. The horizontal axis in Figure 3 represents the number of well distributed control points used in adjustment. The reasons for the higher accuracies obtained from the digital camera images than from the scanned hardcopy images will be discussed later. The tests for the wooden house resulted in a similar conclusion for the optimum number of control points (Deng, 1999).

Optimum Patterns of Control Frames

A control frame is typically used for control in close-range photogrammetry when well (uniformly) distributed control points are not available. Target points marked on a properly designed

Table 1. Best Accuracies Obtained for Two Test Fields and Three Different Types of Non-Metric Images with PM Pro

Test fields and images		Check-point errors in object space (mm): Maximum RMS of 3D coordinate	Check-point errors in object space (mm): Maximum coordinate discrepancies	Distance errors in object space: Average discrepancies (mm)	Distance errors in object space: Average relative errors
Small test field	Scanned images	0.43	1.08	0.59	1/781
	Digital camera images	0.17	0.41	0.20	1/1635
Large test field and digital camera images		9.3	16.6	6.4	1/1684

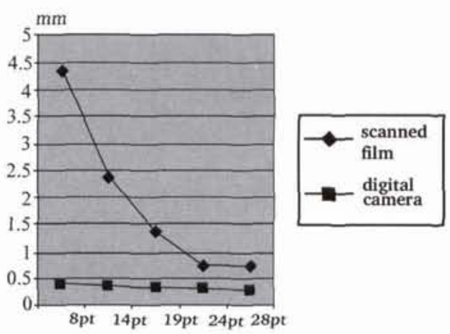

Figure 3. Check-point 3D RMS (mm) versus number of control points.

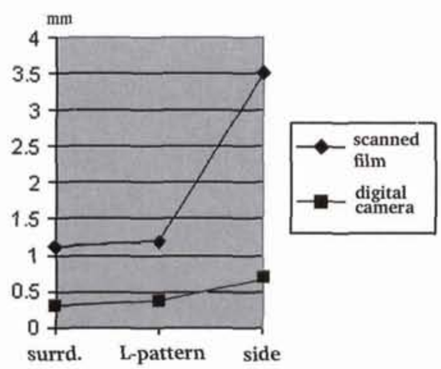

Figure 4. Check-point 3D RMS (mm) of three simulated control frames for the metal plate.

frame that is strong and often portable are coordinated in an arbitrary local 3D coordinate system. These points are then used as control points for measuring an object placed into, and imaged together with, the frame. Three commonly used patterns of control frames were simulated with the metal plate and tested, namely, surrounding control, where the control points on the frame are surrounding the unknown points of the object, semi-surrounding control, where the control points are half surrounding the unknown points, often in an L-shaped frame, (L-pattern control), and side control, where the frame is on one side of the object. Surrounding control proves to be the first recommendation among the three frame patterns in terms of accuracy level and accuracy uniformity in different directions, the L-pattern comes next, and a side pattern is generally not recommended because of the poor accuracy in the side direction. Figure 4 shows the 3D RMS values of the check points for the three control frame patterns. Eleven control points were used in each case of Figure 4.

A control frame is convenient for measuring small objects. For measuring large objects such as architectural or industrial structures, a similarly convenient control pattern, namely, the small area control where control points are restricted to a small area on the object, was tested using the wooden house. The resulting accuracies were unacceptable, as expected, due to the poor geometry of control. Both the coordinate errors and distance errors from the small area control cases are more than five times larger than those from the well distributed control cases. Small area control is therefore not recommended for practical applications.

Photo-Variant Approach for Non-Metric Camera Self-Calibration

An option for self-calibration is provided in PM Pro by solving for the interior orientation parameters, including radial lens distortion coefficients and decentring lens distortion coefficients. Assuming that the principal point is (0, 0), the following formulas are adopted by PM Pro for the x and y components of photo-coordinate corrections for radial lens distortion drx, dry and decentring lens distortion dpx, dpy (EOS, 1997):

