Terrain Change Detection Using Ground-based LiDAR Data

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ABSTRACT: The estimation of riverbed topographic change has been exercised on basis of 3D laser data. A point-cloud of high precision and high density can be obtained in a few minutes for the sensitive riverbed areas. With a limited control survey of precise targets using GPS and total stations, multiple scans of ground-based LiDAR can be registered together to form one cohesive 3D model. And, thus, different periods of topographic data are overlaid for estimating the changes of the target areas. Two cases are practiced in this study. In the first case, the scoured riverbed on Zui-Zi-Jiao-Keng stream, a branch of Cho-Shui river in Nan-Tou County was scanned before and after typhoon MINDULLE on 2 June 2004, with a total of 15 scans in 5 stations by using ILRIS-3D laser scanner. Subsequently, they were registered and joined and re-sampled to a 20 cm grid. The second case is located in San-Boo-Keng upstream. It is found that in the first case that max erosion height of riverbed changes was between 5~10 m. In the second case, the average height of silted-up is about 1~3 m. The effectiveness of applying 3D laser scanning is proved in this study.

KEY WORDS: Landslides, Digital Terrain Model (DTM), LiDAR, Change Detection

1. Introduction

After 921 Ji-Ji Earthquake, top soils of middle Taiwan are shaken and fragmented. Consequently, slopes become unstable and vulnerable to torrential rainfalls. After torrential rainfalls, debris flows are induced and the topography of riverbed are changed severely.

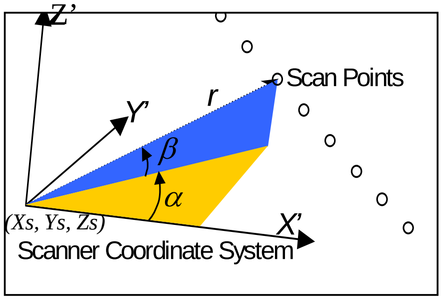
Usually after the hazards of landslides or debris flows, conventional survey or aerial surveys are adopted to generate height information for the evaluation of landform change. As a comparison, new approach with portable ground-based 3D laser scanner can take three-dimensional measurements of the hazards in a very short time (Hsiao et al., 2003a, 2003b). For converting the coordinate of point clouds to local geodetic system, targets of ground-control points are installed and measured. Thus, DEM grids can be deduced and overlaid with existing landform information under a common coordinate system.

The most commonly-used photo maps of Taiwan is in a scale of 1/5000, of which the accuracy is claimed to be half the contour intervals, i.e. 2.5m to 5.0m. Further, the DEM published by Council of Agriculture is in 40m grid. Obviously, they are too coarse to fit the requirements for landslide hazards in the mountainous terrain of Taiwan. In contrast, ground-based LiDAR can achieve centimeter accuracy and give very high point density for the study area. Thus, the feasibility for application in landslide terrain is obvious. An ILRIS-3D laser scanner is thus employed after typhoon Min-Du-Lle on 2 June 2004 to take measurements for 2 study areas of Zui-Zi-Jiao-Keng stream and San-Boo-Keng upstream, respectively. After merging, coordinate conversion, and griding, the resulted DEMs are used to evaluate the erosion and sedimentation of the said streams.

2. 3D Laser Scanning

2.1 Principles of 3D laser scanner

A 3D laser scanner is by using a laser distance measuring with green or infrared laser, and receive the return echoes of the targets. And, with the slant ranges of the laser stations to the targets, the coordinates of the targets can be computed, as shown in Fig.1(Hsiao et. al., 2003a). At the same time, the receiver can record the intensity of the echoes, and thus a grey image can be generated.



$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} r\cdot\cos\beta\cdot\cos\alpha \\ r\cdot\cos\beta\cdot\sin\alpha \\ r\cdot\sin\beta \end{bmatrix}$$

X': latitude
Y': longtitude
Z': height

α:horizontal angle ; β:vertical angle ; γ:oblique distance

Fig. 1 Scanner coordinate system and scan points.

