Assessing Volume Earthwork by Using Unconventional Photogrammetry

Cheng-Yang Hsiao, Pao-Shan Hsieh, and Shu-Yeong Chi

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 m^3; and this is close to the result published by Ministry of Transportation and Communications R.O.C. (2010a). 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

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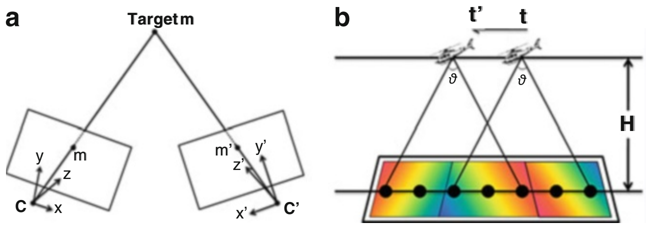

Fig. 1 Convergent and parallel photography: (**a**) convergent photography, (**b**) parallel photography

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 and Ke Tao 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 and Hu 2003; Zhao Xiao et al. 2004; Habed and Boufama 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; Zhang and Ou 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 25, 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.

The Process of Unconventional Photogrammetry

Massive slope failure struck the right side of southbound Freeway No. 3 between Keelung and Hsichih on April 25, 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 six 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 25, 2010 to June 1, 2010, with only conditional opening. Two-way traffic was then completely restored for all six lines, and the restrictions were lifted.

Because the collapsed earth volume cannot 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 (i.e. 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 two 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 7 × 7 pixels.
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

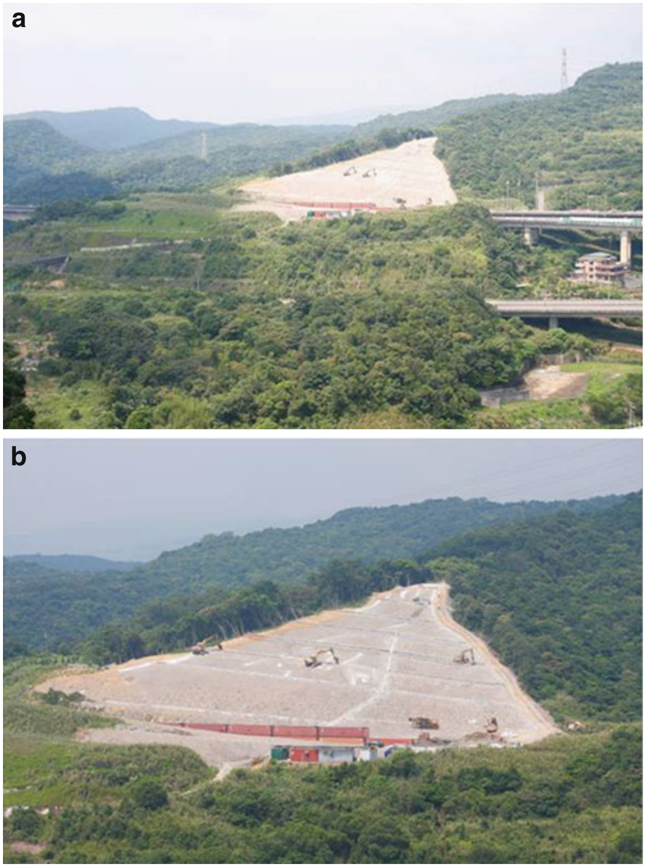

Fig. 2 Photos with different focal lengths at the same shooting place (Shorter focal length allows greater field of vision but has lower resolution): (**a**) short focal length (36 mm), (**b**) long focal length (70 mm)

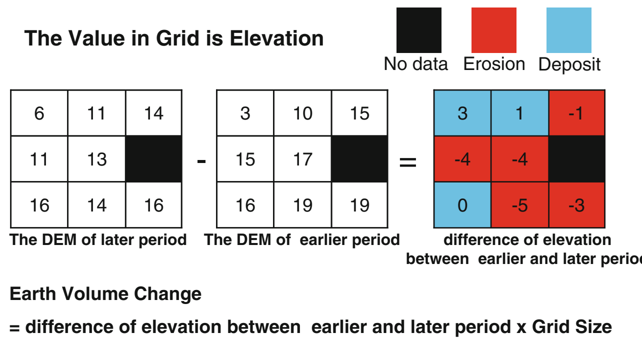

Fig. 3 Calculation of terrain change (Modified from Chen-Yang Hsiao 2009)

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 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. Six or more reference control points are recommended for coordinate conversion (Wang Lei 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 20 cm wide object in a 300,000 pixel (640 × 480) photo in most current 3-dimensional recreation algorithms can reach 0.1 cm. Recently, the accuracy of many photogrammetry by non-metric camera already can satisfy the requirement in creating topographic maps with scale between 1:100 and 1:200 (Wang Lei 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 et al. (2009) used airborne LiDAR with accuracy of 50 cm as an example. If the terrain elevation difference between two periods is less than 50 cm, 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 (i.e. bulldozer or poles, etc.). Therefore, manual editing such as cloud point removal or elevation reduction should be conducted.

