THE TERRITORY-WIDE AIRBORNE LIGHT DETECTION AND RANGING SURVEY FOR THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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ABSTRACT: The Civil Engineering and Development Department (CEDD) of the Government of the Hong Kong Special Administrative Region (HKSAR) has recently completed its first territory-wide airborne Light Detection and Ranging (LiDAR) survey. The survey is primarily intended to obtain detailed topographical information to support natural terrain hazard assessment. The technology employed is capable of recording reflected signals from the natural hillside below vegetation cover, which can be used for deriving high-resolution ground profiles and digital terrain models for mapping landslides and other landform features. The LiDAR data are also being used for other applications such as urban planning, flood analysis and aviation controls in Hong Kong.

Over 6,000 million data were collected over Hong Kong with over 6,000 field test points confirming a vertical data accuracy of about 3cm root mean square (rms) on clear flat ground. Apart from describing the administrative and technical issues of the survey, especially those for the densely populated urban environment of Hong Kong, this paper also outlines a number of the geotechnical applications being used by the CEDD, including identification of relict landslides, change detection of topography after landslides and delineation of anthropogenic features.

INTRODUCTION

Over 60% of the land in Hong Kong comprise hilly natural terrain. The risk from natural terrain hazards (e.g. landslides, debris flows, and rock and boulder falls) continues to increase with urban development of buildings and infrastructure projects closer to the natural hillsides. The Geotechnical Engineering Office (GEO) of the CEDD has been employing remote sensing techniques to acquire high resolution geospatial data to facilitate natural terrain hazard assessment.

In 2006, the GEO conducted a pilot study to evaluate the usefulness of the LiDAR technology in geotechnical studies for the Hong Kong environment. The study demonstrated that the airborne LiDAR has the capability to survey a large area at high accuracy within a short period of time, and to effectively obtain the 'bare-earth' ground profile by virtual deforestation in Hong Kong conditions (AAM, 2006). It also has the potential for identifying ground features, e.g. relict landslides and subtle terrain morphology that are disguised under a thick vegetation cover (Ng and Chiu, 2008). Following the encouraging results of the pilot study, the GEO commissioned AAM Pty Ltd. to carry out a territory-wide airborne LiDAR survey in Hong Kong in 2010. This paper summarizes the LiDAR survey and discusses some possible applications of LiDAR technology in natural terrain hazard assessment and non-geotechnical disciplines.

THE AIRBORNE LIGHT DETECTION AND RANGING (LiDAR) SURVEY

The territory-wide airborne LiDAR data acquisition was completed in 44 hours of flying time between December 2010 and January 2011, covering the land area of the whole territory of the HKSAR of about 1,100 km^2. During the survey, the aircraft flew across the HKSAR with a 50% overlap between swathes of adjacent flight lines. Flight lines over Hong Kong are given in Figure 1, with red lines showing the low altitude flight at about 1,000 m and green lines about 1,200 m for staying clear of the mountains. Flight lines were generally flown in an east-west direction, with a series of perpendicular runs flown to add additional strength to the survey data. Ground Global Positioning System (GPS) data at 1Hz obtained from the Lands Department's Continuous Operating Reference Stations (CORS) were used for computing the aircraft trajectory and orientation.

The returned LiDAR signals data were collected at maximum point spacing of 0.5m, with horizontal and vertical accuracies of 0.3m and 0.1m respectively, which are more stringent than those specified in the 2006 pilot study. The laser sensors had the capability to capture up to 4 range measurements (first, second, third and last return) for each pulse with intensity measurement for each range measurement, and field of view (FOV) of +/-25°. Some of the essential information of the sensor setting finally adopted in this survey is shown in Table 1 (AAM, 2012).

Table 1: The LiDAR sensor setting adopted for the data capturing

Average point spacing:	0.47m
Scan Frequency:	47 Hz
Half Scan Angle:	20 deg
Laser Class:	IV
System Pulse Rate Frequency:	100 Hz

