An Integrated Photogrammetric System with Metric Digital Camera and Total Station

This paper presents several new issues of an integrated photogrammetric system: Photo Total Sation System (PTSS), which was first presented on the XXth ISPRS that installs metric digital camera on total station together with digital photogrammetric software. Because of the automatic obtainment of the photos’ exterior orientation elements during the observation with total station, true non-contact measurement can be possible. The main focuses are on Comparison with other similar instruments, New offset calibration method, Panorama mosaic and building reconstruction, 3D reconstruction with control photo and software design.Zongqian Zhan; Zuxun Zhang; Jianqing ZhangComputer and Computational Sciences, 2006. IMSCCS '06. First International Multi-Symposiums on747-75220-24 June 2006

An Integrated Photogrammetric System with Metric Digital Camera and Total Station

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Abstract

This paper presents several new issues of an integrated photogrammetric system: Photo Total Sation System (PTSS), which was first presented on the XXth ISPRS that installs metric digital camera on total station together with digital photogrammetric software. Because of the automatic obtainment of the photos' exterior orientation elements during the observation with total station, true non-contact measurement can be possible. The main focuses are on: Comparison with other similar instruments, New offset calibration method, Panorama mosaic and building reconstruction, 3D reconstruction with control photo and software design.

1. Introduction

As we know, in spite of great development of traditional terrestrial photogrammetry over the past years, it is still necessary to set some control points around the objects to be measured. However, setting control points around the objects is a very time-consuming and labor-intensive job. So in fact photogrammetrists' dream of "true non-contact measurement" is still on its way.

On the other hand, although widely accepted as an accurate surveying method, surveying with total station still suffers from a number of weaknesses: Firstly, total station does not mean total surveying. It is impossible to record an absolute survey of all the features within a given area. It would be time-consuming and pointless to record every individual brick in a wall, for example. Secondly, many features such as line segments on the buildings can not be fully recorded during measurement, however, which are more important to reconstruct the object to be measured.

For the reason of the above problems, we built an integrated photogrammetric system with metric digital camera and total station. By means of special offset calibration method and photogrammetric algorithms, true non-contact measurement can become reality.

Because several similar systems have been presented before or after ours, this paper firstly presents theories and special characteristics of the PTSS, and gives some comparisons with others. Secondly, we will present a new offset Calibration method, which is slightly different but more efficient to our original one, so as to decrease error caused by camera re-installing procedure. Thirdly, panorama mosaic and 3D reconstruction with PTSS are showed. Fourthly, software design is discussed. Finally, conclusion is given.

2. PTSS and Comparison

The combination of camera and theodolite can be traced to many years ago. However, these instruments went to the end as photogrammetry evolved from analogue and analytical stage into digital era [Zhang. etc., 2004]. Nowadays, total station has been widely used together with digital camera in applications such as accident, archaeological site survey, civil engineering survey as well as 3DGIS, building reconstruction. But in most cases they have been used separately, in which total station is just used to achieve the 3D coordinates of control points for the following photogrammetric process. Carl Gravel presented a computer assisted photogrammetry system(CAPS), which combines a total station with ordinary digital camera and also offers corresponding software for

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processing data [Gravel C. etc., 1999]. In addition, Torres also presented a similar instrument that integrates GPS, theodolite, conventional digital camera and PDA [Torres. etc., 2004]. At the following, we named it as GPSS. Moreover, TOPCON co. had brought out a new product of Image Total Station (ITS) named as GPT-7000i [TOPCON, 2005].

The hardware of PTSS includes metric digital camera of ROLLEI, total station of SOKIA SET 500, Personal Digital Assistant (PDA), control bar and shutter wire. As Figure 1 shows, metric digital camera produced by ROLLEI Co. is rigidly fixed on the telescope of total station with a mechanical adapter but not on the steady of total-station's horizontal axis. So camera can horizontally and vertically rotate with the telescope. PDA is used for storing measurement data and image index, which is correspondent to the horizontal and vertical angles measured by the total station. So PDA controls the whole outside survey process of the PTSS. In addition, control bar and shutter wire are also two important parts of the PTSS, which will be explained at the following. Because metric digital camera is a high quality one, errors of PTSS are mainly aroused from the stability of the instrument when re-installing camera again and again or moving the instrument from one place to the other.