Fig. 4 Photographed location (From Ministry of Transportation and Communications 2010b)

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. Figure 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.

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 3.1 km 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 25, 2010 (9 photos taken) and at 1:00 p.m. on September 16, 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, seven reference points measured by high-precision GPS coordinates were used for conversion to the real world and as reference control points (see Table 1). Figure 6 is the result of 3-dimensional recreation of the cloud point data

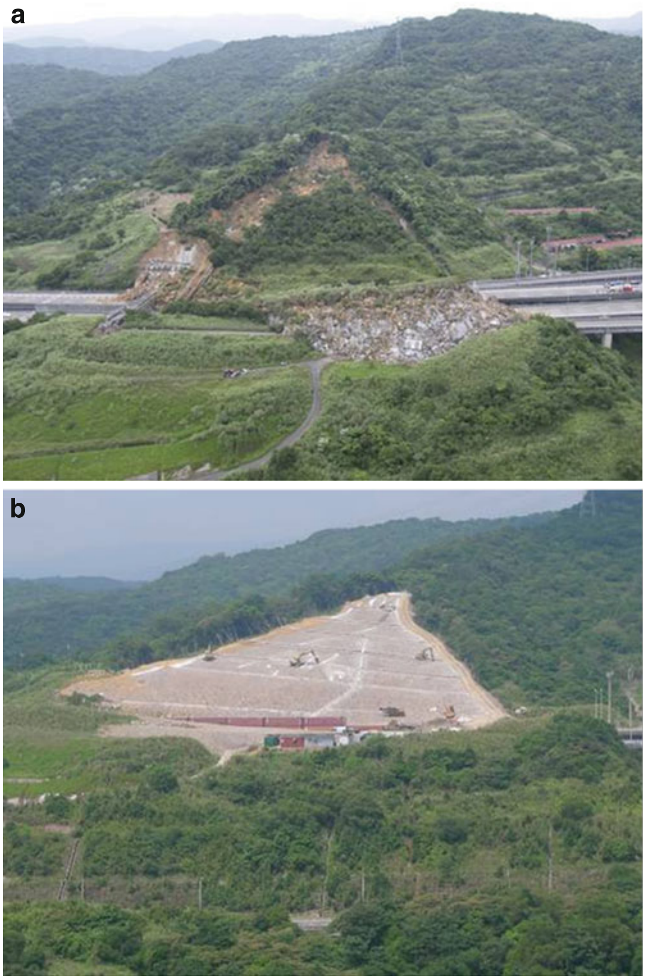

Fig. 5 Before and after the removal (**a**) April 25, 2010, (**b**) September 16, 2010

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	

(a) and (b) are cloud point data that contain 3-dimensional coordinates and RGB color codes (i.e. vegetations, poles, and bulldozers, etc.).