$$drx = x(K_1r^2 + K_2r^4) \quad (1)$$
$$dry = y(K_1r^2 + K_2r^4)$$

where

$$r^2 = x^2 + y^2 \quad (2)$$

and

$$dpx = p_1(r^2 + 2x^2) + 2p_2xy \quad (3)$$
$$dpy = p_2(r^2 + 2y^2) + 2p_1xy$$

The above formulas take into account the most significant components of conventional geometric calibration (Karara and Abdel Aziz, 1974; Fryer, 1996). For non-metric images, the photo-variant approach (Moniwa, 1977) should be employed, where each photograph has an individual set of interior orientation parameters, including systematic image coordinate error corrections. This approach was adopted by PM Pro for the "Inverse Camera Project" in ver. 3.1, upgraded in April 1999, and in later versions. All photos in one adjustment project were assigned one set of orientation parameters in ver. 3.0j as program defaults, except for the photos taken with film cameras without fiducials. Tests using and not using the photo-variant approach were made, and the results clearly showed the necessity and importance of employing the photo-variant approach for non-metric images. Very large errors of check-point object-space coordinates can be seen in Table 2 when the photo-variant approach was not used and all other conditions were kept the same. The images used for the three cases in Table 2 are digital camera images taken with the Kodak DC-50.

Table 2. Check-Point RMS Obtained by Using and Not Using the Photo-Variant Approach for the Metal Plate

Cases	Photo variant/invariant	RMS (mm) X	Y	Z	3D	Maximum discrepancy/pt. ID DX/pt	DY/pt	DZ/pt
1. 8 cntrl pts	variant	0.20	0.22	0.26	0.39	0.57/505	0.49/505	0.77/505
53 chk pts	invariant	41.86	29.09	32.98	60.71	71.33/16	55.19/505	57.43/62
2. 24 cntrl pts	variant	0.16	0.21	0.19	0.32	0.38/53	0.45/203	0.37/65
37 chk pts	invariant	2.00	8.17	6.41	10.57	5.74/305	15.13/305	11.95/305
3. 28 cntrl pts	variant	0.16	0.14	0.17	0.27	0.35/305	0.39/505	0.41/12
33 chk pts	invariant	2.38	8.83	7.01	11.53	6.15/305	16.72/305	13.36/305

Table 3. Check-Point RMS from each Repeated Processing for the Configuration with 14 Well Distributed Control Points and 47 Check Points on the Metal Plate (Scanned Hardcopy Images)

Repeat (modification) times	RMS (mm) X	Y	Z	3D	Maximum discrepancy (mm) DX/pt	DY/pt	DZ/pt
Md 1	1.29	2.80	2.18	3.77	3.82/105	6.51/105	4.47/505
Md 2	1.01	1.95	1.76	2.81	3.01/105	4.62/102	3.58/505
Md 3	0.95	1.68	1.65	2.54	2.76/105	3.97/102	3.31/505
Md 4	0.93	1.60	1.63	2.46	2.67/105	3.74/102	3.34/505
Md 5	0.92	1.56	1.62	2.43	2.63/105	3.63/102	3.22/505
Md 6	0.91	1.53	1.61	2.41	2.60/105	3.57/102	3.22/105
Md 7	0.90	1.51	1.61	2.39	2.58/105	3.52/102	3.23/505
Md 8	0.90	1.50	1.61	2.38	2.53/105	3.48/102	3.24/505

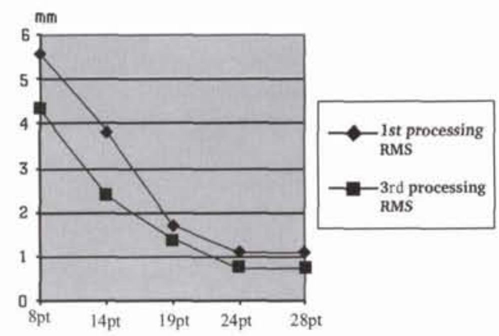

Figure 5. 3D RMS (mm) before and after repeated processing for five control cases with scanned images of the plate.

