

# CHANGE DETECTION OF LANDSLIDE TERRAINS USING GROUND-BASED LIDAR DATA

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### ABSTRACT

The topographic change has been estimated on basis of 3D laser data and aerial photogrammetric survey. The newly-developed, time-saving approach is by using airborne and ground-based lidar. A points-cloud of high precision and density distribution can be obtained in a few minutes for the sensitive latent landslide area. With a limited control survey of precise targets using GPS and total stations, multiple scans of ground-based laser scans can be registered together to form one cohesive 3D model. And, thus, overlaid the different period topographic data for estimating the changes of the target areas. Two cases are practiced in this study. For the first case, a river-bank landslide in Hsin-chu Hsien was scanned with 6 stations. Subsequently, they were registered and joined and re-sampled to a 2m grid for a comparison with information obtained by digitization of a 1/5000 topographic map. The second case is conducted to observe the deformation of a large-scaled dip-slope landslide of Jiu-fen-er mountain, which was triggered by the big shock of the Chi-Chi earthquake at Nantou County of central Taiwan on 1999/09/21. Control points are systematically distributed on the 1000m by 2000m landslide surface. Surveys are made by transits of total stations, GPS, and airborne lidar as well as ground-based lidar data. The terrain changes on ground surface have been detected in thus a scheme. It is found the largest change of height between the earthquake event is about 60m. The effectiveness of applying 3D laser scan is proved in this study.

### 1. INTRODUCTION

The geophysical settings of Taiwan are characterized by highly fractured steep slopes, vulnerable to landslides. It is further enhanced by the big shock of the Chi-Chi earthquake of central Taiwan on 1999/09/21. This has been proved by the hazards taken places in the event of Typhoon TORAJI a small-scaled one on 2000/July/30, causing a damage of more than 100 deaths and a loose of more than US\$300 millions. Topographic changes can be expected subsequently after events of earthquakes and heavy rainfalls.

Traditionally, to obtain the information of topographic changes after a landslide event, ground surveying or aerial photogrammetric surveys are conducted. The new technology of terrain laser scanning can be a way to improve the efficiency of obtaining the information of topographic changes. A ground-based 3D laser scanner can take very dense point clouds with high accuracy in the occasion of a landslide. The aligned and merged 3D models can be used to derive detailed topographic information for taking mitigating measures or for making further study on topographic evolution by comparing to historical topographic datasets.

In this study, ground-based 3D laser scanning is applied to two cases. One is a river-side landslide with an area of circa 100 m \* 200 m, a typical and common one in Taiwan. The other is the toe area of the large-scaled dip-slope landslide with an area of circa 1000 m \* 2000 m of Jiu-fen-er mountain, which was triggered by the big shock of the Chi-Chi earthquake at Nantou County of central Taiwan on 1999/09/21.

### 2. 3D LASER SCANNING

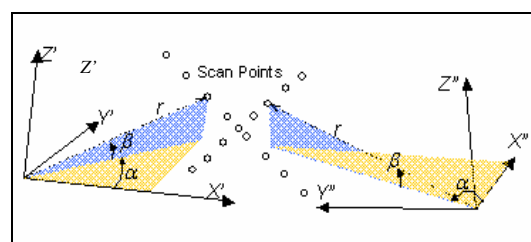
Five datasets are employed in this study, e.g. DTM with a grid of 40m, digitized topographic contours, photogrammetric heights, airborne and ground-based laser scanning datasets. All the spatial data are transformed into a common TWD97 coordinate system. The procedures of ground-based laser scanning adopted in this study are to be discussed as follows.

#### 2.1 Acquisition of 3D Laser Scanning Data

Due to the extent of a hazardous landslide, a range of more than 500 m is generally required to deal with the accessibility and arrangements of the location for taking the multiple scans. Airborne laser systems are able to take multiple returns of ground echoes, thus to facilitate the differentiation of vegetations and other artificial features. The first returns depict a digital surface model (DSM) and the last returns depict digital ground model (DGM). In the building-up areas, the signals may depict a digital building model (DBM). Topographic study usually applies the DGM or last returns to get rid of disturbance of vegetations and other artificial features above ground surface.

#### 2.2 Joining Point Clouds

Laser scanner takes point clouds in sight. The ground surfaces blocked by trees or the likewise features would not be detected. Multiple scans are usually required to obtain a complete dataset for an object. And, thus, an observation network of multiple observing stations is required. In other words, to joint point clouds of various stations is to transform local coordinate systems of each stations into a common coordinate system (Figure 2.1). A hyper-surface matching algorithm is applied for joining the point clouds in this study. In this algorithm, the overlap portions of two adjacent scans are used for matching. Before the exact-matching process, a manual adjustment to make the adjacent scans approaches a pseudo-match status is required.



