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Assessing Volume Earthwork by Using Unconventional Photogrammetry

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Abstract "Unconventional Photogrammetry" is a measurement methodology which does not require "Camera Calibration" and can use regular consumer camera. The calculation of its "internal and external parameters" is more complicated and less precise than "Traditional Photogrammetry". But when disaster occurs, Unconventional Photogrammetry can use readily available photos to reconstruct its 3D terrain data very quickly. By comparing this reconstructed terrain data with the terrain data before the disasters, we can quantify the changes in elevation during disasters.

In this paper, we chose a large-scale slope failure event which occurred on the Cidu section of Formosan Freeway on 2010/04/25 at 14:33 and used "Unconventional Photogrammetry" to reconstruct terrain data from two different periods. We estimated that the earthwork volume of the landslide was around 225,078.5 m³; and this is close to the result published by Ministry Of Transportation And Communications R.O.C (2010³). It shows that this method is indeed feasible and is able to effectively, economically, rapidly, and quantitatively measure the terrain elevation variations before and after disasters.

Keywords Unconventional Photogrammetry, computer vision, SIFT, SfM, earthwork volume

Preface

Because of the many recent natural disasters, measurement methods and their protocols are being studied by the international experts (Ke Tao et al., 2010). They are usually referred to as "unconventional photogrammetry." It differs from the conventional photogrammetry in that it requires lower precision and has less limiting requirements. Its primary feature is its ability to utilize various image data that are easy to obtain such like post-disaster random aerial photos, UAV photography, photos provided by the locals or media and so on. Further, its data processing is semi-automatic, very convenient for post-disaster preliminary investigation. As digital camera becomes more popular, many disaster photos are taken at the site. However, due to these photos are often taken randomly in complications location and without coordinates, then this often look like convergent photography, not traditional parallel

photography and not suitable for traditional photogrammetry (see Fig. 1). Because of the vast improvement in performances such as resolution and sampling rate and the development in measurement theories, digital photogrammetry begins to be used in the measurements and determination of different physical values as well as topographic maps and instant post-disaster data processing. Chen Chien-Chou et al. (2010) successfully replaced high-precision speedometer with consumer-style digital camera in determining the various modal parameters of stayed-cable. Sun Min (2007) and Zhao Xiao et al. (2004) also used digital camera to obtain industrial-grade precision 3-dimensional terrains through computer vision's multiple view geometry technology. In the 2010 Unconventional Photogrammetry Seminar hosted by Taiwan's Cheng Kung University, China's Wuhan University presented their protocols and results in data acquisition and processing during the 512 Sichuan earthquake through non-traditional photogrammetry (Ke Tao et al., 2010; Zhang Yong et al., 2010; Sun Ming-Chuan and Duan Yan, 2010). Therefore, international experts classified Scale-Invariant Feature Transform (SIFT), Structure from Motion (SfM), and multi-view geometry as unconventional photogrammetry. Methods adopted by this study use either calibrated or uncalibrated camera to take a series of photos to calculate the motion parameters during the photographing and establish the related 3D geometric data (Lie Wen-Nung and Wei-Ji Chen, 2010). This is an extremely popular 3-dimensional recreation in the field of Computer Vision (Pollefeys et al., 1996; Triggs, 1997; Kraus, 1997; Meng Xiao-Qiao et al., 2003; Zhao Xiao et al., 2004; Habed et al., 2004; Wang Liang fen, 2010). SfM uses the Self-Calibration technology to acquire the relative camera position of each photo (Maybank and Faugeras, 1992; Faugeras, 1992; Pollefeys, 1999; Lei et al., 2001; Lei Cheng et al., 2001; Zhang Yan-zhen et al., 2001) to obtain camera's rotation and translation parameters. From these two parameters and the axis that going through the point of origin, every photo is calibrated to the same criteria. In other words, 3-dimension recreation is conducted through multiple view geometry (Gordon and Lowe, 2004; Sun Min, 2007).

This study used the large slope failure at the 3.1 km mark of Freeway No. 3 on April 25th, 2010 as a case study. Panasonic LX3 is consumer-style digital camera which was used to take images before and after the debris

removal from different angles. 3-dimensional cloud point data were obtained from these images through unconventional photogrammetry. After some editing, the range of application was determined by using high-precision GPS measurements as the ground true data to verify the error in cloud point data. 3-dimensional graphics software Surfer was used to compare the digital terrains before and after debris removal to assess the volume of earth removed at this area in this particular event.

