AN INTEGRATED DIGITAL CLOSE-RANGE IMAGE ACQUISITION SYSTEM AND ITS APPLICATION ON TERRESTRIAL PHOTOGRAMMETRY

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ABSTRACT:

A digital image acquisition system for close-range photogrammetry is developed by integrating an optical camera, a digital camera back, a notepad computer, a storage battery, a tripod, a specially manufactured connection device and a SCSI data transfer cable. This system can acquire images for any object at high resolution of 6400 by 8000 pixels in true color mode. The system is practically used in terrestrial photogrammetry of a huge subsidence pit caused by underground mining. While acquiring the stereoscopic images, At least 7 wooden plates marked control points are laid out around the pit at approximately the same interval distance, and the three-dimensional coordinates of these control points are measured with GPS-RTK. The acquired stereo images are processed with DLT algorithm to calculate coordinates of detail points within the pit. Using these discrete points, the digital elevation model (DEM) of the pit is constructed with TIN. The DEM of original topography before mining is also constructed with TIN by digitizing the large-scale topographic maps. By overlapping these two TIN models of the subsidence, the parameters of the subsidence such as depth, area, and volume can be calculated. To verify the reliability of this system, the three-dimensional coordinates of some detail points are both surveyed with GPS-RTK and with digital close-range photogrammetry. The differences between these two groups of coordinates can give the precision index. The mean square error of horizontal coordinate is about 0.21 meter, and the mean square error of height is about 0.37 meter.

1. INTRODUCTION

With the rapid development of computer and photogrammetry, photogrammetry technique experienced analogue stage to analytical stage, and now it is stepping into digital age. To be a branch of photogrammetry, close-range photogrammetry is also coming into digital stage. To be a remote sensing technique, close-range photogrammetry have many advantages over traditional surveying approaches that it can obtain three-dimensional coordinates of many detail points of observing target at the same time, and it is operated far away from the target which can avoid accessing the dangerous object such as sliding slope, clay and stone onrush, subsidence of ground, et al (Barker, 1997). The conventional close-range photogrammetry is carried out with stereo metric camera, which restricts its extensive application on engineering practices. Because it must be operated at rigorously photographing mode such as normal case photography, parallel-averted photography, convergent photography or equally titled photography, it needs measure the three-dimensional coordinates of the camera stations and orientation points, the photos acquired should be further processed.

The recent development of CCD-cameras and powerful PC's allows the step from analogue to digital photogrammetry, especially for close-range application (Beyer, 1999; Fraser and Edmundson, 2000). A lot of CCD cameras are available on the market and can be used to obtain stereo image pairs to carry out close-range photogrammetry. Compared with conventional cameras, CCD camera needs no film and the acquired digital image can be directly transferred into computer. The acquired images are at the same size and the coordinate of each pixel on the image can be measured accurately by its column and row. But the CCD camera is not a metric camera, the interior orientation and exterior orientation elements are difficult to measure and the photography attitude is difficult to control. Thus, the digital image pairs acquired by CCD cannot be processed like the photo pairs acquired by metric camera in photogrammetry. The direct linear transformation (DLT) algorithm needs no interior orientation and exterior orientation parameters. The photo pairs can be acquired at arbitrary photography attitude. It is especially suitable for close-range photogrammetry with images acquired by any non-metric camera (Feng, 1985; Jeschke, 1990). This technique is widely used in structural deformation monitoring (Wilson,1990), monitoring and measuring bank erosion (Barker, 1997), real-time 3-D non-contact volume and motion measurements (Fryer,1990), highway design and maintenance (Nastasia, 1998), and so on.

The accuracy of coordinates measured is greatly affected by the resolution of the CCD camera. To achieve high precision, the resolution of the CCD camera must be at least 4K*4K. In this paper, an integrated high-resolution digital camera system and its application on monitoring subsidence pit caused by underground mining are discussed in details.

2.THE INTEGRATED DIGITAL CAMERA SYSTEM

To improve the accuracy of digital close-range photogrammetry, a digital camera with high resolution is necessary. A digital image acquisition system for close-range photogrammetry is integrated by China University of Mining and Technology. The system is composed of an optical camera, a CCD digital scanning back, a storage battery, a mobile personal computer, a tripod, some connecting devices and a SCSI data cable. The system is shown in figure 1.