**Figure 2.1.** A sketch showing coordinate systems for joining multi-scanning point clouds

### 2.3 Modeling of Points Clouds

An explicit useful spatial dataset is achieved by joining all point clouds of multiple scans of a targeting object. The vectors can be projected onto a plan surface or transformed into a map, or even to make a 3D perspective views.

### 2.4 Coordinate Transformation of Points Clouds

After joining all datasets into a single point cloud model with a common coordinate system, a further step is to transform the local coordinate systems into a geodetic system by using ground control points measured by ground surveying, in this study using GPS and Total Stations.

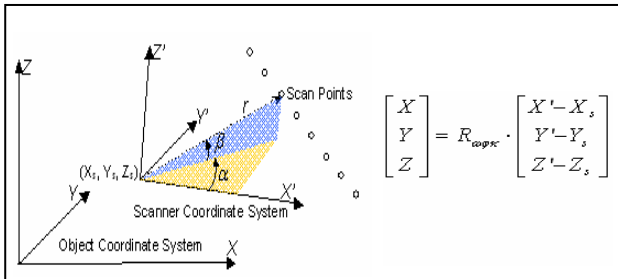


Figure 2.2. A sketch showing the coordinate transformations of multi-scanning point clouds

## 3. RESULTS OF THE CHANGE DETECTION

In this study, ground-based 3D laser scanning is applied to two cases. One is a river-side landslide in Chudong of Hsin-chu County which is a typical and common one in Taiwan (Hsiao et al., 2003a & 2003b). The other is the toe area of the large-scaled dip-slope landslide of Jiu-fen-er mountain in central Taiwan.

### 3.1 The River-side Landslide Case

The Chudong landslide is located in a small valley with a very limited open space for taking a good view of the whole area (Figure 3.1). Six scanning stations with scanner-to-target distances less than 100 m were applied.



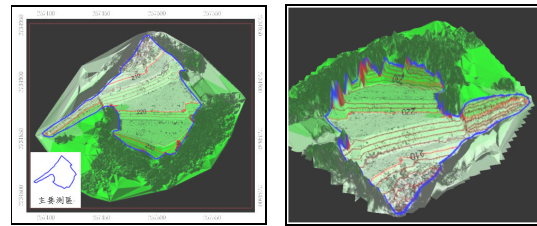
Figure 3.1. The area covered by ground-based lidar with 6 stations.

The extent of a scanning station and the point spacing as well as the duration required for a scan are displayed on the PDA controlled panel of the scanner ILRIS-3D. Six datasets generated by six scanning stations are subsequently merged into one single dataset. And, then, a coordinate transformation was conducted by using six control points distributed in the area and measured by GPS (Figure 3.1). Thus, a useful topographic model is established. Figure 3.2 shows the application of a 2D plane map and a 3D perspective map.

For understanding the topographic change of the landslide area, an existing topographic map in a scale of 1:5000 was digitized to obtain the topography before the sliding event. Though no other more detailed topographic information could be accessed for the study area, the most common topographic information of the 5K photomaps are useful for a quick understanding of the

landform evolution of the study area. As shown in Figure 3.3, the topographic information from 5K topographic maps and that from laser scan are compared to obtain the altitude variation. A volume change with obvious spatial variations indicates a significant result can be achieved by this approach. The estimated change of earth volume is 11,691 m<sup>3</sup> with a landfill of 4,899 m<sup>3</sup> and a cut of 6,792 m<sup>3</sup>.

Additional information, a merit in contrast to the traditional topographic survey, is the portrait of detailed profiles of the landslide using the densely distributed data points, as shown in Figure 3.4.