2.2 Targets measurements by 3D laser scanner

2.2.1 Data acquisition of 3D laser scanner

In the field, as shown in Fig. 2, obstacles between targets and the scanners such as effective distances and vegetations should be considered. Multiple stations are usually required for a real case (Fig. 3). And, like in airborne scanning, multiple return echoes are possible. As shown in Fig. 4, DSM (Digital Surface Model) are obtained by first returns, DTM (Digital Terrain Model) by last returns, and for building-up areas, DBM (Digital Building Model) can be obtained. Usually, for avoiding the disturbance of obstacles caused by vegetations, last returns are selected for computing DTM (Hsiao et. al., 2003b).

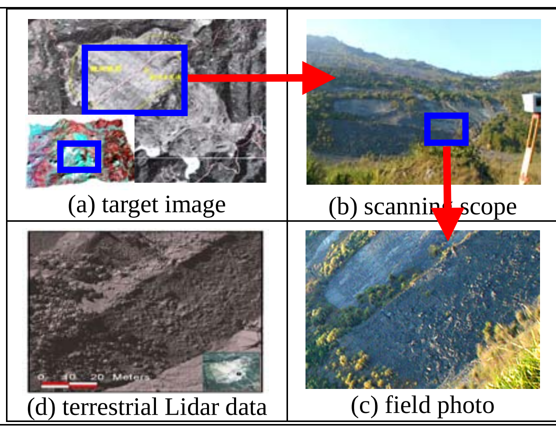


Fig.2 A scan station covers a small portion of the study area.

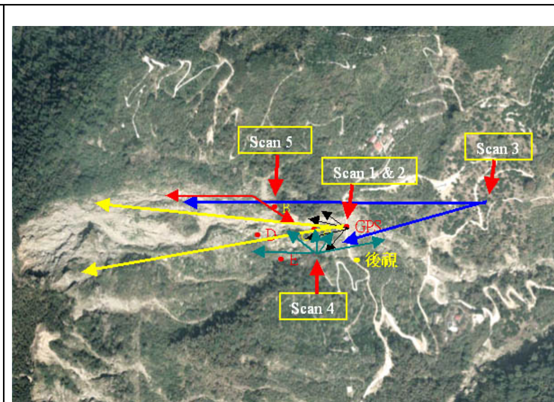


Fig.3 Multiple stations for a study area.

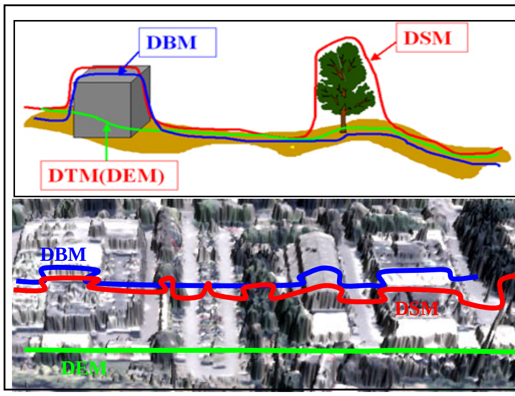
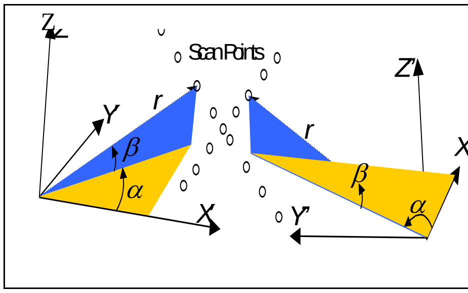


Fig.4 Various results of laser scanning.

2.2.2 Preprocessing of point clouds

Obstacles between an observing station and targets are common for a field study area. Multiple stations with multiple scanning directions are required to cater for this case. And, thus, merge of multiple data sets are required (Fig.5). Subsequently, coordinate transformation of the merged datasets to a geodetic coordinate system is needed for further applications, including converting to vector contours and grid DEM.

