

# AIRBORNE LIDAR SURVEY FOR NATIONAL GEOHAZARD MAPPING OF TAIWAN

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## ABSTRACT:

Typhoon Morakot hit Southern Taiwan on 8-9 August 2009. The tropical cyclone unleashed record rains of 2110 mm in 24 hours with highest record of accumulated rainfalls of more than 3000 mm in southern Taiwan, causing the worst flooding in a century. The area hit by the typhoon is around 10 thousand square kilometres. Landslides are one of the most important primary disasters. A national geohazard mapping program employing state-of-the-art technology of integrated airborne LiDAR and digital photography is thus initiated by Central Geological Survey Taiwan. The results include very detailed DEM and DSM of 1m grid and digital aerial photograph of 50 cm grid, as well as an inventory of the geological disastrous features with the acquired LiDAR data and images. The major issues encountered include heavy cloud covers, extremely high terrain relief, dense vegetation cover, as well as the wide coverage of the study area. In average, time suitable for aerial survey is around 30 hours in one month. With the requirements of high resolution data and short period of project time, the challenge is to implement a scheme to obtain a complete coverage of data free of voids and artifacts. The project was authorized in June, 2010 and will be ended in May, 2012. These key issues, the strategies, and the implementation scheme for deploying such a program are presented and discussed in this paper.

## 1. INTRODUCTION

To confer and grant under conditions laid down in the “Special Statute For Reconstruction For Post-Typhoon Morakot Disaster”, a dedicated project was initiated by Central Geological Survey Taiwan to cope with National Land Conservation of Geologically Sensitive Zones (official title of the project) and, thus, to employ airborne LiDAR survey to establish a new nationwide 1 m grid of elevation models for hazard analysis and assessment. The period of this Special Statute is from September 1, 2009 to September 31, 2012.

Typhoon Morakot hit Southern Taiwan on 8-9 August 2009. The tropical cyclone unleashed record rains of 2110 mm in 24 hours with highest record of accumulated rainfalls of more than 3000 mm in southern Taiwan, causing the worst flooding in a century. The area hit by the typhoon is around 10 thousand square kilometres. Landslides are one of the most important primary disasters. In total, new landslides triggered by this event is more than 34,878 hectares as interpreted from Formost-2 images. As an example, Siaolin landslide is the most catastrophic landslide buried an entire village of Siaolin, located underneath the slope foot very near to the riverbed. During the torrential rainfall, huge amount of materials moved quickly downward and became a debris flow, topped over the highland, spread on the hillslope, and finally reached and destroyed the Siaolin Village, and blocked the main Chisan Stream forming an endangering barrier lake (Lee et al., 2009; Lee & Towhata, 2010). About 1 hour after the lake was formed, the barrier dam broke and the flood flushed out the buried village. The unfavourable geomorphological and geological conditions become critical issues for people to understand and to further explore. The national LiDAR project is in nature a national geohazard mapping program employing state-of-the-art technology of integrated airborne LiDAR and digital

photography and aiming to obtain both morphological and geological features.

The national geohazard mapping program includes 3 parts of major tasks: (1) LiDAR survey, (2) Third party quality assurance of LiDAR results, and (3) Mapping of geologically sensitive zones. And, it is further divided into five individual projects/tenders. The LiDAR survey which will be described in this paper in more details was conducted by three LiDAR survey teams. The quality assurance was assigned to a team organized by a survey professor. The project for geohazard mapping was dealt with by a team consisting of six professors, taking care of each geographical region where each of them is familiar with. By the interpretation of LiDAR images and other ancillary information, results of geohazard mapping should include (a) geological structures, (b) landform change of river beds, river terraces, and river channels, (c) landslide features, (d) high landslide vulnerable zones, and (e) Detailed mapping and assessment for selected areas near mountain settlements.

In this paper, focus will be on the LiDAR survey itself. The survey plan and specifications, the major challenges, key for success, and present status including type of editing errors of LiDAR data will be presented in this paper.

## 2. THE SURVEY PLAN & SPECIFICATIONS

### 2.1 The Survey Plan

Map tiles of survey plan are on basis of the frames of a large-scaled national map of scale 1:5000 series. As shown in Figure 1, the small rectangles on the map are the tiles of a 1:5000 map-sheet with an area of around 7 square kilometres. In total, 3177 tiles with 22491 square kilometres are to be completed in less than three years. The whole disaster area is sub-divided

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into 9 survey blocks. Three survey teams are awarded. Each year a team has to complete around 2500 square kilometres. The first survey team deals with survey block 1-1, the second survey team block 1-2, and the third survey team block 1-3 in the first year. Similarly, they will deal with blocks 2-1, 2-2, and 2-3 for the second year, and blocks 3-1, 3-2, and 3-3 for the third year, respectively.