(a) 2D plane map (b) 3D perspective map

Figure 3.2. 2D plane and 3D perspective maps after modeling of points cloud data

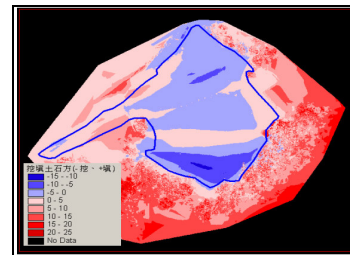


Figure 3.3. The altitude variation map of landslide area

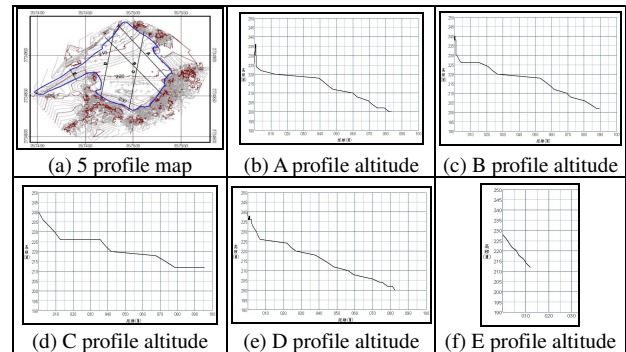


Figure 3.4. Profiles of the Chudong landslide

### 3.2 The Jiu-fen-er Slide Area

The most common digital terrain information in Taiwan is the DTM with a 40 m grid. Another most common topographic information is the 5K photomaps. Another datasets for this area is the point clouds taken by airborne lidar (Shih et al, 2002). Stereo-pairs of aerial photographs of the area are used to generate 1 m contour interval topography. Figures 3.5 and 3.6 are the study area and its DEM modeling. Figure 3.7 is a 3D perspective view generated by from SPOT image and 40m DTM. Figure 3.8 shows the topography before and after the Ji-Ji Earthquake. A dramatic change of topography can be perceived.

Airborne lidars of Optech ALTM 2030 and LH ALS40 were introduced to Taiwan by Agriculture Council for taking test

datasets. Figure 3.9 shows a result of the study (Shih et al., 2002). Furthermore, two times ground-based lidar scanning were performed. Figure 3.10 shows the images of ground-based lidar scanning of Jiu-fen-er mountain area.

In summary, though accuracies of various datasets have not yet been estimated, a preliminary result shows a significant change of the topography of the area for different times. Figure 3.11 shows the change of DTMs before and after the earthquake. The post-earthquake DTM was generated by aerial photographs taken on February of 2003. Similar results can be drawn from Figure 3.12 of which the posterior DTM is generated by airborne lidar.

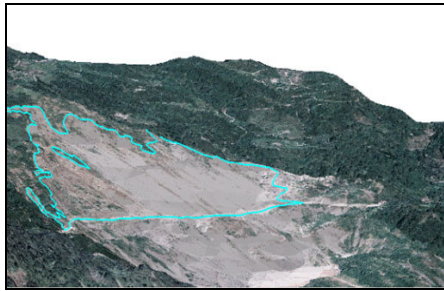


Figure 3.5. Study area of Jiu-fen-er mountain

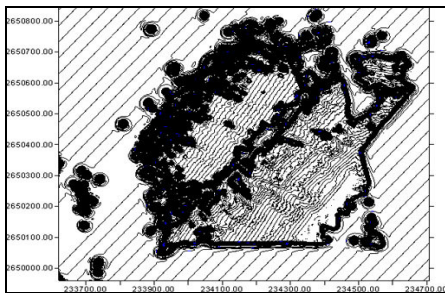


Figure 3.6. Modeling DEM of Jiu-fen-er mountain area

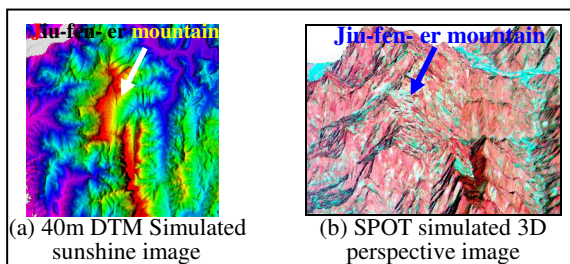


Figure 3.7. Jiu-fen-er mountain before earthquake

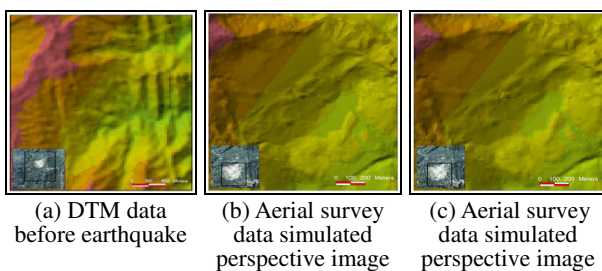


Figure 3.8. Simulated 3D perspective images of two periods of aerial survey of Jiu-fen-er mountain.