Control points as implemented in the field by setting targets in the field of view of each scan should be surveyed and well planned in proper locations for serving the purpose.



$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = R_{\omega\varphi\kappa} \cdot \begin{bmatrix} X' - X_s \\ Y' - Y_s \\ Z' - Z_s \end{bmatrix}$$

Common features are selected for solving the transformation parameters

Fig. 5 Merging data sets from multiple stations

3. Results of Detecting Landform Change

Two cases in Nan-Tou County are practiced in this study. Data are obtained before and after typhoon Min-Du-Lle on 2 June 2004. The landform change of the riverbed is evaluated for the event.

3.1The study area

The images of study area 1 -- Zui-Zi-Jiao-Keng stream and study area 2 -- San-Boo-Keng upstream are shown in Fig. 6 and Fig. 7, respectively. Both of them are in landslide vulnerable areas, artificial conservation works have been applied to mitigate hazards.

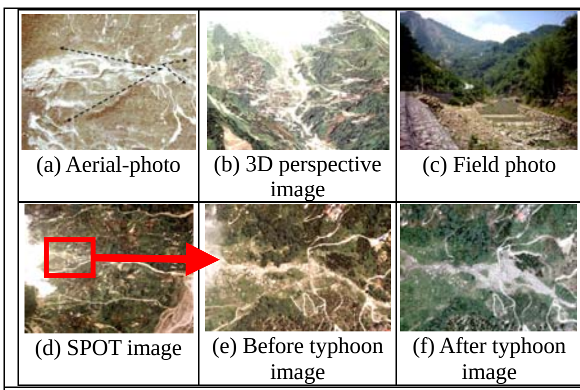


Fig. 6 Images of Zui-Zi-Jiao-Keng stream, showing the landform before and after typhoon event.

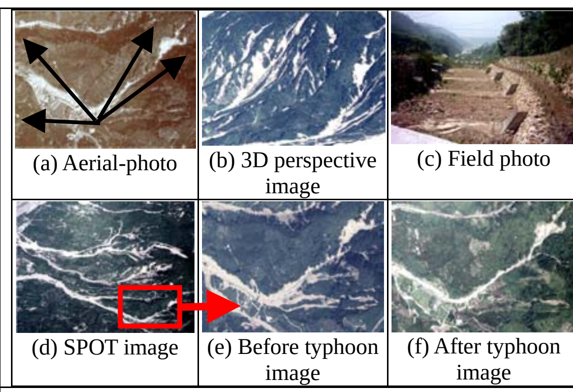


Fig. 7 Images of San-Boo-Keng upstream, showing the landform before and after typhoon event.

3.2 Data acquisition

Before field operation, control targets are deployed and surveyed with GPS and total stations, as shown in Fig. 8, for subsequent merge processing of point clouds of multiple looks and for converting to geodetic coordinate system. Typhoon Min-Du-Lle took place on 2 July 2004. Laser scanning was conducted on 2004/06/17~18 and on 2004/08/05~06 before and after the typhoon, as shown in Fig. 8 and Fig. 9. All the looks are also covered by images taken by digital camera (Fig.10) for subsequent comparison.

(a) Total station for control points

(b) Control targets with reflecting targets

Fig. 8 Geodetic coordinate measurements by total stations.

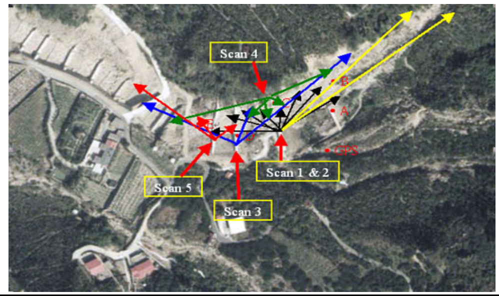


Fig. 9 Scanning Plan for study area in San-Boo -Keng upstream.