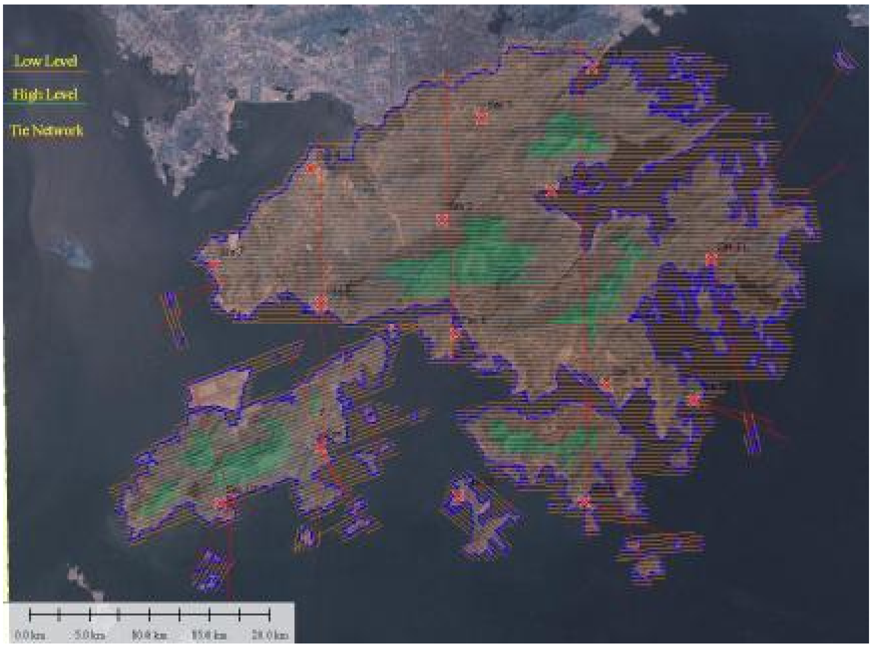

Figure 1: Flight lines over the Territory-wide LiDAR Survey

To ensure the accuracy of the LiDAR data, an independent ground verification process was carried out. A total of 6000 field test points were collected at fifteen locations across the HKSAR and the results confirmed that the LIDAR data met the contract requirements.

Project Planning

Whilst the prime purpose of the LiDAR survey was intended to provide topographical information for natural terrain hazard assessment, it was considered that LIDAR data could also be useful in other disciplines. Therefore, at the project planning stage, a working group with representatives from various government departments was formed to collect user requirements for preparation of the contract specification. Soon after awarding the contract, a pre-survey workshop was conducted providing a platform to both working group members and AMM to understand more about the project, including the contract requirements and constraints, user requirements and expectation as well as the potential applications. Such arrangement provided an effective communication channel to the parties concerned to ensure that the project could be implemented smoothly and effectively. A post-survey workshop was subsequently held to brief the working group members about the survey and the results. Whilst the wider applications of the LiDAR data were discussed, the limitations of the LiDAR data were also pointed out to the members in this workshop.

Hong Kong is one of the busiest places in air traffic and obtaining sufficient flying time for the LiDAR survey was one of the most critical project issues. In order to ensure that data capturing could be done smoothly, careful planning and frequent and clear communications with the Air Traffic Controllers (ATC) of the Civil Aviation Department were required. With the assistance of the ATC, the survey was successfully carried out without incidents or interruption to Hong Kong's very busy airspace. And more importantly, this clear line of communication had allowed data capturing to be carried out at the desired flying height and had avoided the data being captured in discontinuous sub-blocks, as this would have jeopardized the overall project homogeneity.

Terrain Consideration

Hong Kong exhibits extreme terrain variation where the terrain can rise from sea level to 700m in just a few kilometres. These significant variations in terrain elevations must be taken into consideration when deciding each flight line's altitude because the aircraft must stay close enough to the ground to maintain data accuracy, but yet not so close as to affect the aircraft safety or data coverage.

The dense urban canyons offer challenges when designing the flight lines to minimise the effect of data shadowing. As the laser will not penetrate buildings, the flight lines were designed so that they offered maximum visibility to the ground in-between tall urban buildings.

Due to the complex landforms in Hong Kong, the classification of LiDAR data into 'ground' and 'non-ground' is no easy task, even with the help of automatic software algorithms. For example, a building located close to a steep cliff, where the building is at ground level on one side, but many stories high on the other side of the building, can cause problems in data classification. Based on the experiences gained in the 2006 pilot study, the data processing technique had been enhanced to take account of the complicated nature of Hong Kong's landform.

