CRUSTAL DEFORMATION DETECTION USING CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT: The objective of this study is to perform high temporal frequency crustal deformation monitoring using close-range photogrammetric technique, which has high accuracy and spatial resolution, to distinguish small relative displacement caused by the movement of fault. For this purpose, we propose the use of coded targets and man-made permanent white round targets through close-range photo triangulation software that is capable of automatic recognition and referencing. The test site is located near Guanshan Township in eastern Taiwan where a significant rupture on the concrete wall of a drainage channel is caused by the movement of Chihshang creeping fault. We equally spread and fixed 786 round white targets on the wall using stainless nails and measure their coordinates every month. A DSLR camera with fixed focal length lens (20mm) is adopted in order to maintain the stability of its internal geometry. During image acquisition, a convergent imaging scheme is essential in order to obtain strong imaging geometry with best positional accuracy. For each data acquisition period, a set of three-dimensional coordinates for all round white targets were obtained. Comparing with two different periods, we may evaluate the relative displacement of all targets by selecting several targets located on one side of the crack as control points through conformal transformation. Experimental results show that the proposed scheme can obtain reliable results and recognize the relative displacement caused by the movement of fault.

1. INTRODUCTION

According to the measurements from continues GPS stations during 1991-1996, the Philippine Sea plate was moving north-westward relative to Eurasian plate about 82 mm/year in the Taiwan area (Yu et al., 1997). Such huge displacement rate causes dramatic orogeny, earthquakes and many active faults. In east Taiwan, the Longitudinal Valley fault (LVF) includes its branches like Yuli fault and Chihshang fault are located along the boundary between Eurasian plate and Philippine Sea plate. In history, two major earthquakes are Chihshang (Mw = 6.2, 1951) and Chengkung earthquake (Mw =6.8, 2003) ruptured by the activity of Chihshang fault.

In the view of related work, the relative displacement of Chihshang fault calculated by GPS continuous station, leveling, trilateration work and creep meters monitoring is 20 - 30 mm/year in the N310°E direction near the Chihshang Township(Mu et al., 2011). However, the methods need continuous monitoring and complexity calculation, which could derive results only in horizontal direction by GPS observation and vertical direction by leveling. Thus, the close-range photogrammetry is studied for monitor the displacement caused by the activity of Chihshang fault, which could provide 3 dimensions data.

1.1 Close-Range Photogrammetry

The traditional aerial triangulation method is taken images from aircraft, which is generally for ortho map production, DEM generation, building extraction, image classification, etc. In such case, the ground sampling distance (GSD) is ranged from 20 cm to 60 cm, which is based on the focal length, flight height and image resolution. However, the close-range photogrammetry is to take photo on the object in a short distance, i.e. 50 cm to 5 m, the spatial resolution could small than 1 cm.

In close-range photogrammetry, it usually takes photos on the interested objects for 3D modeling (Rau & Yeh, 2012) or object recognition. The procedure can divide into two approaches: image matching and artificial targets detection. The first one generally uses feature extraction methods (SIFT(Lowe, 2004), SURF(Bay et al., 2008), etc.) for interest points matching and the accuracy of image measurement error is less than 0.3 pixels. The other one is automatic target detection which is adopted in this study. We utilize Australis (Fraser and Edmundson, 2000) artificial coded targets which can detect white circle points and get more accurate result less than 0.04 mm(Fraser, 1998). Thus, its high accuracy could help to monitor little creep displacement caused by fault activity.

1.2 Study Site

The study site is near Guanshan Township in eastern Taiwan where a significant rupture on the concrete wall of a drainage channel is caused by the movement of Chihshang creeping fault. As shown in Figure 1 (a), the wall was constructed by pebble with concrete and some plants grow on it, one could also see the blue ruptured curve in the middle photo and uplift in the right hand side, where the red arrow means the relative movement direction about 10 mm/year in this region.

In order to monitor the relative displacement of this site, about 800 stainless nails are fixed in 5 rows by 160 columns on the wall surface as permanent targets, where the dimensions is 5m * 120m. In the meantime, to reduce the noise and increase the measuring accuracy during targets detection, the background has been painted in black with white circle target, an example shown in Figure 1 (b). Thus, the coordinates of these permanent targets could be estimates by taking photos and calculate their relative displacement by different time series data sets (one data set represents a series of photo taken in a time).