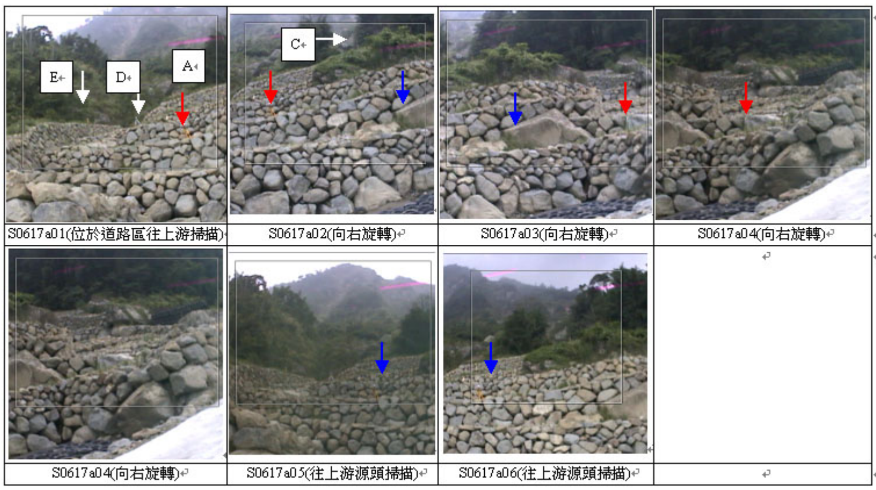
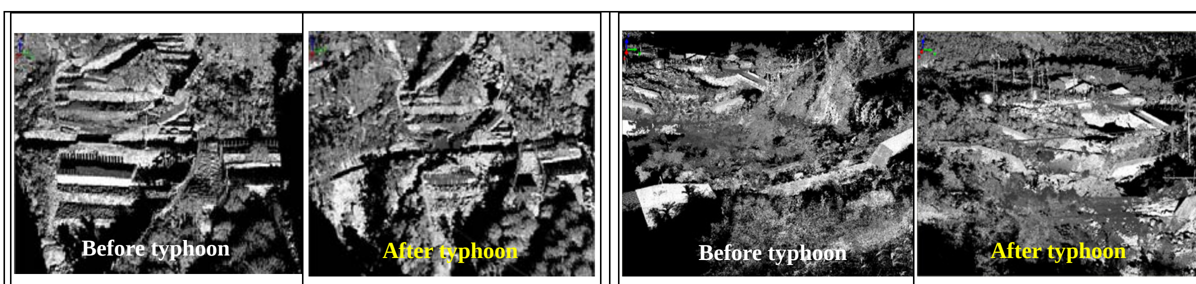


Fig. 10 Digital images taken at the time of scanning.

3.3 Merge of multiple scans and modeling

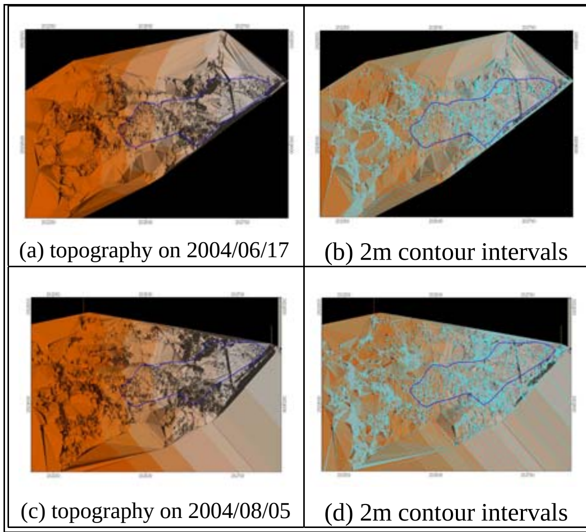
As shown in Fig.11, multiple scans of the study area are merged by surface-fitting, and converting all points to a common coordinate system. Subsequently, they are converted to geodetic coordinates, on basis of the measurements of control targets as shown in Fig. 8. These geodetic registered point clouds are used for interpolation for generating contour lines and DTM grid. Fig.12 and Fig.13 are the 20 cm grid and contours of 2m intervals for Zui-Zi-Jiao-Keng stream and San-Boo-Keng upstream, respectively.