Figure 1. The Integrated Digital Camera System

2.1 Technical Elements About The Digital Camera System

The optical camera used is HORSEMAN® 45HD which produce a photo at the size of 4 inches high and 5 inches width. The camera is equipped with three RODEN STACK® lens with the focal length of 210mm, 150mm and 75mm respectively to satisfy acquiring legible images for objects at different distance away from the camera station. The CCD digital image Scanning back is Phase One® made in Denmark which can directly provide a digital image with the resolution of 6400*8000 pixels at true colour mode. The size of every acquired image is about 144Mb. The time for transmitting the image to a mobile computer by a SCSI cable is about 5 minutes when the scanner is working. The storage battery can supply at least 8 hours of power needed by the scanner. This system is a non-metric digital camera, the interior and exterior orientation elements cannot be measured or demarcated at all.

2.2 Digital Image Acquisition

First the system is set up on the well chosen camera station, then the definition of the image on the coarse glass plate is checked with a special magnifier by focalising the camera, foist the digital scanner back into the backing frame of the camera, connect the scanner back and mobile computer with the data cable and SCSI interface, and also connect the scanner to the storage battery, switch on the scanner and start the scanning driven software, then it is ready to acquire digital image of any ground object. The acquired 144Mb digital image is directly transmitted into the computer with TIFF format.

3.SUBSIDENCE MONITERING WITH DIGITAL CAMERA SYSTEM

Due to long period of underground iron ore mining, the earth's surface of Meishan mining area subsidised and collapsed greatly, which cause a huge subsidence pit at a size of about 600 meter by 800 meter and at the depth of nearly 150 meter. The shape, size and depth of the subsidence should be precisely measured to protect the safety of mining. But it is too dangerous to access because it is active. The integrated close-range data acquisition system is used to fulfil this task.

3.1 Technical Route

Monitoring the subsidence pit with digital camera system is a multi stage work. This includes data acquisition, data processing, data visualization and reliability analysis. The technical route of this approach is shown as figure 2.

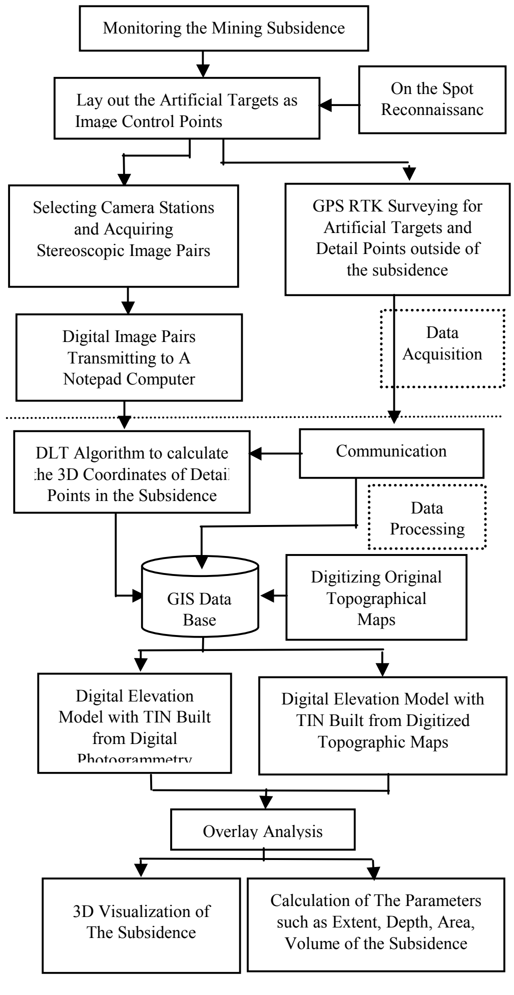

Figure 2. Technical Flow Chart for Digital Close-Range Photogrammetry of the Subsidence

3.2 Stereo Image Pairs Acquisition of The Subsidence

With the integrated digital camera system, a series of stereo image pairs that can cover all the subsidence area are acquired at different camera station far from the pit according to preplanned design. Every image pair must have 80 percent of overlapping. While acquiring the stereoscopic images, at least 7 wooden referent plates marked control points which can form clear image on the stereoscopic image are laid out around the subsidence pit at approximately the same interval distance

(Gong 1998; Feng, 2000; shown as figure 3). The three -dimensional coordinates of the control points are simultaneously measured with GPS-RTK while acquiring the stereo image pair. A part of the pit and all these referent targets are scanned in one stereographic image pair. When the camera station is changed to other location to acquire another stereo image pair, these control points are also changed to new location under the instruction of the image taker. Four pairs of digital images on the opposite side that can cover all this subsidence are acquired at the outdoor work stage.