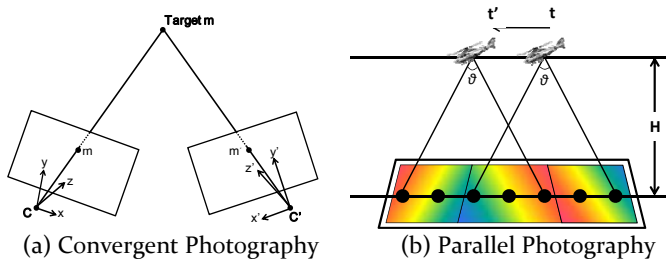


Figure 1 Convergent and Parallel Photography.

The Process of Unconventional Photogrammetry

Massive slope failure struck the right side of southbound Freeway No.3 between Keelung and Hsichih on April 25th, 2010 at 2:33 p.m. (Ministry of Transportation and Communications, 2010b) The failure occurred on a windless, rainless, sunny day. Masses of debris destroyed the Dapu Bridge above Freeway No.3 and buried 6 lines (including both northbound and southbound) of the freeway. The Jinshan-Keelung section was completely shutdown for both ways during the rescuing/repairing period. The estimated re-opening date was postponed from May 25th, 2010 to June 1st, 2010, with only conditional opening. Two-way traffic was then completely restored for all 6 lines, and the restrictions were lifted.

Because the collapsed earth volume can not be easily estimated immediately after the disaster struck and safety procedures are complex and time-consuming, the re-opening data is prone to be delayed. Timely measurement/assessment of collapsed earth volume conducted after the disaster helps with the removal planning. Moreover, in a large disaster area, the distribution of hazards is often sporadic, and traffic is often disrupted, which makes manpower support difficult. This is further compounded by the fact that there are fewer equipments and operators that can perform quick measurement (ie. LiDAR). Timely terrain measurement of all disaster areas is therefore difficult. Acquiring timely quantified data and, consequently, assessment of further earth removal measures are difficult.

The step of Assessing Volume Earthwork by Using Unconventional Photogrammetry are illustrated below:

1. Photographing Target in Multi-angle: 3-dimensional recreation is similar to stereo vision. More than 2 photos taken from different angles are required for such a recreation. Longer the focal length from the target

requires more photos taken from same distance and same angle(see Fig. 2). However, the resolution is better, which improves the accuracy and density of recreated 3-dimensional cloud point data, and as a result, the computer processing time is longer. Finally, these cloud point data undergo coordinate conversion by using reference control points. In order to identify these reference control points, the experiments performed in this study suggest they should contain at least 7x7 pixels.



(a) Short Focal Length (36mm) (b) Long Focal Length (70mm)

Figure 2 Photos with Different Focal Lengths at the same shooting place. (Shorter focal length allows greater field of vision but has lower resolution.)

2. Image Matching: Feature detection must be performed first, followed by feature matching. Feature must be robust and describable. This robustness requires the particular feature to maintain its invariance in rotation, scale, perspective, and brightness. By compiling statistics on feature points and through conversion or combination, they are transformed into descriptive formats that are easily identifiable and matched. From there, robust match of two very different images can be performed. Therefore, this study used SIFT algorithm (Lowe, 1999, 2004, 2006), which include "eigenvector creation" and "eigenvector matching" (Hu Xiao-feng and Zhao Hui, 2004). This allows acquisition of scale and rotation invariance as well as description operator to accomplish a good image match.

3. Acquisition of Camera Position and Parameter: Two images that have the most feature point matches are selected as the starting point. Sparse Bundle Adjustment Library (Lourakis and Argyros, 2004) is used to reduce the target functions in each calculation cycle. Adjacent photos with sufficient feature point matches are then added in order. SfM cycle is repeated to calculate the camera position and parameters in each photo of the target until no photo is available for 3-dimensional recreation (Noah et al., 2010).

4. 3-dimensional Reconstruction: 3-dimensional reconstruction is based on the calculation of 3-dimensional cloud point data. This study used Multi-View Stereopsis (MVS) (Yasutaka and Jean, 2010) and conducted calculation on the 3-dimensional cloud point data of specific images that already have camera parameters: MVS is accurate and efficient. Its calculation of the 3-dimensional cloud point data is also concentrated with the original RGB color codes.

5. Coordinate Transformation: 3-dimensional cloud point data of the target is converted from coordinates in the relative areas to those in the real world through reference control points. When conducting 3-dimensional

recreation using non-metric camera, the distribution of the control-reference points need to satisfy calculation conditions. The entire area to be measured should be under control as much as possible. Too many reference control points, however, do not improve the precision. 6 or more reference control points are recommended for coordinate conversion (Wang L., 2002).