Survey Results

Over 6,000 million LiDAR data points were collected, processed and were geo-referenced in Hong Kong 1980 Grid System and Hong Kong Principal Datum height, and were then classified into ground and non-ground points. The non-ground points were divided into vegetation and building. For those non-ground and non-building data points, they were sub-divided into three vegetation categories. Raster models of 0.5m grid digital terrain model (DTM), digital surface model (DSM), intensity images and vegetation classes were also generated from the LiDAR data points. Additionally, electronic terrain obstacle data (ETOD) was developed using the LiDAR data points. 1.2 Tb file size datasets were supplied and delivered in the following format:

(a) Post-processed LiDAR survey data (All data points, first, second, third and last return, and classified ground points) in LAS Version 1.1 format.

(b) Classified ground points and non-ground points in ASCII format and dBaseIV format containing the co-ordinates, DTM, intensity values and flight line numbers (Figure 2);

(c) DTM, DSM, intensity images and vegetation classes in 0.5m grid raster models in GeoTiff, PCI Geomtica and ER Mapper formats (Figure 3).

Figure 2: Classified ground points

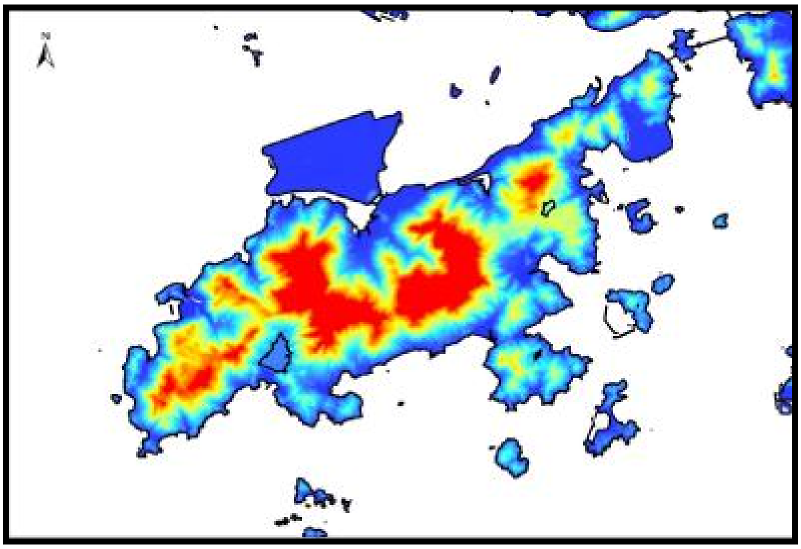

Figure 3: Map of Lantau Island generated from 0.5m grid DTM

APPLICATIONS OF LIDAR TECHNOLOGY IN NATURAL TERRAIN HAZARD ASSESSMENT

Parry & Jonas (2007) had demonstrated the potential applications of LiDAR technology in natural terrain hazard assessment. Efforts have been spent on exploring the applications of this technology in geotechnical studies under the unique Hong Kong setting. Some useful applications are outlined in the following sections.

Visualization

In natural terrain hazard assessment, aerial photographs are used to identify geomorphological features such as landslide scars or debris trails. However, these features are sometimes obscured by dense vegetation and cannot readily be seen in aerial photographs. The LiDAR-derived bare earth surface model provides additional information to overcome the limitations of the conventional approach and help identify geomorphological features in vegetated areas (Figure 4). Additionally, ortho-photos can be superimposed onto a DTM to create a 3-D image or video to enhance visualization (Figure 5).