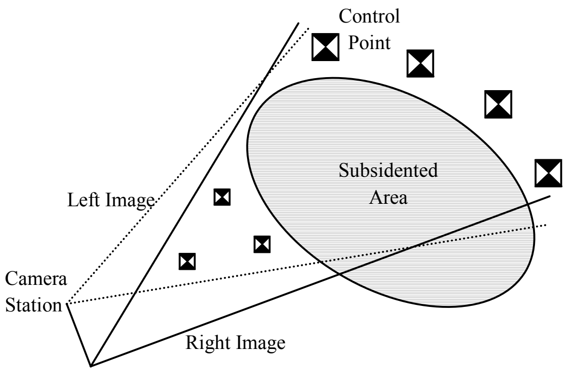

Figure3.Layout of Camera Stations and Control Points on One Image Pair

4.DATA PROCESSING FOR STEREO IMAGE PAIRES

4.1 Ground Coordinates Computation of Detail Points

To calculate the configuration parameters of the subsidence, the three-dimensional coordinates in the object space of the detail points within the subsidence area should be measured. Because our digital image acquiring system is not a metric camera like a theodolite camera which can take photo pairs at normal or oblique or split photography mode, the stereoscopic image pairs are acquired at arbitrary photography mode, and there are no fiducial marks on the image pairs. All the interior and exterior orientation parameters are unknown and cannot be measured. To carry out terrestrial photogrammetry, the control points are the only clue. The Direct Linear Transformation (DLT) algorithm developed by Adbel-Aziz and Karara (Jeschke, 1990; Feng, 1985, Wang, 1990) is a good choice. The DLT algorithm is distinguished by no fiducial marks are needed on the image and the approximate values of the elements of interior and exterior orientation of a image are also unnecessary. This algorithm can be realized in computer program to calculate the real coordinates of any object in the stereo image pairs with the pixel coordinate, ie, the column and raw of the pixel.

The DLT algorithm comes from the collinearity equation. From the collinearity equation:

$$\begin{cases} \bar{x} + f\dfrac{a_1(X-X_s)+b_1(Y-Y_s)+c_1(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} = 0 \\ \bar{y} + f\dfrac{a_2(X-X_s)+b_2(Y-Y_s)+c_2(Z-Z_s)}{a_3(X-X_s)+b_3(Y-Y_s)+c_3(Z-Z_s)} = 0 \end{cases} \tag{1}$$

We can obtain the basic relationship formula of DLT (Feng, 1985; Wang, 1990):

$$\begin{cases} x + \dfrac{l_1X+l_2Y+l_3Z+l_4}{l_9X+l_{10}Y+l_{11}Z+1} = 0 \\ y + \dfrac{l_5X+l_6Y+l_7Z+l_8}{l_9X+l_{10}Y+l_{11}Z+1} = 0 \end{cases} \tag{2}$$

Where x, y represent the image coordinates and X, Y denote the real coordinates in object space. In equation 2, the 11 coefficients l_i (i=1 through 11) are the functions of 11 independent photogrammetry parameters, which are X_S, Y_S, Z_S, Φ, ω, κ, x_0, y_0, f_0, dS, $d\beta$.Thus, these coefficients l_i are independent, too. To solve out the coefficients l_1 through l_{11}, at least 6 control points must be taken into equation 2. Considering the systematic errors and random errors involved in measuring x and y, equation 2 can be changed into:

$$\begin{cases} x + v_x + \Delta x + \dfrac{l_1X+l_2Y+l_3Z+l_4}{l_9X+l_{10}Y+l_{11}Z+1} = 0 \\ y + v_y + \Delta y + \dfrac{l_5X+l_6Y+l_7Z+l_8}{l_9X+l_{10}Y+l_{11}Z+1} = 0 \end{cases} \tag{3}$$

Where v_x, v_y denote the correction of the observed image coordinate, and Δx, Δy represent correction of the non-linear systematic distortion mainly caused by the lens of the camera. Δx, Δy can be expressed as:

$$\begin{cases} \Delta x = (x-x_0)(k_1r^2+k_2r^4+\cdots\cdots) \\ \Delta y = (y-y_0)(k_1r^2+k_2r^4+\cdots\cdots) \end{cases} \tag{4}$$