For controlling the quality of LiDAR results, a dedicated team is awarded by Central Geological Survey to monitor the whole process and check the results of each survey team.

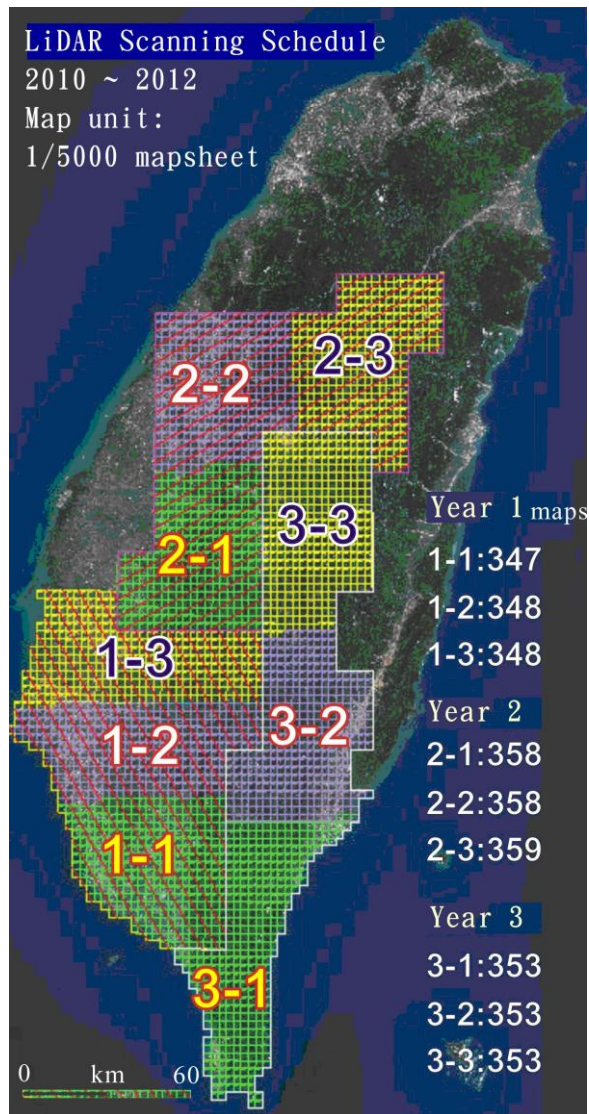


Figure 1. LiDAR survey plan in 2010-2012 of Taiwan for Morakot disaster area. The area is sub-divided into 9 survey blocks for three survey teams to finish in three years. Each map unit is a 1/5000 national map frame with a size around 2.5x2.8 km<sup>2</sup>.

## 2.2 Specifications

Deliverables, flight parameters, process-control items and product-control items are included in the specifications of this LiDAR survey. The major challenges imposed by these relatively strict specifications for implementing the LiDAR survey in tropical and sub-tropical regions of Taiwan will be discussed in next section of this paper.

### 2.2.1 Deliverables:

In addition to interim and final reports, three major deliverables are required for this LiDAR survey:

- LiDAR point clouds:** (a) Raw point clouds. Raw point clouds for both before and after strip adjustment with tie features from neighbouring strips and control points from ground should be delivered in data files include all strips of these two types of raw LiDAR data. (b) Classified point clouds. An area of small block stands for a map unit of 1:5000 mapsheet is used for point cloud editing. One of the four classes should be assigned to each point, namely outlier, water, ground, and others. Outliers including low points, high points, and other possible noises should be identified and filtered before go further for other point editing. Water points should be assigned to all points that fall on water-bodies as interpreted by ancillary information such as colour aerial photographs. Intensive manual editing is required to further distinguish ground points and others. Classified point clouds should be delivered by data files of map-sheet with nomenclature of 1:5000 national map series.
- Synchronous colour aerial photographs:** Medium format colour aerial photographs are required to be acquired in synchrony with the laser scanning. Exterior orientation parameters of each frame of aerial photographs have to be estimated by direct geo-referencing and control points as applied to raw LiDAR strips. Orthophotos with a GSD of 0.5m should be generated and delivered along with the medium format aerial photographs. For those deteriorated orthophotos not free of clouds, substitute from recent orthophotos procured from other sources can be used.
- Digital Terrain Models:** One meter grid of DEM (Digital elevation model) and DSM (Digital Surface Model) are the two most important products to be delivered in this project because they will be used by geologists for geohazard interpretations. Both DEM and DSM are at 1m grid resolution. DEMs are in 1m grid interpolated from ground points, whereas DSM from all points filtered out all outliers and water points.