(a) Point clouds of Zui-Zi-Jiao-Keng stream

(b) Point clouds of San-Boo-Keng upstream

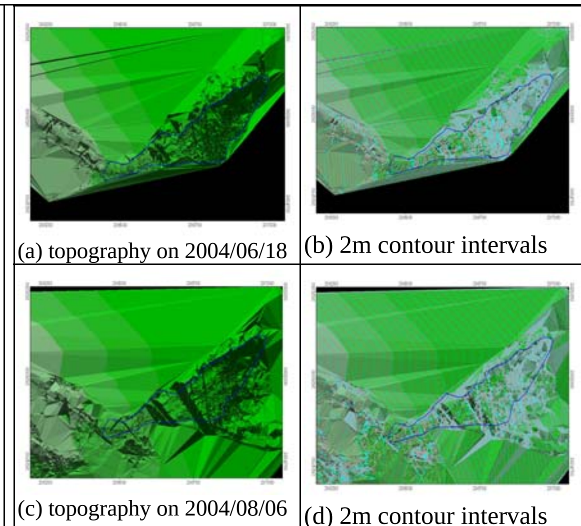
Fig.11 Point clouds before and after the typhoon event for the two study areas



(a) topography on 2004/06/17 (b) 2m contour intervals

(c) topography on 2004/08/05 (d) 2m contour intervals

Fig.12 The topography as depicted by 20 cm grid and 2m contour intervals for Zui-Zi-Jiao-Keng stream.



(a) topography on 2004/06/18 (b) 2m contour intervals

(c) topography on 2004/08/06 (d) 2m contour intervals

Fig.13 The topography as depicted by 20cm grid and 2m contour intervals for San-Boo-Keng upstream.

3.4 Landform change detection

3D laser scanning is a new approach to obtaining detailed landform information of a view in a very short time, e.g. in terms of minutes. Data sets taken in multiple dates of the same area can be used for the detection of landform change, and, thus, for the assessment of silt of a river channel. However, detailed physical properties of the materials of the bedding loads such as sorting and types of materials can't be deduced from LiDAR data.

A shortcoming when the scanner is employed for the study of the landform of river channels is the limitation of field of view. In practical, the view in a scan is very limited in field site due to obstacles in the view and the terrestrial-based nature, which is not a bird-eye view (SWC, 2004). Nevertheless, this is an efficient means for observing the landform change posed by landslides, erosion and sedimentation of a local area, as shown in Fig.14 and Fig.15 for the 2 study areas. An overall assessment of the landform change of a watershed is feasible only by using airborne LiDAR. Landslide hazards are usually very severe in Taiwan and this can cause significant landform change in watersheds. Airborne LiDAR can achieve an accuracy of 15 cm. Though this is relatively larger than ground-based LiDAR, in an extent of watersheds airborne LiDAR would be more suitable and feasible.

A premise for applying LiDAR technology is that the amount of landform change should be roughly comparable to the accuracy of the LiDAR system. In other words, it is required that the height change is 2 times more than the limitation of the LiDAR accuracy. If proper control targets are installed and properly surveyed, ground-based LiDAR can achieve an accuracy of 2~5 cm. If no suitable control targets, an accuracy of 5~10 cm can be achieved as shown in Fig.15. For a long term monitoring of the landform change of landslide prone areas for hydrological simulation and prediction, LiDAR measurements can be a proper means to adapt.