Where x_0, y_0 denote the image coordinate of principal point, and k_1, k_2 denote the symmetrical aberration coefficients at radial direction, and:

$$r = \sqrt{(x-x_0)^2+(y-y_0)^2}$$

Taken

$$A = l_9X + l_{10}Y + l_{11}Z + 1$$

Abnegate the term of high power in equation 4, then equation 3 can be converted as

$$\begin{cases} A(x+v_x) + Ak_1(x-x_0)r^2 + l_1X + l_2Y + l_3Z + l_4 = 0 \\ A(y+v_y) + Ak_1(y-y_0)r^2 + l_5X + l_6Y + l_7Z + l_8 = 0 \end{cases} \tag{5}$$

When more than 6 control points are taken into these equation, the parameters must be computed with least square methods. The observation equation is:

$$\begin{cases} v_x = -1/A[Ak_1(x-x_0)r^2 + x + l_1X + l_2Y + l_3Z + l_4 + +xXl_9 + xYl_{10} + xZ_{11}] \\ v_y = -1/A[Ak_1(y-y_0)r^2 + y + l_5X + l_6Y + l_7Z + l_8 + +yXl_9 + yYl_{10} + yZ_{11}] \end{cases} \tag{6}$$

Write it in the form of matrix:

$$\boldsymbol{V} = \boldsymbol{ML} - \boldsymbol{W} \tag{7}$$

Then the unknown parameters can be solved by:

$$\boldsymbol{L} = (\boldsymbol{M}^{\mathrm{T}}\boldsymbol{M})^{-1}\boldsymbol{M}^{\mathrm{T}}\boldsymbol{L} \tag{8}$$

Because equation 8 is not linear, it must be calculated iteratively. After the parameters in equation 8 have been solved, the space coordinates X, Y, Z of any point can be computed in two steps:

(1) Adding non-linear systematic distortion corrections to the observed image coordinates:

$$\begin{cases} x + \Delta x = x + k_1(x - x_0)r^2 + \cdots\cdots \\ y + \Delta y = y + k_1(y - y_0)r^2 + \cdots\cdots \end{cases} \tag{9}$$

(2) Computing the space coordinates X, Y, Z of any discretionary points on the image pair.

Taken the corrected coordinates ($x+\Delta x$, $y+\Delta y$) as the original measured image coordinates, and considering the random error in measuring these coordinates, then equation 2 comes to be as follow:

$$\begin{cases} x + v_x + \dfrac{l_1X + l_2Y + l_3Z + l_4}{l_9X + l_{10}Y + l_{11}Z + 1} = 0 \\ y + v_y + \dfrac{l_5X + l_6Y + l_7Z + l_8}{l_9X + l_{10}Y + l_{11}Z + 1} = 0 \end{cases} \tag{10}$$

Write it in the form of observation equation, we obtain:

$$\begin{cases} v_x = -1/A[(l_1 + l_9x)X + (l_2 + l_{10}x)Y + (l_3 + l_{11}x)Z + (l_4 + x)] \\ v_y = -1/A[(l_5 + l_9x)X + (l_6 + l_{10}x)Y + (l_7 + l_{11}x)Z + (l_8 + y)] \end{cases} \tag{11}$$

To solve out X, Y and Z , at least two images acquired at different camera stations are needed. Supposing equation 11 is for the left image, we can white out the observation equation for right image in the same form as equation 11. Then this equation can be denoted in matrix form:

$$\boldsymbol{V} = \boldsymbol{NS} + \boldsymbol{Q} \tag{12}$$

Where

$$\boldsymbol{V} = [v_x \quad v_y \quad v_{x'} \quad v_{y'}]^{\mathrm{T}}$$

$$\boldsymbol{N} = \begin{bmatrix} -1/A(l_1 + l_9x) & -1/A(l_2 + l_{10}x) & -1/A(l_3 + l_{11}x) \\ -1/A(l_5 + l_9y) & -1/A(l_6 + l_{10}y) & -1/A(l_7 + l_{11}y) \\ -1/A'(l_1' + l_9'x) & -1/A'(l_2' + l_{10}'x) & -1/A'(l_3' + l_{11}'x) \\ -1/A'(l_5' + l_9'y) & -1/A'(l_6' + l_{10}'y) & -1/A'(l_7' + l_{11}'y) \end{bmatrix}$$

$$\boldsymbol{S} = [X \quad Y \quad Z]^{\mathrm{T}}$$

$$\mathbf{Q} = [-1/A(l_4 + x) \quad -1/A(l_8 + y) \quad -1/A'(l_4' + x) \quad -1/A'(l_8' + y)]^{\mathrm{T}}$$

Then the unknown values can be solved by the normal equation:

$$\boldsymbol{S} = -(\boldsymbol{N}^{\mathrm{T}}\boldsymbol{N})^{-1}\boldsymbol{N}^{\mathrm{T}}\boldsymbol{Q} \tag{13}$$

Equation 13 must be computed iteratively like for equation 8. The terminated discriminant can be 1/10 or less of the accuracy that is expected about the object coordinates.