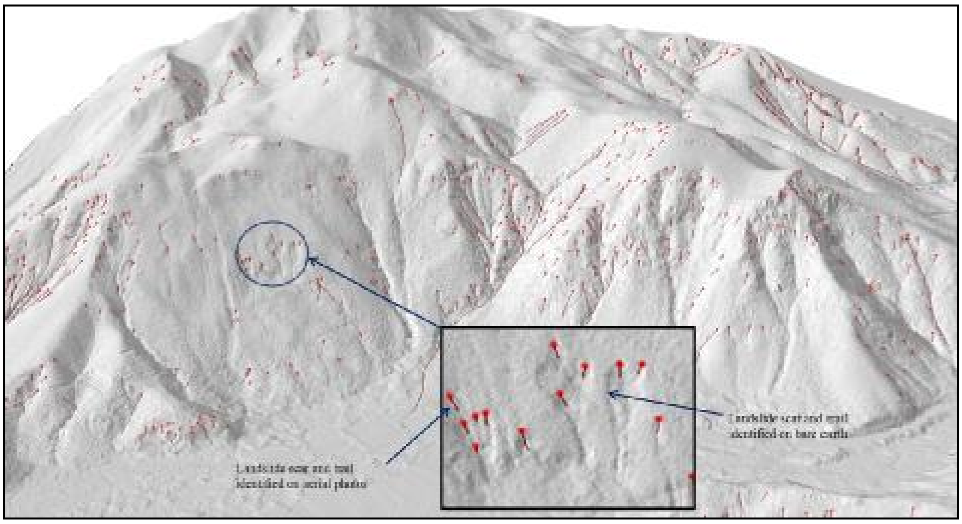

Figure 4: Landslide scars and trails clearly seen on bare earth surface model

Figure 5: Ortho-photos aerial photos draping over DTM to create a 3-D image

Unlike the terrain estimation approach commonly adopted in producing survey maps, the DTM values of the terrain are obtained directly from LiDAR survey. The LiDAR-derived contours in densely vegetated areas are therefore considered more accurate than those produced from conventional mapping method using photogrammetric technique (Figure 6).

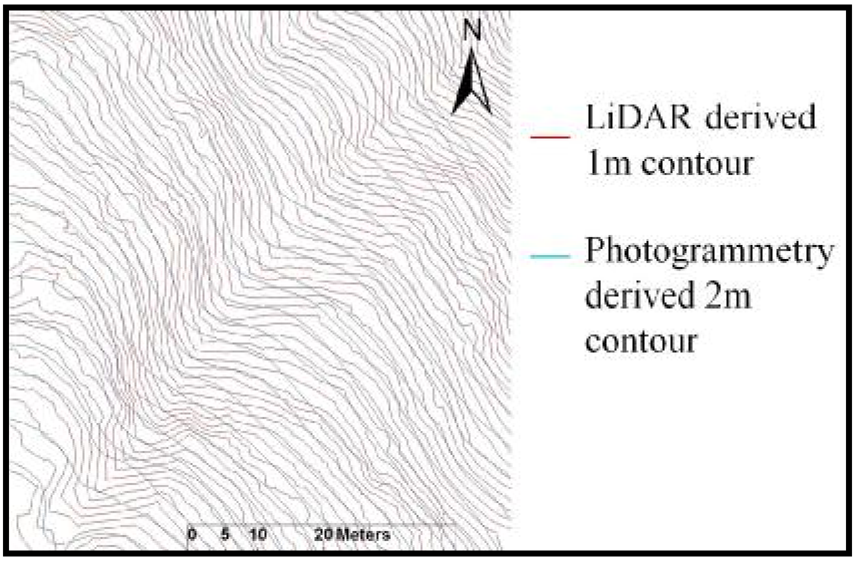

Figure 6: LiDAR-derived contours show more details than contours derived from photogrammetry

Detection of Landform Change

LiDAR technology can also be used to detect changes in landform if the surveys of the same area are done in successive time periods. It is particularly useful for studying changes in topography after landsliding. A landslide that occurred on the hillside behind Hong Kong University in 2008 was studied using the LiDAR data obtained in the 2006 and 2010 surveys. The LiDAR-derived contour maps of 2006 and 2010 were compared to assess the change of ground profile before and after the landslide (Figure 7).

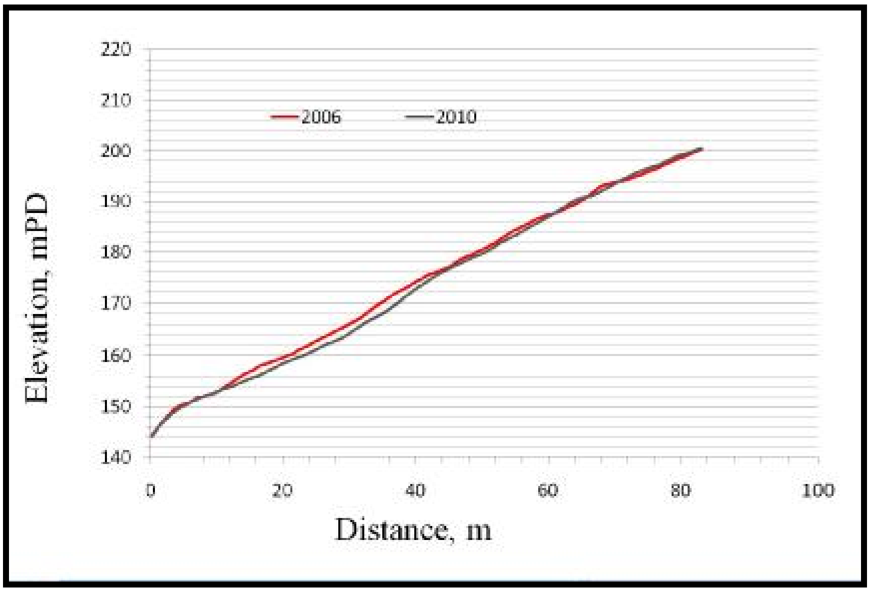

Figure 7: Terrain profile before and after the 2008 landslide in Hong Kong University