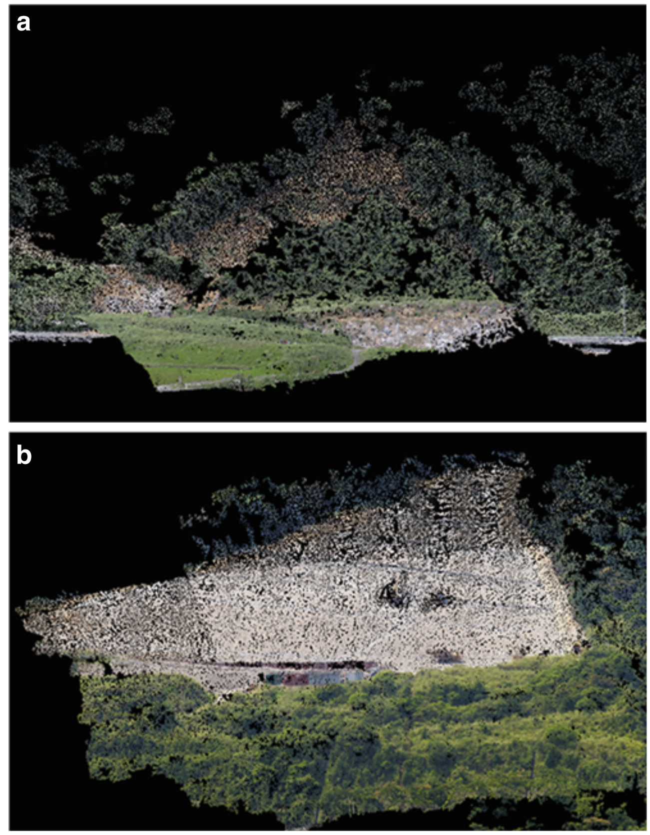

Fig. 6 3-dimensional cloud point recreation (**a**) April 25, 2010. (**b**) September 16, 2010

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 11 and 16 cm (see Table 2) and meets the terrain measurement acceptance criteria by the Urban and Rural Development Branch of the Construction and Planning Agency (Wu 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.

Assessment of the Collapsed Earth Volume

After completing manually editing the cloud point data, Surfer was used to establish 5 × 5 m 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). Figure 9 is illustrates the elevation changes before and after the earth removal.

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
	Elevation (m)	114.62	114.89	125.31	125.47
3-D recreation	TWD97_X	320,064.26	320,063.80	320,026.35	320,026.19
	TWD97_Y	2,779,250.99	2,779,250.83	2,77,9267.72	2,779,267.73
	Elevation (m)	114.78	114.76	125.42	125.31
Absolute elevation difference (m)[a]		0.16	0.13	0.11	0.16

[a]Absolute elevation difference = |GPS measured ellipsoid height – 3-D recreation measured ellipsoid height|

Fig. 7 Topographic shading map before removal

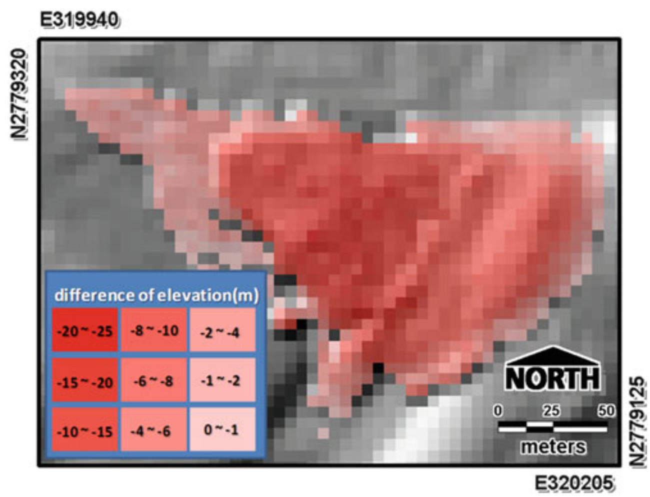

Fig. 9 Distribution of terrain elevation changes before and after the removal

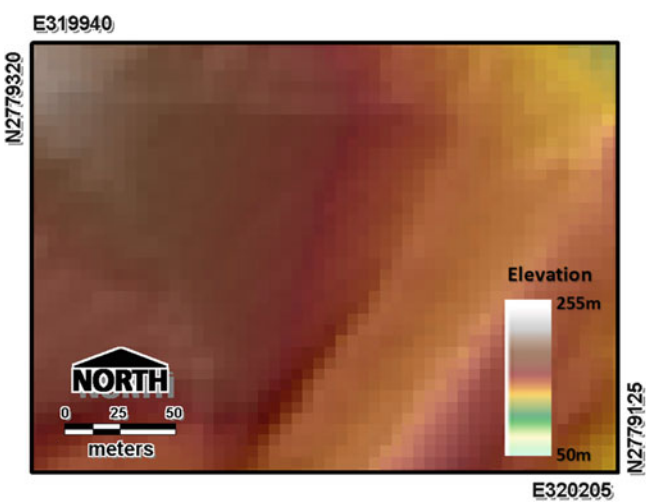

Fig. 8 Topographic shading map after removal

The estimated earth removed was approximately 225,078.5 m^3. Compared against the data posted by the Ministry of Transportation and Communications (2010a) of 219,527 m^3 removed, they were close with only 2.5 % of difference.

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 (i.e. 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 et al. (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 (i.e. failure, deposit, etc.) to effectively and timely reflect terrain changes as a reference for future policy making.
2. Geological Survey: For inaccessible locations (i.e. 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 et al. 1996, 2006; Ke Te-Chih and Chen 2006; Lo 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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