A software under Windows platform is developed to carry out these processing. With the acquired four pairs of images, the space coordinates of a totally of 4200 detail points distributed almost equally within the subsidence pit are computed. The calculated coordinates of ground points are directly saved to an ASCII file.

4.2 Computation of Morphological Parameters of the Subsidence

To compute the morphological parameters of the subsidence pit, the three-dimensional coordinates of discrete points calculated by DLT algorithm are used to produce digital terrain model with triangulated irregular network (TIN). The original topographic digital terrain model before mining extraction of this area is also constructed with TIN by digitizing from large-scale topographic maps. These DTMs are created with the 3D Analysis Module in ArcView3.2 which is a software produced by ESRI. By overlapping and comparing these two temporal TIN models of the subsidence pit, we can obtain that the area of the subsidence is 2.9*10^5 square meter, the maximum subsidizing depth of the surface is 110 meter which is compared with the original height before mining, and the volume of this subsidence is 5.863*10^6 cubic meter. The shape of this subsidence can also be visualized in three-dimension that is shown in figure 4.

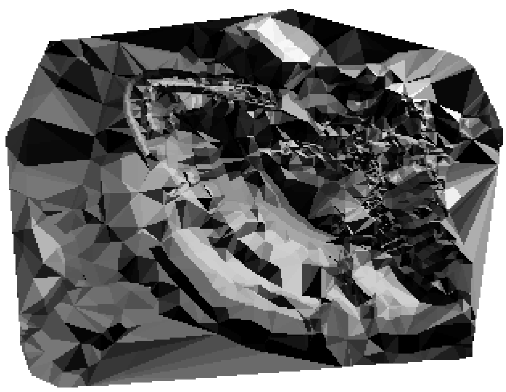

Figure 4. Visualization of the subsidence

5.ACCURACY ANALYSIS ABOUT THE SYSTEM

Just like traditional close-range photogrammetry with optical camera, the photogrammetry with digital camera system also exists many sources of error. From data acquisition to data processing, the errors may be caused by refraction of atmosphere, radial distortion and decentering distortion of the lens, non-uniform response and unequal pixel size in scanning direction and in its perpendicular direction of the CCD camera, arrangement pattern and surveying accuracy of control points, object distance to camera station, attitude of the camera when it is working, definition of object on the digital image, accuracy of observing and measuring the image coordinates of any point, strictness of the DLT algorithm, and so on. It is almost impossible to evaluate the reliability and accuracy of this system theoretically. To verify the surveying precision of this system, the only feasible method is taking experiment on the spot. The three-dimensional coordinates of some obvious detail points scattered around the subsidence pit are surveyed with GPS RTK, and their coordinates are also measured with the digital close-range photogrammetry. 78 points at different location are used in this experiment. The coordinates surveyed by GPS-RTK are taken as actual value, and the coordinates computed with DLT are taken as observing value. The differences between these two groups of coordinates can give the precision index. The mean square error of horizontal coordinate is about 0.21 meter, and the mean square error of height is about 0.37 meter. The precision is largely depend upon the distance from the camera station to the measured points. The further a point away from the camera station, the larger an error occurs. The closer a point is the higher precision we can obtain.

6. CONCLUSIONS

The integrated digital camera system is efficient in acquiring digital image pairs that can be processed with close-range photogrammetry approach. It can be used in terrestrial photogrammetry and engineering photogrammetry. DLT algorithm with more than 7 control points can be used to computer any detail points within the image pairs. But the accuracy of this system is largely depended on the distance from camera station to the object and distribution of control points. With DLT algorithm, it needs observe and measure image coordinate of any detail point manually on the image pair. When the points to be measured are numerous, the efficiency of this approach is very low. To improve the efficiency of photogrammetry with this digital camera system, a better solution is automatic image matching and produce the stereo model of the object. But the images acquired by terrestrial photograph have idiographic characteristic that image pairs maybe photographed at arbitrary altitude, the scale is varied at different distance, and except for the observing object, the sky may take a great part on the images. These reasons cause that automatic match algorithms can not obtain good result. Further studies should be made to solve these problems. In addition, the time for acquiring one image with this integrated digital camera system is so long that this system cannot be used in monitoring any moving objects. It is only suitable for measuring static object such as buildings, dams, and so on.

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