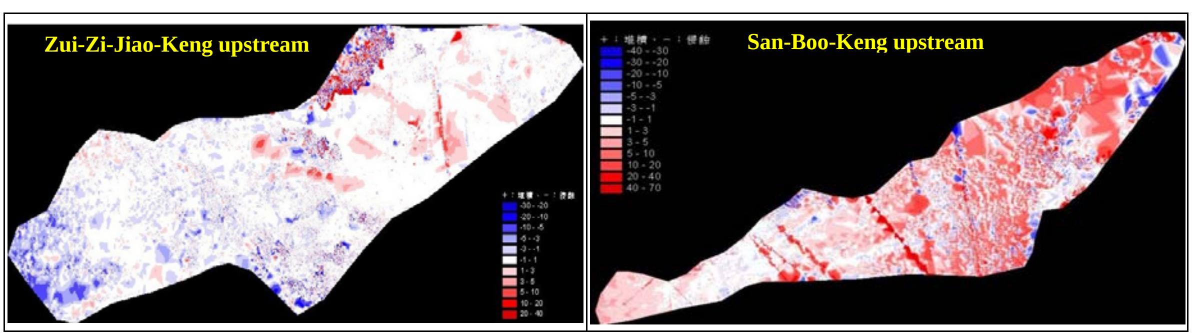
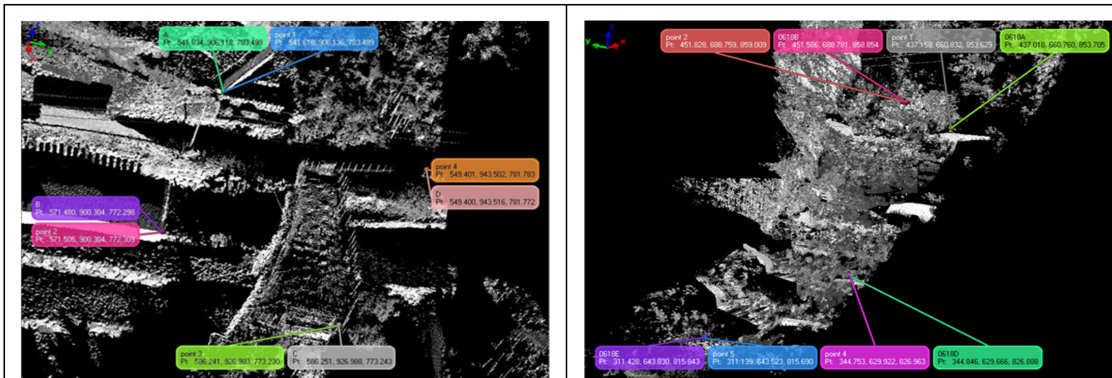


Fig.14 Landform changes before and after typhoon



(a) in Zui-Zi-Jiao-Keng stream | (b) in San-Boo-Keng upstream

Fig.15 Control targets used in this study.

4. Concluding Remarks and Suggestions

With a few control targets, multiple scans can be merged and converted to a geodetic coordinate. And, subsequently, the results can be compared with existing landform information for assessing the landform change. In this study, laser scans were taken before and after typhoon events and the change of landform is derived. The accuracy achieved in this study is around 5~10cm, which is a lot smaller than the landform change of the typhoon event. Locally, the change of the landform of the 2 study areas before and after typhoon Min-Du-Lle was as large as 5~10 m.

Laser scan would not be suitable for the study of natural degradation of landforms such as natural weathering, as the process is slow. However, landslides, debris flows, and quarry are in a fast process of changing the landforms. And, usually, the order of change is in meters for these fast processes. Obviously, laser scans are applicable.

Ground-based LiDAR is especially suitable for detecting small change in centimeters in a very small extent. For a large extent such as a watershed, airborne LiDAR would be more suitable. For the study of a whole channel or river system, local change requires high accuracy and global change require complete coverage. Thus, the combinations of ground-based and air-borne LiDAR approaches are recommended.

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