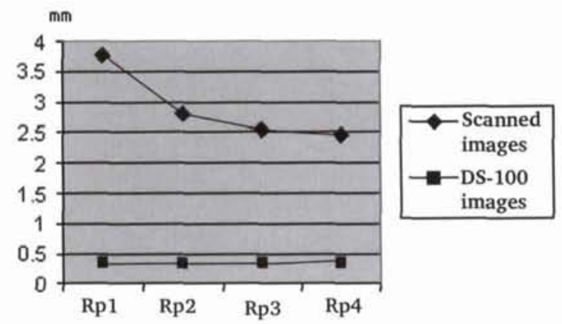

Figure 6. Check-point 3D RMS (mm) from four repeated processings: hardcopy images versus digital camera images.

Repeated Processing for Scanned Hardcopy Images
It was found from the test that different results were obtained from repeated processing (adjustment) of the same project with PM Pro. The accuracies of the object-space check points solved for by PM Pro were significantly improved through repeated processing of the scanned hardcopy images while, for the digital camera images, essentially no improvements in accuracy were obtained by repeated processing. Table 3 shows the check-point RMS values obtained from each repeated processing for a particular case with the scanned hardcopy images: the configuration with 14 well distributed control points and 47 check points on the metal plate. The orientation parameters were modified using the results of each processing.

Figure 5 shows the 3D RMS improvements achieved by repeated processing for five different well distributed control-point configuration cases with the scanned hardcopy images of the metal plate. Figure 6 shows a comparison between the effects of each of the four repetitions of processing (Rp 1 to Rp 4) on the accuracies from the scanned hardcopy images and from the digital camera images for one particular case, namely, the configuration with 14 well distributed control points and 47 check points on the metal plate.

It is obvious, according to the tests, that repeated processing with PM Pro is necessary for scanned hardcopy images, and that the proper number of repetitions should be four to eight. It remains as a problem, however, for a user to find out whether repeated processing is needed and how many times the processing should be repeated for a practical application. The reasons for the sensitivity of the scanned hardcopy images to repeated processing and the insensitivity of the digital camera images to it are still to be explained.

Related Concerns

Differences between Scanned Hardcopy Images and Digital Camera Images

When comparing the results from the scanned hardcopy images and from the digital camera images for the same control and check-point configurations of the same object, it became apparent that significantly higher accuracies were achieved in the adjustment results for the digital camera images than for the scanned hardcopy images, in spite of the fact that the scanned images adopted by PM Pro have a higher resolution (1170 by 1170 pixels) than the digital camera images (less than 400 by 400 pixels). Figures 3, 4, and 6 all clearly show the higher accuracies of the digital camera images compared with the scanned hardcopy images. A similar but less significant accuracy difference was reported by Faig *et al.* (1996). Further analysis revealed that the digital camera images are neither sensitive to changes of the number of control points (Figure 3) nor to the repetition of processing (Figure 6). This phenomenon is an encouragement to using the fast developing digital cameras in close-range photogrammetry. On the other hand, it implies a demand for investigating the reasons, primarily the modeling and compensating for the effects of scanning on scanned hardcopy images. An affine transformation for example, could be tested.

Camera Calibration

Camera calibration determines the interior orientation parameters of a camera, and the systematic image errors are compensated for by analytical calibration algorithms at the same time. The most significant components of conventional geometric calibration are radial and decentring lens distortions, which are included in Equations 1 and 3. It was found in the tests that the radial lens distortion coefficients K_1 and K_2 are generally larger than the decentring lens distortion coefficients P_1 and P_2 by approximately two orders of magnitude.

For dealing with digital images, radiometric calibration has been considered by researchers (Shortis and Beyer, 1996; Fraser, 1997; Robson and Shortis, 1998). Geometrical factors, including the sensor geometry of digital cameras (Fryer, 1996) and the image transformation geometry such as for scanning, should also be taken into account. The geometric factors are more important to maintain metric accuracy while the radiometry is often a secondary issue (Shortis and Beyer, 1996). The significantly lower accuracy of the scanned hardcopy images is expected to be improved when the influences of scanning are effectively modeled. The reasons for the accuracy differences between the digital camera images and the scanned hardcopy images will then be explained. Precise grid patterns on glass plates were reportedly employed to calibrate desk top publishing scanners (Baltsavias and Waegli, 1996), and an accuracy of up to 4 to 7 μm was achieved. It would be more feasible to many users, however, if the scanner's calibration could be adopted into an algorithm of analytical self-calibration. More efforts are still needed to reach this goal.