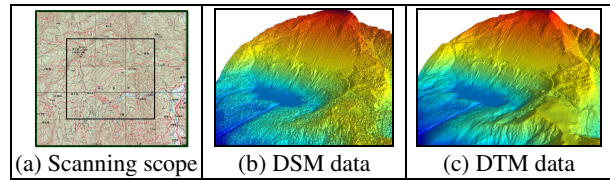


Figure 3.9. The airborne lidar data simulated Jiu-fen-er mountain 3D perspective image (Shih et al., 2002)

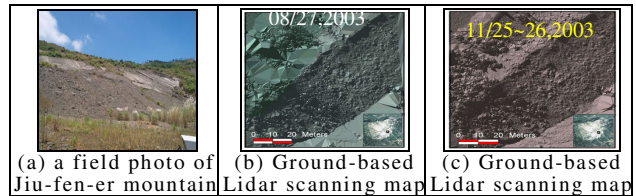


Figure 3.10. The images of ground-based lidar scanning of Jiu-fen-er mountain area

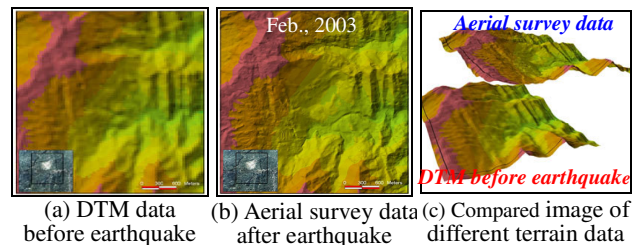


Figure 3.11. A comparison of DTM and aerial survey terrain data of Jiu-fen-er mountain area

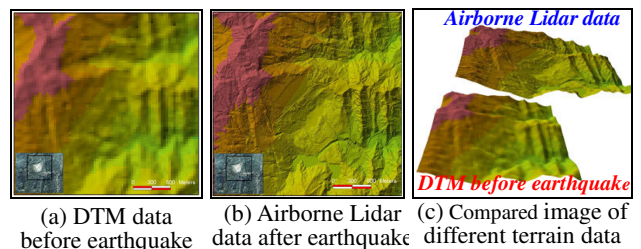


Figure 3.12. A comparison of DTM and airborne lidar data of Jiu-fen-er mountain area

To monitor the change of micro topography of a landslide area, ground observation stations are usually employed for taking leveling and horizontal measurements by tradition means such as EDM or even GPS. However, the disadvantages of limited density of observations are obvious. The accuracy of 3D laser scanners is mostly in the range of a few centimeters for a ground-based system and in the range of sub-meters for an airborne system. This feature makes it meaningful to apply for landslide monitoring.

Figure 3.13 shows the results of 5 profiles of a traverse survey by Total Stations of a monitoring network on the landslide surface. A sequence of 5 times of observations is taken to observe the changes of the coordinates of the stakes installed on the slide surface. With the analysis of the variation of the coordinates of each stakes, the deformation and micro topographic change can be observed (origin of the datasets: Bureau of Soil and Water Conservation, 2003). It is found the largest change of height between the earthquake event is about 60m. Another, the terrain change is not clear according to airborne and ground-based lidar data after earthquake (figure 3.14).



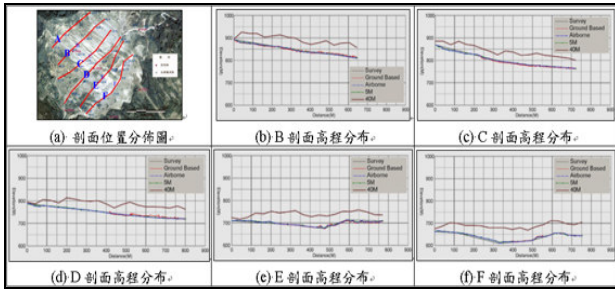


Figure 3.13. Five profiles of Jiu-fen-er landslide area

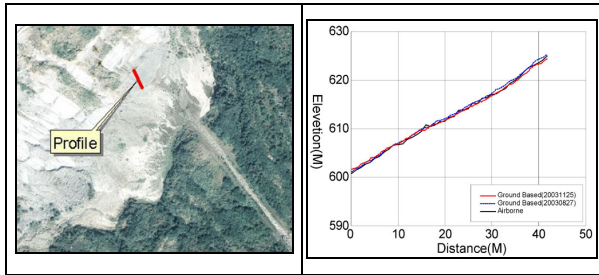


Figure 3.14. A profile of Jiu-fen-er landslide area according to airborne and ground-based lidar.

### 3.3 Accuracy Evaluation of 3D Laser Scanning

The range accuracy of laser scanner is in millimeters as shown by the manufacturers. In addition, the attitude of the scanners in field operations is also key factor to the final accuracy (Lichti *et al.*, 2000; RIEGL *LMS GmbH*, 2002). Besides, the natural conditions and personnel capability are contributing to the overall accuracy.