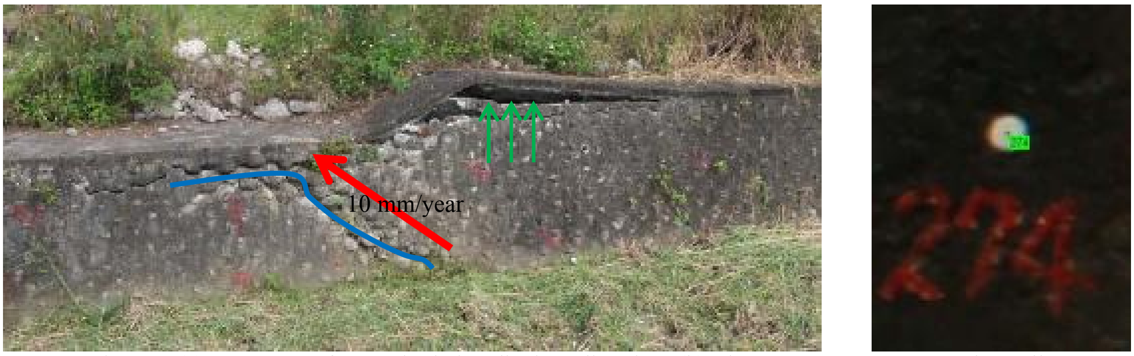


Figure 1 (a) Rupture surface and relative displace direction; (b) The permanent targets on the wall

2. METHODOLOGY

The workflow for monitoring the displacement of a ruptured surface caused by Chihshang fault is shown in Figure 2. In preprocessing stage, the wall needs weeding to reduce the occlusion area and patch the artificial coded targets on the wall surface. Before photo acquisition, the camera parameters should be well calibrated, then take the photos of the wall with multi-angle to get a good intersection angle. Then, the photos are imported into Australis software © for automatic coded target detection and recognition, and get the estimate coordinates of permanent targets through bundle adjustment and auto-referencing. Thus, we can calculate relative displacement by different time series of photos (separated with about one month). The details of each stage are described below.

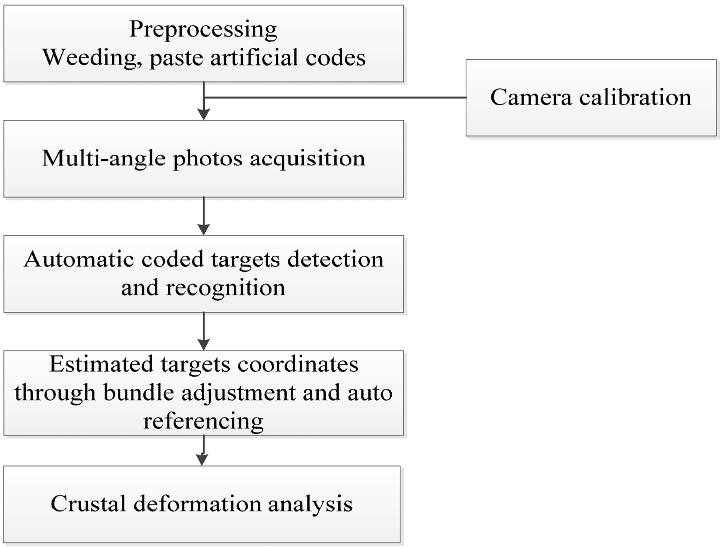


Figure 2 The flow chart for monitoring the displacement of crack by close-range photogrammetry

2.1 Preprocessing

Due to there are some plants grow on the drainage wall which may cause some occlusion area in the photo, thus, weeding is necessary to remove it. After checking this, around 150 Australis artificial coded targets are averagely pasted on the wall surface. These coded targets have the flexibility for automatic detection and have high accuracy less than 0.04mm. They are also used for camera calibration and auto photo referencing for bundle adjustment to estimate permanent targets coordinates. Figure 3 shows an example of Australis artificial coded target, which is composed by several 6 mm diameter white points, in which the lengths of the two red crosses are treated as known observations during bundle adjustment for the purpose of scaling.

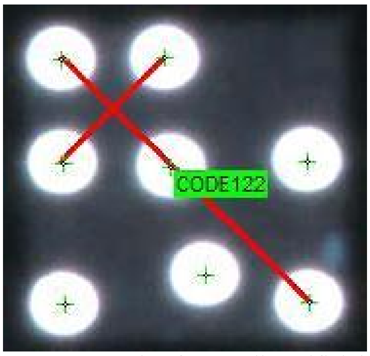


Figure 3 An example of Australis artificial codes

2.2 Camera Calibration

In this study, a 20 mm focal length consumer grade DSLR camera is used to take photos. Due to its wide field of view (FOV), the image could cover the codes and targets as more as possible, and also reduce the numbers of photo and increase the convergent angle. However, the interior orientation parameters (IOP, i.e. focal length, principle points, radial and decentering lens distortion) of the consumer grade camera are not stable. As a result, to increase the accuracy of image measurement, the camera parameters should be well calibrated before taking the photo. To realize the goal, a calibration filed is built for the estimation of camera parameters through self-calibration bundle adjustment with additional parameters (Rau and Yeh, 2012).