6. Camera is used as basis for data measurement, and the primary source of error is the camera and 3-dimensional recreation algorithm. Seitz et al. (2006) pointed out the accuracy of a 20cm wide object in a 300,000 pixel (640*480) photo in most current 3-dimensional recreation algorithms can reach 0.1cm. Recently, the accuracy of many photogrammetry by non-metric camera already can satisfy the requirement in creating topographic maps with scale between 1:100~1:200 (Wang L., 2002). Measurement accuracy is very important to estimating terrain difference. Understanding the accuracy of terrain data is critical to determining the real difference from measurement error. Hsiao Cheng-Yang et al. (2009) used airborne LiDAR with accuracy of 50cm as an example. If the terrain elevation difference between two periods is less than 50cm, it is not recommended to be directly used in analysis and estimation. Therefore, this study used the reputable German brand Leica's high-precision GPS to measure and to recreate the 3-dimensional cloud point data to conduct measurement error comparison.

7. 3-dimensional cloud point data often include vegetation and other extraneous features (ie. bulldozer or poles, etc.). Therefore, manual editing such as cloud point removal or elevation reduction should be conducted. 3-dimensional scientific graphics software Surfer is then used to compare the digital terrains before and after the earth removal to estimate the collapsed earth volume. Fig. 3 is a diagram that simulates the volume calculation of terrain changes. The high-precision digital terrain from the earlier period was subtracted from that of the later period. A negative grid value means outgoing earth volume, and a positive grid value indicates incoming earth volume. The result is multiplied by the area of the digital terrain grid, and that gives the terrain change within a single grid. Consequently, the earth volume removed/collapsed is the sum of the terrain change volumes.

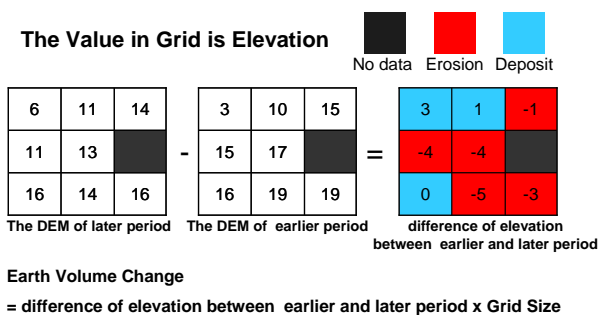


Figure 3 Calculation of Terrain Change. (modified from Chen-Yang Hsiao, 2009)

Case Studies

This section uses the estimation of earth removal volume from the Dapu dip slope failure as a case study. 3-dimensional recreation, measurement error comparison, and collapsed earth volume estimation are described below.

3-dimensional Recreation

After the collapse at the 3.1km mark of Freeway No.3, we arrived at the clearing on the Tzu-chiang Industrial Road (see Fig. 4) across from the disaster site to photograph the site (see Fig. 5) at 3:00 p.m. on April 25th, 2010 (9 photos taken) and at 1:00 p.m. on September 16th, 2010 (52 photos taken). Next, image matching and SfM calculation were performed on these photos. 5 photos from before the removal and 26 photos from after the removal were selected for 3-dimensional recreation, producing 964,021 and 1,590,206 cloud point data respectively. Finally, 7 reference points measured by high-precision GPS coordinates were used for conversion to the real world and as reference control points (see Tab. 1). Fig. 6 is the result of 3-dimensional recreation of the cloud point data. (a) and (b) are cloud point data that contain 3-dimensional coordinates and RGB color codes (ie. vegetations, poles, and bulldozers, etc.).

Measurement Error Comparison

Comparing the feature point coordinates from 3-dimensional recreation with the result of high-precision GPS site survey, the elevation error is between 1cm and 16cm(see Tab. 2) and meets the terrain measurement acceptance criteria by the Urban and Rural Development Branch of the Construction and Planning Agency(Wu Tsung-Chiang et al., 2007). To increase its accuracy, cross-matching among different algorithms or upgrading camera equipments to increase resolution can reduce estimation error through comparison of standard indoor models.

Table 1 Result of Measurement by High-precision GPS Coordinates.