The high resolution topographical information derived from LiDAR data is valuable for a variety of analyses pertaining to natural terrain hazard assessment. These include debris mobility analysis, extraction of basic terrain parameters (e.g. slope, angle and aspect) and drainage network analysis (Figure 8).

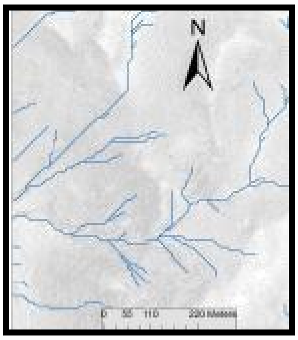

Figure 8: Drainage networks generated in GIS using LiDAR-derived DTM

Interpretation of Landform Features

Apart from generating digital terrain models, multi-return signals and intensity data recorded from the LiDAR survey can be used directly for producing images to identify different geomorphological and geotechnical features, for example, detection of tension cracks (Figure 9) and identification of large boulders (Figure 10).

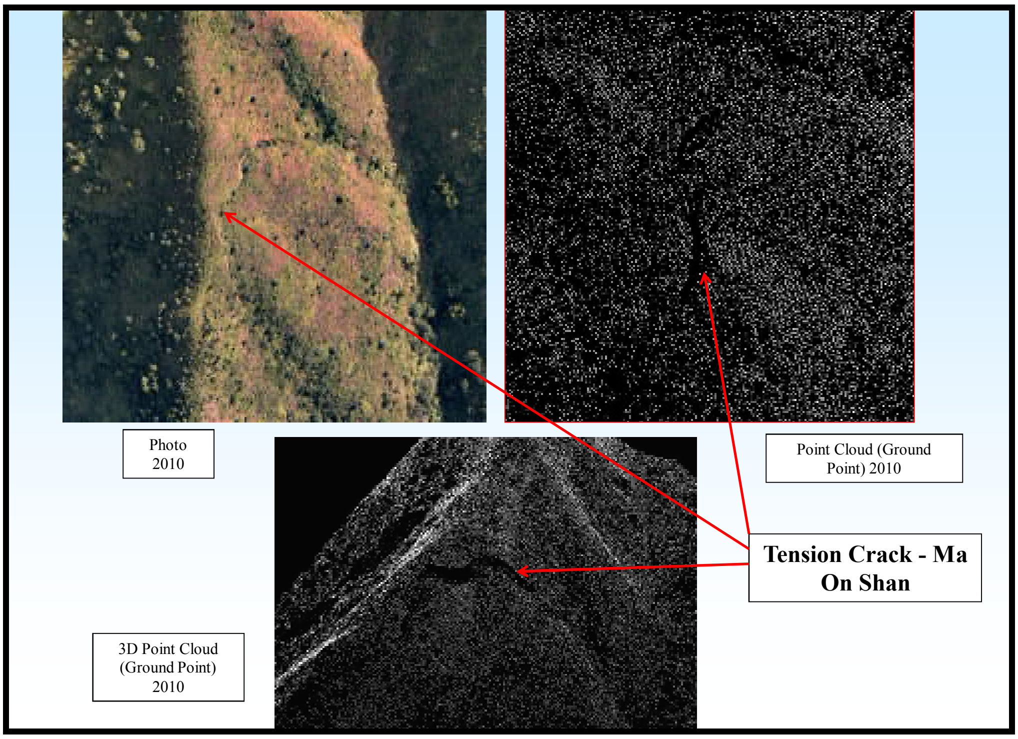

Figure 9: Tension crack in Ma On Shan

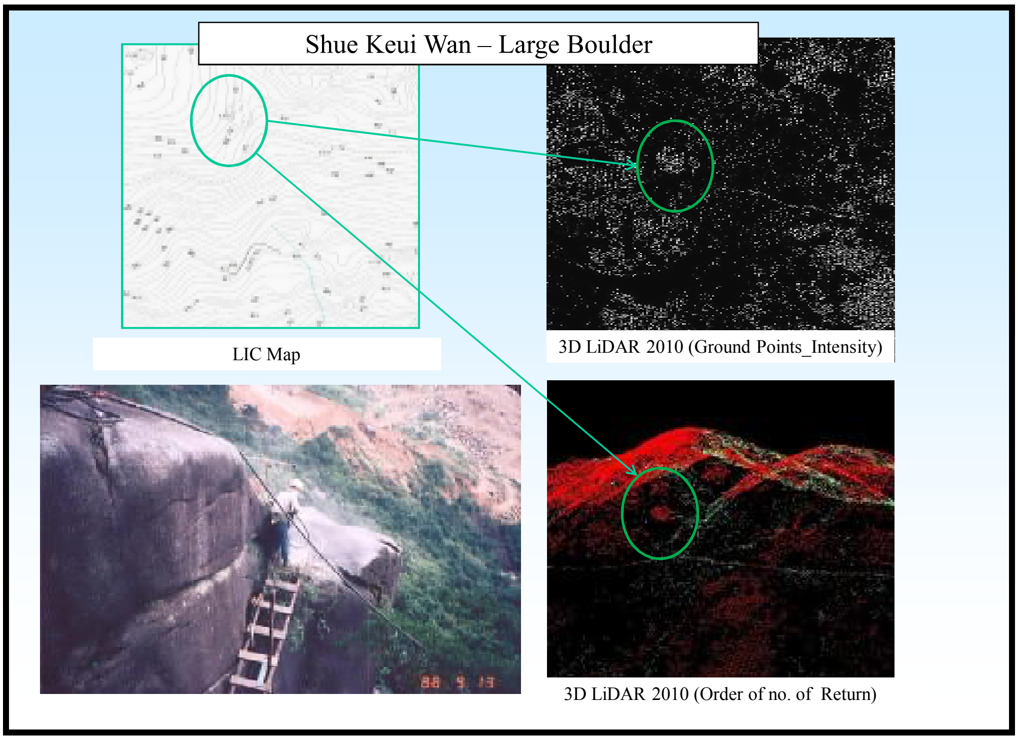