PM Pro is equipped with a separate camera calibration program named Camera Calibrator. It is, however, impractical to calibrate the camera when dealing with pre-existing images, and it is of trivial value to pre-calibrate non-metric cameras due to the instability of the interior orientation parameters between exposures (Faig, 1976; Moniwa, 1977, Shortis *et al.*, 1998). It was noticed that an accuracy improvement was reported after pre-calibrating an Ashai Pentax non-metric camera with the Camera Calibrator (Hanke, 1998). The generalization of this improvement is to be expected. Uncertainties in solving for the interior orientation parameters, including lens distortion coefficients, with PM Pro's self calibration function were experienced in some tests, and should be further investigated.

In determining the orientation parameters of a camera from control points (called "inverse camera" in PM Pro for determining interior orientation parameters), a conceptual confusion appears in the literature, that the orientation parameters solved for from the images which are transformed from the originally photographed images by enlarging, scanning etc., are assigned to the original camera as its corresponding parameters. This is incorrect and causes problems. The suggestion of the "pseudo camera" concept below will clarify this.

Concept of the Pseudo Camera

The final images used in close-range photogrammetry from which photo coordinates are measured for analytical processing are often images transformed from the originally photographed images. The transformations are usually 2D-to-2D perspective transformations, caused by enlarging, scanning, etc. The transformation from a 3D photographic object to the original photograph and then to the final image is expressed by Equation 4 (Faig *et al.*, 1988): i.e.,

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & 1 \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} \\ b_{21} & b_{22} & b_{23} & b_{24} \\ b_{31} & b_{32} & b_{33} & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (4)$$

where x and y are the photo coordinates on the final image; and X, Y, and Z are the object space coordinates of the identical point in object space.

The first 3 by 3 matrix with eight coefficients is the 2D-to-2D perspective transformation coefficient matrix for photo enlargement or image scanning; the second 3 by 4 matrix with 11 coefficients is the 3D-to-2D perspective transformation matrix from the photographic object to the original photograph. Every time one more enlargement or scanning is applied, a 3 by 3 matrix should be pre-multiplied. The whole resulting coefficient matrix, however, is always a 3 by 4 matrix, no matter how many 2D perspective transformations are superimposed onto Equation 4. In other words, after a series of 2D-to-2D transformations such as photo enlargement and image scanning from the original photograph, the resulting final images are equivalent to a frame of original images with a new set of transformation coefficients from the object to the final images. The final photograph containing the final images is applicable to any photogrammetric processing because of the equivalence to an original photograph. However, the interior and exterior orientation parameters of the final photograph are obviously not the same as the corresponding parameters on the original photograph, because the interior and exterior orientation parameters are functions of the elements in the coefficient matrix. The final photograph with its interior and exterior orientation parameters and systematic image distortions corresponds in theory to a camera with these parameters and distortions. This camera is referred to as the pseudo camera. A pseudo camera has all of the geometrical properties required by photogrammetry, although it does not necessarily exist physically in real life (Deng, 1988). The interior and exterior orientation parameters and systematic image distortion coefficients solved for with the photo coordinates of a final photograph do not belong to the original camera, but to a pseudo camera. Only when the final images happen to be the original images, i.e., no additional 2D-to-2D perspective transformations have been superimposed onto Equation 4, can these solved for camera parameters and image distortions belong to the original camera. Figure 7 illustrates the concept for forming a pseudo camera ($S_2b_1d_1$) by enlarging the original image bd into the final image b_1d_1. It is clearly shown that both the interior and the exterior orientation parameters of the pseudo camera $S_2b_1d_1$ are different form those of the original camera Sbd.