No.	TWD97_X	TWD97_Y	Elevation (M)	Purpose
1	320,092.16	2,779,282.87	111.25	Coordinate Conversion
2	320,024.04	2,779,289.75	128.08	
3	319,998.46	2,779,288.23	134.63	
4	319,978.13	2,779,292.41	140.52	
5	319,958.26	2,779,299.91	146.63	
6	319,949.26	2,779,291.17	146.40	
7	319,962.33	2,779,276.91	142.65	
8	320,064.65	2,779,253.63	114.62	Error Comparison
9	320,063.61	2,779,252.56	114.89	
10	320,027.11	2,779,266.49	125.31	
11	320,026.10	2,779,265.24	125.47	

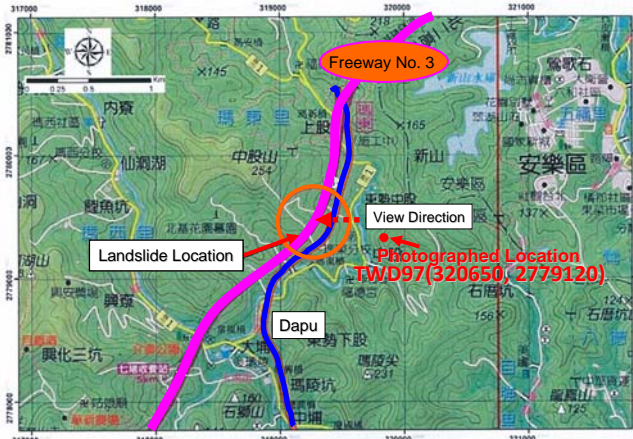


Figure 4 Photographed Location. (from Ministry of Transportation and Communications, 2010b)

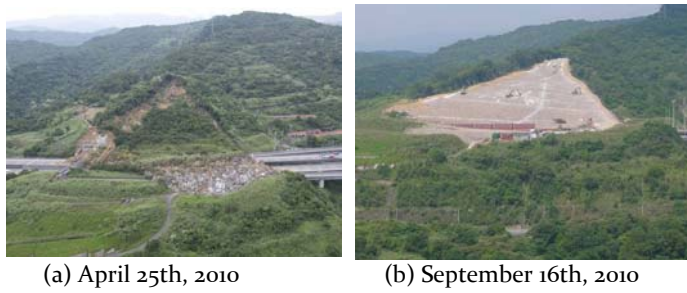


Figure 5 Before and After the Removal

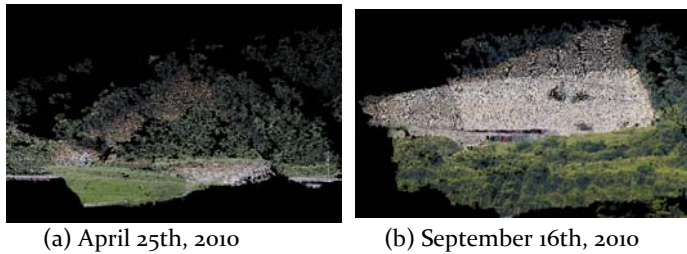


Figure 6 3-dimensional Cloud Point Recreation

Assessment of the Collapsed Earth Volume

After completing manually editing the cloud point data, Surfer was used to establish 5mx5m digital elevation models(DEM) before and after removal. Collapsed earth was visible on the slope before removal(see Fig. 7). After the removal, the slope was smooth and without any remaining earth(see Fig. 8). Fig. 9 is illustrates the elevation changes before and after the earth removal. The estimated earth removed was approximately 225,078.5m³. Compared against the data posted by the Ministry of Transportation and Communications (2010a) of 219,527m³ removed, they were close with only 2.5% of difference.

Table 2 Error Comparison.

GPS Measurement	TWD97_X	320,064.65	320,063.61	320,027.11	320,026.10
	TWD97_Y	2,779,253.63	2,779,252.56	2,779,266.49	2,779,265.24
3-D Recreation	Elevation (m)	114.62	114.89	125.31	125.47
	TWD97_X	320,064.26	320,063.80	320,026.35	320,026.19
Absolute Elevation Difference (m)*	TWD97_Y	2,779,250.99	2,779,250.83	2,77,926.72	2,779,267.73
	Elevation (m)	114.78	114.76	125.42	125.31

* Absolute Elevation Difference= |GPS Measured Ellipsoid Height - 3-D Recreation Measured Ellipsoid Height|