In CAPS, digital camera is installed on the side steady of horizontal axis. So camera can not vertically rotate with the telescope, which limits camera to capture wider range. In GPSS, camera is installed on the theodolite and GPS is also applied to obtain site coordinates. Torres also presented some softwares and detailedly analyzed many sources of error, which came upon in our tests too. In order to solve such problems, we used shutter wire to decrease the depressing error when pressing shutter. And control bar combined with on-job offset calibration method is for eliminating the re-installing error, which will be presented in the third part of this paper. In addition, metric digital camera with exact focal length can avoid zooming error and camera calibration. GPT-7000i is a novel high integrating product, which is more stable and manipulatable. However, its great promotion in photogrammetry will be blocked by two deficiencies if they can not be improved. The one is bad quality of its 0.3 megapixel camera; the other is its image shooting condition that forcing camera to shoot after laser distance measurement, which causes that the instrument can not be used for measuring far distance object with its images when distance measurement fails.

3. On-Job Offset Calibration

Offset of PTSS is defined as the difference between camera coordinate and telescope coordinate.

Figure 2 shows the offset between camera coordinate $S-xyz$ and telescope coordinate $T-X_T Y_T Z_T$, which is compose of three position elements X_{S0}、Y_{S0}、Z_{S0} and three angle elements φ_0、ω_0、κ_0. To calculate such offset is named as Offset Calibration.

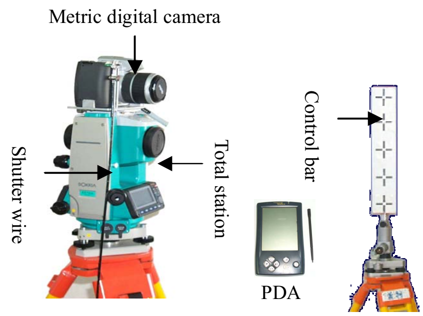

Figure 1. Hardwares of PTSS

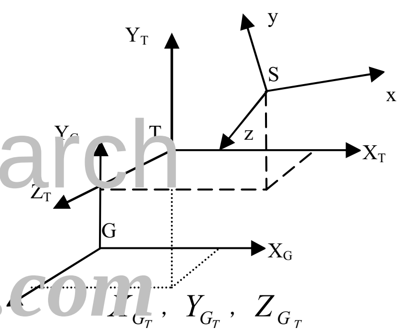

Figure 2. Coordinate systems and offset

Because each photo is correspondent to a known angle-pair of horizontal angle α and vertical angle β measured by the total station, exterior orientation elements of each photo are compose of two parts: angles measured by total station and unknown offset. Fortunately, although the former is different with each photo, they are recorded by the total station during the traverse. So in any photogrammetric processing task with the PTSS, unknown parameters are only the offset, which must be calibrated real-time because of the instability of camera re-installing.

According to the reference [5], functional model of PTSS can be derived, which is similar to the conventional collinear function in photogrammetry. Equation (1) shows the functional model. where X_{G_T}、Y_{G_T}、Z_{G_T} are coordinates of total station center in ground coordinate system $G-X_GY_GZ_G$, X_G、Y_G、Z_G are coordinates of 3D point in ground coordinate system, x、y are image coordinates of the 3D point, $R_{\varphi_0\omega_0\kappa_0}$ is rotation matrix of the offset' angle elements, and f is the focal length of camera.