The mismatching of the pseudo camera's orientation parameters with the original camera will not cause any problem in the cases where the purpose of the project is to solve for the object space coordinates on the object, which are the most

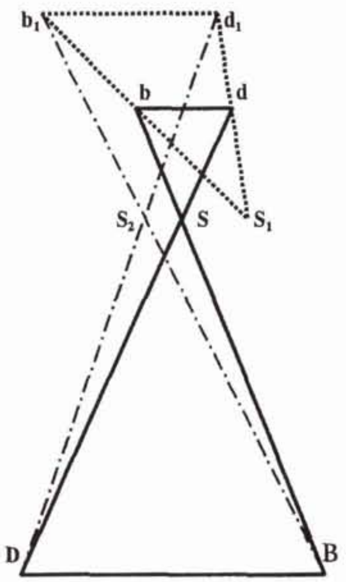

Figure 7. Pseudo camera ($\Delta S_2 d_1 b_1$) concept illustration.

common cases in practical applications. The camera parameters are of little concern to the user under this circumstance. But when a reversal processing is required to determine the orientation parameters of the original camera from the final images formed by a series of superimposed perspective transformations from the original images, extra mathematical effort is still needed to derive the correct solution.

Conclusions and Suggestions

Conclusions

- PhotoModeler Pro is a promising digital close-range photogrammetric software package with flexibility especially suitable for various non-photogrammetric applications. The features of multi-formats of input and output, direct measurement in a 3D view and on digital photographs, and 3D output with or without photo textures are attractive to many users. PM Pro is representative of the development of software of this kind. The knowledge of photogrammetry, however, is still helpful for making more efficient use of this or similar software.
- Reliable accuracies of object-space coordinates acceptable to many practical applications (1/800 to 1/1700 of the object distance) can be obtained with PM Pro using non-metric images, both in scanned hardcopy image form and digital camera image form, taken with non-calibrated cameras. Better accuracies were reportedly achieved by pre-calibration of the cameras with the Camera Calibrator provided by PM Pro (Hanke, 1998).
- The optimal strategies for practical applications tested and summarized in this paper will be helpful to different corresponding applications for measuring different objects with different images in using PM Pro or using or designing similar software.
- Significantly higher accuracies were obtained from digital camera images than from scanned hardcopy images in all test cases. This is an encouragement for using the fast developing digital cameras in close-range photogrammetry, while it also implies the need for investigating the reasons, primarily the modeling of the effects of scanning on scanned images.

Suggestions

- The concept of the pseudo camera suggested by the authors is helpful in clarifying the issues of zero to multiple perspective transformations from the original photograph to the final images and the issues of mismatching with the original camera of the orientation parameters solved for from the final images. Further mathematical developments will be needed to derive the orientation parameters of the original camera from those of the pseudo camera.
- A potential for merging close-range photogrammetry into geographic information systems (GIS) is provided by the feature of direct measurement of digital photographs. The intuitive extraction of the geometrical information, including point coordinates, line lengths, and plane areas, will make a GIS package more user friendly.
- It is important to employ the photo-variant approach for obtaining correct results and good accuracy when dealing with the self-calibration of non-metric images. It is expected that PM Pro will be further improved in solving for the interior orientation parameters, including lens distortion coefficients, without uncertainties and taking into account the other influential factors of geometric and, where necessary, radiometric calibration in addition to the currently included radial and decentring lens distortions.

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Remote Sensing and Human Health

In November 2001, the American Society for Photogrammetry and Remote Sensing will devote its issue of *Photogrammetric Engineering and Remote Sensing* (*PE&RS*) to remote sensing and human health.

The continued importance of a range of infectious diseases in tropical regions and the resurgence and introduction of new pathogens in temperate areas, result in a significant present, and increasing future problem for the global public health agenda. Against this background, novel and cost-effective control techniques are being continually developed and the government and private sector becoming increasingly motivated towards disease control. These factors lead to an increased impetus to those developing our ability to map spatial and temporal risk of disease so that those interventions that are available may be rationally deployed. It is against this background that the following special issue was conceived. All submissions relating to remote sensing applications in human health will be considered. Of particular interest, however, will be those studies that are developing predictive capabilities for disease early warning.

Guest Editors

Simon I. Hay, University of Oxford
Monica F. Myers, International Research Partnership for Infectious Diseases (IntRePID)
Nancy Maynard, Goddard Space Flight Centre, NASA
David J. Rogers, University of Oxford

All manuscripts should be prepared according to the "Instructions to Authors" published in each issue of *PE&RS*. Papers will be peer-reviewed in accordance with established ASPRS policy. Please send manuscripts to:

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