In the calibration filed, the coded targets are fixed on different heights of pillars on a rotated table, where the heights from 0 to 30 cm. Due to the table could be rotated, the convergent angle will be 60-90 degrees by take photo in an oblique direction 30-45 degrees, without changing the photo position everywhere, as shown in Figure 4.

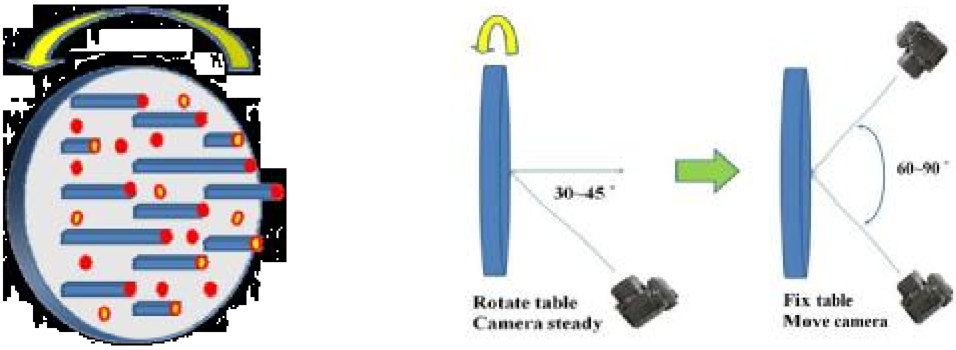


Figure 4 Camera calibration field (Rau and Yeh, 2012)

2.3 Image Acquisition and Permanent Target Detection

To automatically detect the coded targets and reduce noise effect in Australis software ©, the photos are taken under less sun light condition using flash light, which could acquire a high contrast images. In the meantime, to increase the tie-point connection of the imaging geometry, the multi-angle images are taken from vertical direction to the wall and four oblique directions (i.e. upward, downward, leftward and rightward) to increase the convergent angles. Examples of photos taken in different directions are shown in Figure 5 (a)-(c).

With the help of automatic detection of coded targets in Australis software ©, the permanent targets could be automatic referenced and their coordinates can be computed through bundle adjustment. However, some permanent targets are missed at the boundary of oblique photos, where reflect less flash light. Hence, manual editing for measuring those unreferenced points and the removal of blunder points are necessary. An example of detected targets and measured permanent targets shows in Figure 6.

(a) Vertical (Orthogonal to the wall) (b) Oblique (leftward) (c) Oblique (downward)

Figure 5 (a)-(c) examples of images taken from different directions

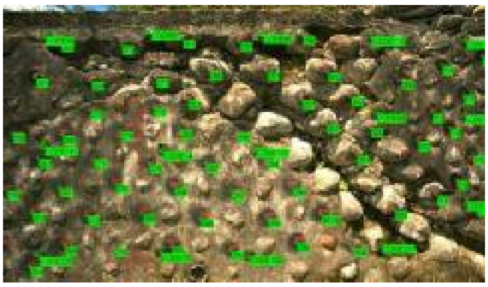


Figure 6 An example of detected targets and measured permanent targets

2.4 Crustal Deformation Analysis

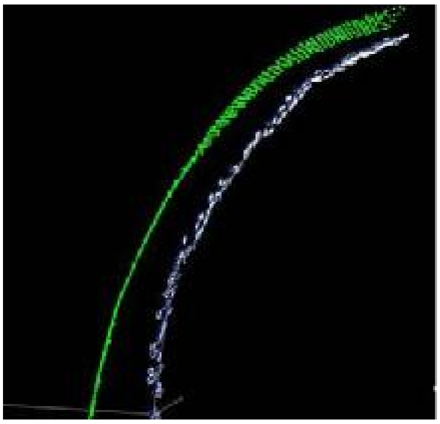
The frequency of photo acquisition is about one month in the study area. In this study, the reference permanent targets coordinates are calculated by the first data sets. For the purpose of crustal deformation analysis, the relative displacement is calculated by comparing the reference coordinates with different time series' results through three-dimensional conformal transformation.

3. RESULTS AND ANALYISIS

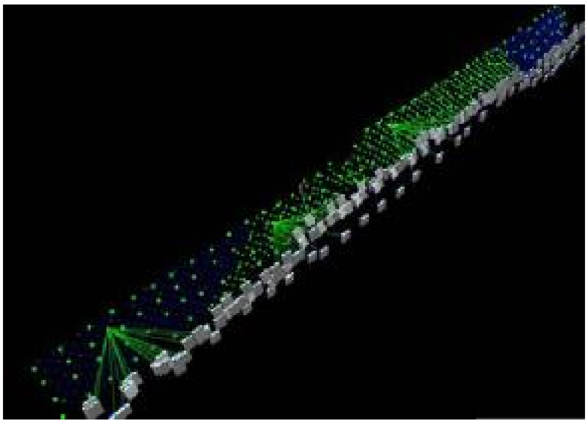
In this section, the importance of camera calibration, the differences of using different photo acquisition directions for bundle adjustment and the preliminary relative displacement results in 6 months are illustrated.