Simplifying the equations (1), in addition of interior orientation elements x0, y0 (the coordinates of the image principal point), we can get collinear equation in PTSS as equation (2). Where: A_i、B_i、C_i and l_i, m_i, n_i (i = 1, 2, 3) are coefficients.

$$\begin{bmatrix} X_G - X_{Gi} \\ Y_G - Y_{Gi} \\ Z_G - Z_{Gi} \end{bmatrix} = \begin{bmatrix} \cos\alpha & 0 & -\sin\alpha \\ 0 & 1 & 0 \\ \sin\alpha & 0 & \cos\alpha \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta \\ 0 & \sin\beta & \cos\beta \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix}$$
$$= \begin{bmatrix} \cos\alpha & -\sin\alpha\sin\beta & -\sin\alpha\cos\beta \\ 0 & \cos\beta & -\sin\beta \\ \sin\alpha & \cos\alpha\sin\beta & \cos\alpha\cos\beta \end{bmatrix} \left(\begin{bmatrix} X_{S_0} \\ Y_{S_0} \\ Z_{S_0} \end{bmatrix} + \lambda R_{\varphi_0\omega_0\kappa_0} \begin{bmatrix} x \\ y \\ -f \end{bmatrix} \right)$$
$$= \begin{bmatrix} A_1 & A_2 & A_3 \\ B_1 & B_2 & B_3 \\ C_1 & C_3 & C_3 \end{bmatrix} \begin{bmatrix} X_{S_0} \\ Y_{S_0} \\ Z_{S_0} \end{bmatrix} + \lambda \begin{bmatrix} A_1 & A_2 & A_3 \\ B_1 & B_2 & B_3 \\ C_1 & C_3 & C_3 \end{bmatrix} \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} x \\ y \\ -f \end{bmatrix} \quad (1)$$

$$x - x_0 = -f \frac{\begin{matrix} l_1[(X_G - X_{Gi}) - (A_1X_{S_0} + A_2Y_{S_0} + A_3Z_{S_0})] + \\ m_1[(Y_G - Y_{Gi}) - (B_1X_{S_0} + B_2Y_{S_0} + B_3Z_{S_0})] + \\ n_1[(Z_G - Z_{Gi}) - (C_1X_{S_0} + C_2Y_{S_0} + C_3Z_{S_0})] \end{matrix}}{\begin{matrix} l_3[(X_G - X_{Gi}) - (A_1X_{S_0} + A_2Y_{S_0} + A_3Z_{S_0})] + \\ m_3[(Y_G - Y_{Gi}) - (B_1X_{S_0} + B_2Y_{S_0} + B_3Z_{S_0})] + \\ n_3[(Z_G - Z_{Gi}) - (C_1X_{S_0} + C_2Y_{S_0} + C_3Z_{S_0}) \end{matrix}}$$

$$y - y_0 = -f \frac{\begin{matrix} l_2[(X_G - X_{Gi}) - (A_1X_{S_0} + A_2Y_{S_0} + A_3Z_{S_0})] + \\ m_2[(Y_G - Y_{Gi}) - (B_1X_{S_0} + B_2Y_{S_0} + B_3Z_{S_0})] + \\ n_2[(Z_G - Z_{Gi}) - (C_1X_{S_0} + C_2Y_{S_0} + C_3Z_{S_0})] \end{matrix}}{\begin{matrix} l_3[(X_G - X_{Gi}) - (A_1X_{S_0} + A_2Y_{S_0} + A_3Z_{S_0})] + \\ m_3[(Y_G - Y_{Gi}) - (B_1X_{S_0} + B_2Y_{S_0} + B_3Z_{S_0})] + \\ n_3[(Z_G - Z_{Gi}) - (C_1X_{S_0} + C_2Y_{S_0} + C_3Z_{S_0})] \end{matrix}} \quad (2)$$

Because the equation (2) is a non-linear system, we can obtain general form of error equations as equation (3) by linearization with Taylor expansion.