Figure 7 Topographic Shading Map before Removal

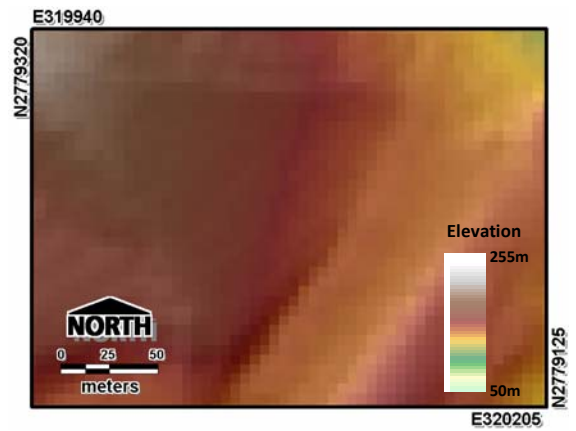


Figure 8 Topographic Shading Map after Removal

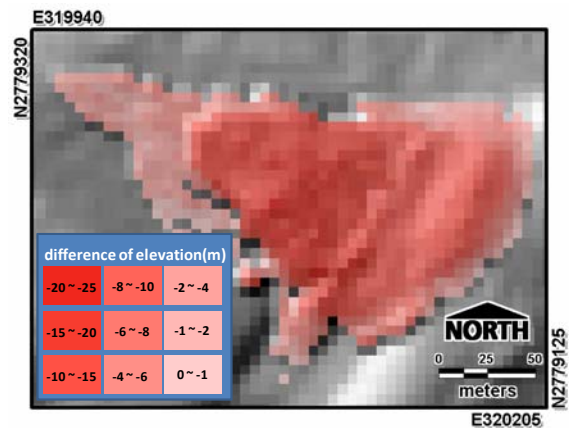


Figure 9 Distribution of Terrain Elevation Changes before and after the Removal

Conclusion and Recommendations

The unconventional photogrammetry described in this article uses self-calibration and does not require professional metric camera. Moreover, it is simple to operate, has few limitations, and can be applied to historical photos or photos taken by anyone after the disaster, drastically increasing its flexibility. Case studies suggest the measurement error was sufficient to assess the collapsed earth volume in this event, which was similar to the result of the final removal. Its effectiveness was thus confirmed. In addition to ground photography, we recommend combining UAV to overcome the limitation of photographing angles from the ground. Although self-calibration isn't yet stable, sometimes has lower accuracy, and has a high error rate which often results in failed 3-dimensional recreation, these can be compensated by collecting/taking more of target's photos to increase the 3-dimensional recreation success rate. If calibration before photographing is possible and the environment isn't excessively complex, we recommend using high-precision camera calibration (ie. Tsai's Two-step Calibration (Tsai, 1986), Weng's Calibration (Weng et al., 1992), Zhang's Calibration Square (Zhang, 1999, 2000), Bouguet's Calibration (1999) which is based on the Duality Principle, Heikkilä (2000) Calibration that uses circular symbol as the control point, and Ahn's (2001) Calibration, etc.) to replace the self-calibration raised by this article to reduce camera's calibration error rate.

Future Application

Unconventional photogrammetry can effectively, economically, and expediently perform terrain measurement. We recommend future application in the following areas:

1. Identifying the Disaster's Extent on the Surface and Scale: It can be used to establish quantified data for preliminary assessment of the disaster (ie. failure, deposit, etc.) to effectively and timely reflect terrain changes as a reference for future policy making.
2. Geological Survey: For inaccessible locations (ie. the other side of a canyon), it can be used to study the direction and angle of the formation.
3. Soil Erosion Investigation: Data obtained by erosion pins are merely points, but combining this method, sweeping data across the entire area can be acquired.
4. Quantifying Debris Flow and Failure Evolution: Long-term monitoring of the same debris-flow or failure region can establish its history.
5. Verifying 3-dimensional Digital Slope Simulation: Currently, 3-dimensional digital slope simulation is a hot topic. The development of rock slope's weak planes and expedient terrain measurement before/after the disaster are critical to proposing failure mechanism, setting model's boundaries, and correcting simulation parameters. The 3-dimensional digital rock slope

simulations in Taiwan are mostly rockfall landslides (Ku C-Y, et al., 1996; 2006; Ke Te-Chih and H.K. Chen, 2006; Lo Chia-Ming, 2010), and the parameters often lack complete development of rock slope's weak planes and the digital elevation models before/after the disaster. This study provides a quick method to acquire relevant digital simulation data (including weak plane distribution such as tension fissures, joints, cleavages, schistosity). The accuracy of model's boundaries and the parameters entered are drastically improved, providing an important basis for an expedient determination of landslide's mechanism in the future.

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