Figure 10: Boulders in Shau Kei Wan

In addition, LiDAR data also provide useful information for identification of old cut and fill terraces, which were formed in the 1950s to 1970s for squatter dwelling and cultivation. These small terraces are now concealed by dense vegetation. The outlines of these terraces, however, are visible in the LiDAR image produced by classified ground points (Figure 11). These old cut and fill terraces tend to form a series of continuous discernable lines of similar elevations.

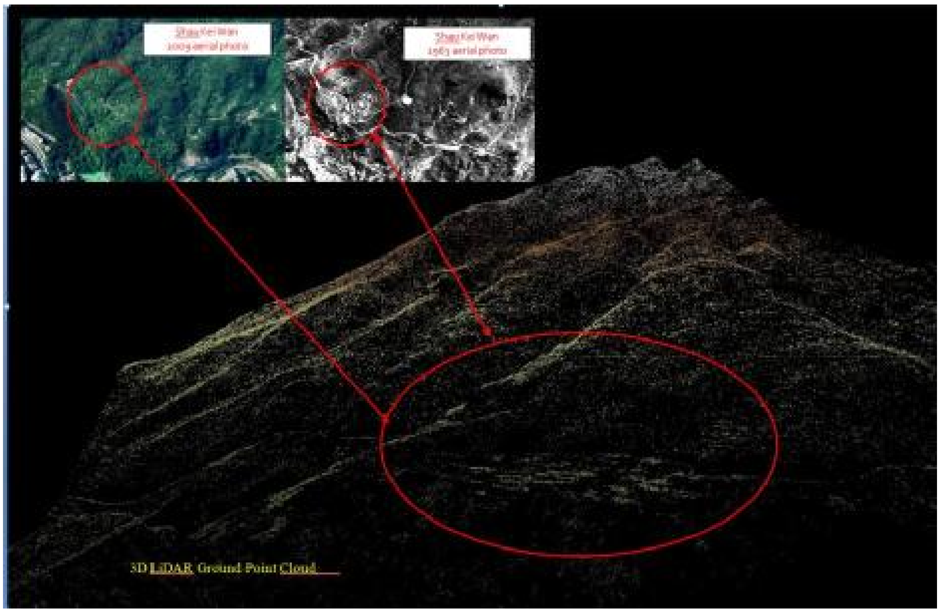

Figure 11: Old cut and fill terraces can be seen on LiDAR image generated from classified ground points

NON-GEOTECHNICAL APPLICATIONS OF LiDAR DATA

Besides the potential applications in geotechnical studies, the LiDAR data are also being used by other government departments for urban planning, flood analysis and aviation controls.