The accuracy of the test datasets obtained by airborne lidar in Jiu-fen-er slide area is shown in Table 3.1 (Shih *et al.*, 2002). On basis of the 137 check points observed by RTK, RMS accuracy of Opetch ALTM 2030 dataset is 10 cm, that of LH ALS 40 is 12 cm. This result shows that accuracies varies with terrain and landcover types.

Table 3.1. Terrain conditions for evaluation of the accuracy of airborne lidar data of Jiu-fen-er area.

Area	# of points	Area Description	Validation Category
A	137	Average slope less than 10 degree, Road width 7 meters, open to the sky	Flat road surface
B	81	Road width 5 meters, 5 to 30 meter height difference between road and road-side, sky visibility generally poor	Covered road surface
C	349	Slope ranges from 15 to 35 degrees, open to the sky, bare rock	Cover-less, uniform slope, nature bare rock
D	169	Open to the sky, soft soil	Cover-less, nature bare soil
E	125	Slope about 10 degree, Orchid and Tea field	Vegetated with uniform height
F	46	Slope about 30 degree, Tea field	Tea Field
G	82	Slope about 15 degree, Tea field	Tea Field
H	70	Slope about 10 degree, bare soil	Flat bare soil

As to the accuracy of ground-based laser scanner, Lichti (2002) made observations by using I-SITE TLS (Terrestrial Laser Scanner) in a flat beige wall surface and setting for coarse, medium, fine, ultra resolution and receiving multiple returns. The range accuracy of the manufacturing specifications is  $\pm$

25mm for high accuracy mode and  $\pm 50$ mm for standard accuracy mode. With 16 scans of each of 3 sets of 999 observation points, the bias was less than 0.05m. Thus, the technique was used to observe a stringer bridge for observing deformation after heavy overburdens.

The accuracy of applying ground-based laser scanner such as ILRIS-3D has not been reported in an natural conditions of the mountainous terrain in Taiwan. It is known that overall accuracy is affected by the distance to the targets (RIEGL *LMS GmbH*, 2002). Preliminarily, the results revealed by geodetic control points on the slide surface observed both by EDM and scanner is roughly around 1 cm (Figure 3.15)(Bureau of Soil and Water Conservation, 2003).

For observing the topographic change in a time span, a pre-requisite is to obtain datasets in accuracy better than the variation of the topography. For Jiu-fen-er slide area, the landslide is in very-large scale and the change is severe. Therefore, all available datasets in this study are significant for a preliminary evaluation despite the heterogeneous natures of all the datasets. However, a further observation of the deformation is in a micro topographic nature. The scale is in centimeters. Ground-based lidar or permanent GPS stations could be a suitable means for the deformation study.

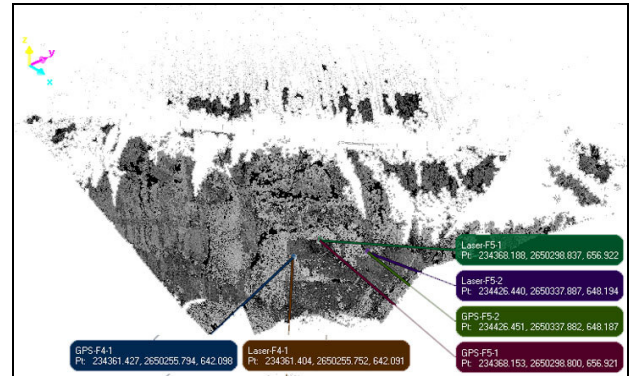


Figure 3.15. The coordinates of the control points by EDM and Ground-based lidar of Jiu-fen-er slide area.

## 4. CONCLUSION

A geodetic transformed 3d model generated by merging multiple laser scans on basis of properly distributed ground control points is proved to be an important efficient source for observing the topographic change of landslides in Taiwan. Supplementary information can be resorted to existing 40m DTM and the 5k photomaps. The earth quantities of fill-and-cut of a landslide can be estimated by the DEM generated by various approaches. Better accuracy can be achieved by applying ground-based laser scanner.

Both ground-based or airborne laser scanner are not suitable for evaluating erosion for that erosion processes are in a millimeter scale. However, the change of the topography of landslides is in a centimeter-to-meter scale. As proved in this study, significant changes of landslide topography can be depicted in the results by comparing the laser scanning datasets with those of other sources.

The advantages of laser scanner are the efficiency of obtaining a dataset with high density and high accuracy of 3D coordinates. It is worthwhile to conduct further study on examining exact accuracy for application in the landslides in high mountain terrains and in the deformation of large-scaled landslips.

## ACKNOWLEDGES

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