3.1 The Importance of Camera Calibration

As mentioned, the camera parameters are decided by self-calibration bundle adjustment with additional parameters by taking photo in a calibration field. Thus, the results are fixed as known parameters during bundle adjustment to estimate the permanent targets coordinate. To realize the importance of camera calibration, two experiments with and without camera calibration are conducted. From Figure 7 (a), one could realize the 3D points in the object space are blended without calibrating camera parameters. However, when the known camera parameters are applied, the results will turn into correct plane surface, as shown in Figure 7 (b).



(a) Without camera calibration, the 3D points distribution are incorrect and bended



(b) With camera calibration, the 3D points are correctly distributed

Figure 7 Points distribution with and without camera calibration

3.2 Photo Convergent Angle

As mentioned, the photos are taken from vertical and four different oblique directions (i.e. leftward, rightward, upward and downward) to increase the convergent angle and increase the accuracy. In Table 1, it summarizes the difference of accuracy of three different sets, i.e. using vertical image only, using oblique image only and combining the vertical and oblique images. From the table, these indexes represent the absolute error in the object space (X, Y, Z), one could realized that the errors were reduced when combining the vertical and oblique images together. However, the overall image coordinates measurement accuracy (Sigma0) was dropped from 0.13 pixels to 0.19 pixels, due to perspective distortion introduced by oblique imaging.

Table 1 Accuracy assessment between Vertical and Vertical with Oblique

Dataset 0227	X	Y	Z	Overall	Sigma0
Vertical	0.2281	0.1358	0.2796	0.2145	0.13
Oblique	0.0786	0.0515	0.1007	0.0769	0.19
Vertical with Oblique	0.0740	0.0481	0.0940	0.0720	0.19

3.3 Estimation of Relative Displacement

In this study, only photos taken on 27th Feb. and 12th Aug. are selected. The accuracy indexes of each datasets are summarized in Table 2. From the table, the overall accuracy of data set 12th Aug. is small than 27th Feb, the reason is the number of measurements are less than 27th Feb by less images, but the result is acceptable.

Table 2 Accuracy of each dataset

Dataset	X(mm)	Y(mm)	Z (mm)	Overall (mm)	Sigma0	No. of Images
0227	0.0740	0.0481	0.0940	0.0720	0.19	172
0812	0.0894	0.0534	0.0971	0.0800	0.19	96

After computing the difference of coordinates of each permanent targets in 6 months, as shown in Figure 8, the error vectors shows a maximum relative displacement near the rupture curve (depicted in blue curve) is about 5 mm (3mm in X direction and 4 mm in Y direction), which is closed to related work mentioned 10 mm/year, and decreased far away from the rupture curve. However, we also noticed that the results at the boundary of the wall are not reasonable (Green circles). Three possible reasons are: the error propagation caused by imperfect camera calibration, smaller convergent angle (60 degree) and less constraint near the boundary.

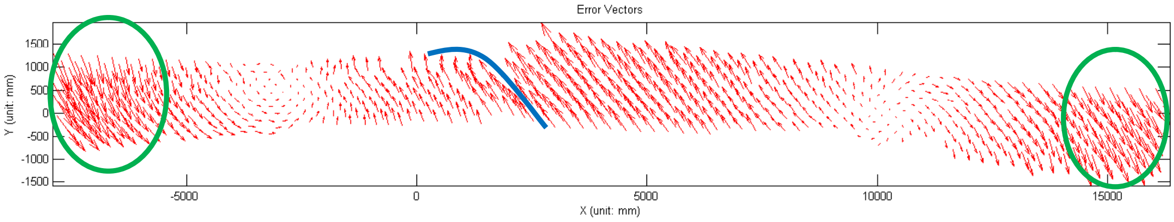


Figure 8 Error vector of permanent targets in 6 month period

4. CONCLUSIONS AND FUTURE WORK

In this paper, we utilize close range photogrammetry to monitor the relative displacements of the concrete wall, which has a significant rupture caused by the movement of Chihshang fault. The Australis artificial coded target is suggested to automatic detecting and referencing the manmade targets arranged on the wall and calculates the coordinates of targets for different time series of data set. From the experiment, the results show the vertical and oblique images get the best accuracy in X, Y and Z direction, the accuracy of each data sets are all less than 0.08mm. After comparing the difference of coordinates in 6 months, the maximum relative displacement near the rupture is 5 mm, which is reasonable comparing with other literatures. It also demonstrates that this method has the flexibility to monitor small displacement caused by fault activity, particularly only a low-cost consumer grade DSLR digital camera is used. In the future, a periodical monitoring and auxiliary surveying data including total station, leveling and GPS to verify the results will be conducted.

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