$$\begin{aligned} v_x &= a_{11}\Delta X_{S0} + a_{12}\Delta Y_{S0} + a_{13}\Delta Z_{S0} + a_{14}\Delta\varphi_0 + \\ &\quad a_{15}\Delta\omega_0 + a_{16}\Delta\kappa_0 + b_{11}\Delta X_i + b_{12}\Delta Y_i + b_{13}\Delta Z_i - l_x \\ v_y &= a_{21}\Delta X_{S0} + a_{22}\Delta Y_{S0} + a_{23}\Delta Z_{S0} + a_{24}\Delta\varphi_0 + \\ &\quad a_{25}\Delta\omega_0 + a_{26}\Delta\kappa_0 + b_{21}\Delta X_i + b_{22}\Delta Y_i + b_{23}\Delta Z_i - l_y \end{aligned} \quad (3)$$

Where a_{ij} and b_{ij} are coefficients derived from linearization; ΔX_i、ΔY_i、ΔZ_i are correction values of each unknown 3D point. The derivation process is omitted here because of the limitation of pages for this paper.

Evidently, it is easy to obtain six elements of the offset by single photo resection with 3D control field.

According to our tests and Torres', error caused by re-installing camera from total station (or theodolite) is significant, especially in the three angle elements. Our experiments also show that transferring the whole instrument from one site to the other without re-installing the camera will not bring significant error. Table 1 is the results with single photo resection in the 3D control field, which shows that the angle elements of offset are quite alike when without re-installing the camera. However, three angles are quite different when re-installing. So if two kinds of photos that shot before and after camera reinstalling are processed together, it will bring results significant error. In the table 1, photo 1 and 2 were shot at the same site with different rotation angle; photo 3 was shot at another site but without re-installing the camera; photo 4 and 5 were shot at the third site with re-installing the camera. Measurement unit is *radian*.

Table 1. Instability of angle elements

photo	φ	ω	κ
1	-0.00344	-0.00971	-0.00658
2	-0.00333	-0.00971	-0.00676
3	-0.00359	-0.01016	-0.00654
4	-0.00667	-0.00552	-0.00543
5	-0.00698	-0.00517	-0.00571

As anybody knows, it isn't convenience if the offset of PTSS must be calibrated in the 3D control field each time. So we introduced control bar and on-job offset calibration to realize true non-contact photogrammetry. And its feasibility and accuracy are also proved to be good [Zhang. etc., 2004]. Here, we will present another method, which is similar to the old one but with rotational photography and single control bar (Figure 1). Experiments show that the accuracies are excellent. New method can be generalized as the following seven steps: (1) Traverse is done around the object to be measured with total station; (2) Control bar is putted not far from the current traverse point, while measured objects may be far away; (3) Control points on the control bar are measured by the total station; (4) Rotational photography is imported to obtain nine calibration photos that, in each photo, control bar evenly locates at the different part of the camera frame; (5) Photos covering the measured object are captured, which are only for measuring objects or checking accuracy of the offset calibration. So we named them as measurement photos; (6) When traversing total station to another site, control bar is moved to the front of the current traverse point and same works are repeated, then another nine calibration photos and some other measurement photos are obtained; (7) When finishing the outside traverse, traverse data and photos are exported from PDA and camera. And then bundle adjustment is used to obtain high precision offset with the equation (3). Because calibration work is done at the same time with the surveying, we named it as on-job offset calibration.

In order to prove the feasibility of the new calibration method, we designed a test site with three traverse points, eleven 3D check points around the measured objects and about 16.5*m* (D) from the camera to the measured object (Figure 3). Table 2 shows the results. Where case 1 only included 18 calibration photos of the first and third traverse point, and case 2 included all 27 calibration photos of three traverse points. Symbol m in the table is mean square error of check points around the measured object. Measurement unit is *mm*.

Figure 3. Test scene of new offset calibration method

Table 2. Accuracy of new Calibration Method

Case	m_{XY}	m_Z	m_{XY}/D	m_Z/D
1	5.8	3.1	1/2845	1/5323
2	3.5	2.2	1/4714	1/7500

4. Panorama Mosaic and Building Reconstruction

After offset calibration, exterior orientation elements of each measurement photo can be easily calculated. Then according to the collinear function, panorama mosaic of rotational photos at each traverse point can be realized with central projection.