The Civil Aviation Department had used the LiDAR data to develop ETOD for air navigation applications such as aircraft operating limitations analysis, flight simulator and synthetic vision systems, etc. The LiDAR technology offers a valuable tool for compiling the ETOD as it automatically measures the terrain plus every tower, powerline, building, tree and other obstacle relevant to aviation safety.

The territory-wide LiDAR data are also useful for generating DTM in the River Flood Risk study initiated by Drainage Services Department. The Planning Department has made use of the non-ground points of the LiDAR data and the building imageries to create a realistic 3-D city model of the Hong Kong Harbour Front for planning purposes and visual assessment.

One of the potential applications of the LiDAR data is to identify historical structures, in particular those being covered by vegetation. A study of an abandoned staff quarters in the Mount Parker area was carried out. Although the building had been demolished and the platform is now completely covered by vegetation, the platform supporting this building can still be observed in the LiDAR images generated from the return signals (Figure 12). This example illustrates the potential of wider application of the LiDAR data in Hong Kong.

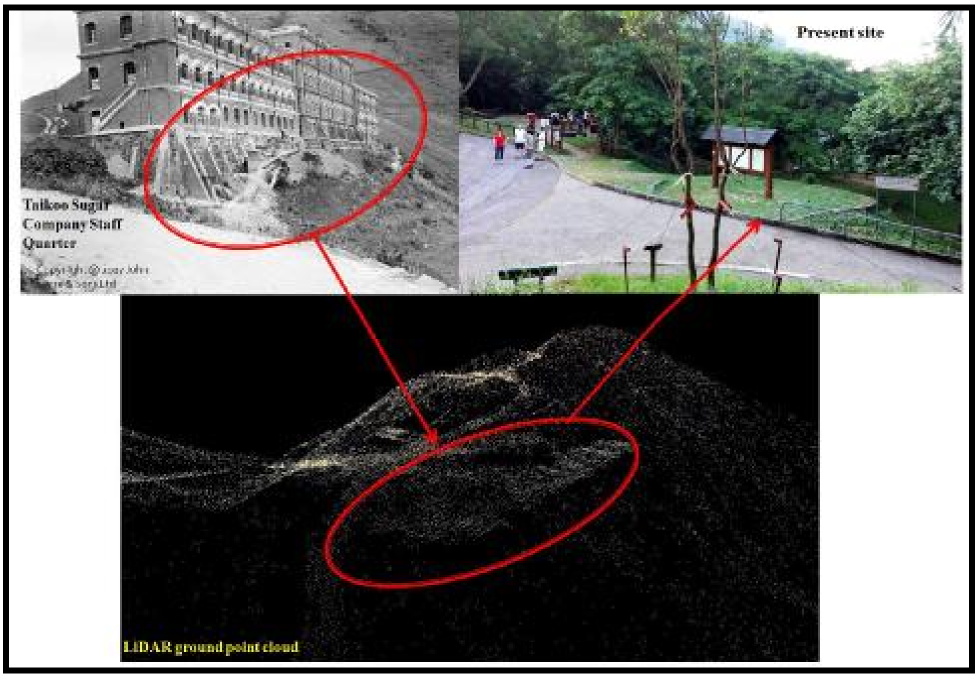

Figure 12: LiDAR technology can faciliate the identification of buried structures of historical interest

CONCLUSIONS

The evaluation made in the pilot survey in 2006 concluded that LiDAR technology has great potential to facilitate geotechnical studies. Despite the stringent technical requirements, the complexity of the landform and the crowded airspace, the 2010 LiDAR survey was successfully completed. The success of this challenging project demonstrates the importance of clear user requirements, careful planning, good communications and effective controls in project management.

With the availability of the good quality and high resolution LiDAR data, different applications of the LiDAR technology in geotechnical studies have been explored including visualization of landslides, detection of changes in landform, delineation of geomorphological and geotechnical features, as well as identification of anthropogenic features. The LiDAR data are also being used for a wide range of applications such as urban planning, flood analysis and aviation controls.

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