Experiments show that panorama is greatly helpful for extracting lines' initial position of building and constructing their topology. In order to get better results, fine lines can be precisely located by least square line template matching in the original photo [Hu. 2001]. After lines extraction, line correspondence must be done and line intersection is used for getting 3D lines. Because building reconstruction is a complicated problem, it will not be detailedly discussed in this paper. Figure 4 is one of panorama with six rotational photos shot at a traverse point.

Figure 4. Panorama mosaic image

5. 3D Reconstruction

When we obtain exterior orientation elements of the measurement photos, photogrammetric processing can be done in three modes [Zhang. etc., 2004]. In the following of this paper, one of them is discussed in detail and test result is also presented.

As we know that traverse is also a high intensity work, so all the photos are obtained by the camera on the total station is not a good choice. For it will force us to increase traverse points, so as to obtain more photos with enough overlap and good intersection angle. Good strategy is to combine few photos obtained by the camera on total station and other photos obtained by hand-hold camera, in which the former is also named as control photo with known exterior orientation elements. Then the reconstruction procedure can be described as the following five steps: (1) the first and last photos are obtained by the PTSS, and middle photos (non-control photos) with short baseline are obtained by hand-hold camera. Specially, if the distance between the first and last photos is too far, some other control photos may be added in the middle to obtain high precision result. (2) control photos' exterior orientation elements are obtained by the offset calibration; (3) relative and absolute

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orientation are used for building the block network of all photos; (4) bundle adjustment with the control of control photos is done to obtained exact parameters of non-control photos; (5) 3D model can be reconstructed by multi view stereo matching, Triangulated Irregular Network and texture mapping. Detailed description will not be presented in this paper. Figure 5 shows the reconstruction result.

Figure 5. Image and reconstruction model

6. Photogrammetric Software Design

In order to automatically realize all procedures mentioned above, photogrammetric software with several modules had to be developed. The following are some of main modules and their brief descriptions.

Module for processing traverse data. It is used for data transmission between PDA and the total station. Moreover, it can process traverse data and output good spatial coordinates of control point on the control part.

Module for offset calibration. It can import traverse data of known angle-pair, which are correspondent to each rotational photo. And it can also calculate the offset of PTSS with bundle adjustment. Finally, it outputs exterior orientation elements of each rotational photo.

Module for panorama mosaic. This module allows us to obtain the panorama of each traverse point that merges all rotational photos together.

Module for building reconstruction. This module includes lines extraction algorithm. Then, panorama of each traverse point with rough exterior orientation elements can be used for extracting and calculating initial spatial coordinates of building's lines. Exact position of lines can be located in the original photo with good exterior orientation elements. And building reconstruction work can going on.

Module for 3D reconstruction. After the exterior orientation elements of control photos are obtained and photos are captured by hand-hold camera, aerial triangulation with bundle adjustment is done, in which data include control photos, non-control photos and model points from matching. Then other conventional photogrammetric processing can be carried on and reconstruction model can be obtained.

7. Conclusion

In this paper, we presented a completely novel surveying system, Photo Total Station System (PTSS), which is an integration of mature digital photogrammetry technique, metric digital camera and high accurate engineering surveying equipment (total station). Main Contents include new offset calibration method, accuracy and application of PTSS.

Compared with traditional terrestrial photogrammetry, control points around or on the measured object are not needed in this system. And compared with traditional engineering survey, which mainly involves field survey, PTSS is much more laborsaving, efficient and automatic.

Test results show that PTSS can implement true non-contact measurement and its measurement accuracy is high enough to meet the need of normal close-range measurement. In addition, this paper also points out that the PTSS has great potential in building reconstruction, which should be taken more experiments and further discussed.

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