### 2.2.2 Flight parameters:

Parameters for flight plan include:

- Point density should be at least 2 points per m<sup>2</sup> in an above-mean-sea-level elevation below 800m and at least 1.5 points per m<sup>2</sup> above 800m.
- Normal flight lines should be parallel with at least 40% overlap.
- Cross flights perpendicular to normal flights are required every 20km.
- Two ground control GPS stations should be installed in a distance less than 20km to the airplane for a flight mission. The GPS receivers should be dual-frequency. And, every second a record should be taken.
- PDOP of ground control GPS stations should be less than 3.0. And, a high sky visibility should be maintained with a cut off angle should be no more than 10 degrees. GPS records should start 10 minutes before the take-off of airplane and end 10 minutes after airplane landing.
- The combined separation between forward and backward solutions of trajectories should be less than 20cm.
- The FOV scanning angle should not exceed 40 degrees.

### 2.2.3 Process-control items:

Items for controlling the execution of survey process are also included in the tender, including:

- (a) Survey blocks: The subdivision into 9 survey blocks is to accelerate the process of survey to include three task forces and, thus, to have LiDAR results in a sequence for the geological people to carry on their interpretation.
- (b) Boresight calibration is required when the LiDAR sensor is re-mounted to the air plane.
- (c) Coastal zone is required to flight along the coast in separate missions within two hours of daily low tide.
- (d) Terrestrial measurements and control features have to be used for geometric corrections and quality control.
- (e) Geodetic system adopts TWD97, Taiwan Datum 1997. And, vertical datum adopts WGS84 ellipsoid. Ortho-heights of DSM and DEM are derived from a reduction of ellipsoid heights with Taiwan Geoid Model published by Ministry of the Interior.
- (f) Map margins between tiles and survey blocks should be well processed with well-defined methods. No obvious artificial discontinuities are allowed.
- (g) Well-trained personnel for manual editing of point clouds should be conformed.
- (h) A secured working environment should be maintained to safeguard all the datasets.

### 2.2.4 Product-control items:

For checking the validity of deliverables, a third party was designated. This is to maintain a consistency and conformance to the requirements set in deliverables, flight parameters and process controls. These includes checks of LAS products, gridded DSM/DEM products, and aerial photographs

- (A) Checking LAS strips: Checks for following items (a) the conformance with flight parameters; (b) the voids and gaps due to inadequate overlapping or occlusions or cloud covers; (c) Root mean square error in boresight calibration should be less than 10cm; (4) flight strips at the turning points with high banking angles should not be used for strip adjustment and subsequent applications; (5) In each strips, at least 3 ground points distributed in the beginning, middle, and ending portions should be included in strip adjustment; (6) Root mean square errors of elevation either between adjusted strips or between normal strip and cross strip should be less than 10cm; (7) Maximum error in planimetry should not exceed 1m after strip adjustment; (8) check the dis-conformance of trajectory with trajectory derived from an independent calculation by the third party (9) check the root mean square error with field measurement of bare ground points with Terrascan's "output control report".

- (B) Checking gridded DSM/DEM products: Checks for following items (a) 5% of map-sheets are randomly selected. In each of the map area, 30 points for each of 5 landcover types should be measured in field survey for comparison. The 5 landcover types include bare ground, urban area, low vegetated, sparsely forested, and densely vegetated. Root mean square errors should be conformance with the formula defined in LiDAR survey guidelines issued by the Ministry of the Interior in 2005, as:  $\sigma = a + b + c \cdot t$ , where a is a basic accuracy, b is a constant for topographic effect, c is a constant for reflecting vegetation

type, and t is a variable for average vegetation heights. (b) In each survey block, two traverses crossing the normal flight lines should be surveyed with at least 60 points of measurements extending more than 40km along accessible routes. Root mean square errors comparing the measurements of ground and those of LiDAR DEM should be assessed.

- (C) Checking aerial photographs: Checking following items: (a) Photography parameters should include synchronization with LiDAR scanning, a frame of more than 4000x4000 pixels, and cloud coverage less than 5%. (b) ortho-rectification of aerial photographs should take into account following guidelines: (i) Exterior orientation parameters estimated by POS (Positioning and Orientation System) is properly applied; (ii) GSD (Ground Sample Distance) should be 0.5m; (iii) In addition to the extension name of TIF and TFW, nomenclature of each map-sheet should follow the name of the national map series; (iv) Colour balance and map margin mismatching should be treated.

## 3. MAJOR CHALLENGES

To successfully carry out this project in the schedule defined in the flight plan and specifications mentioned above, major challenges are caused by many factors which can be grouped into two categories, namely natural factors and human factors. Natural factors include weather, tidal change of coastal line, terrain relief, heavy cloudy sky, and heavy forest coverage. Human factors include inadequacy of platforms, limitations due to national security, air traffic clearance, military training, as well as late procurement procedure.

### 3.1 Challenges due to natural factors

Weather and terrain relief conditions are the two utmost issues limiting the performance of the project.

#### 3.1.1 Weather:

Air sortie for data collection is very much dependent on weather conditions. The survey area is located at latitude from 21 to 25 degrees in tropical and subtropical zones. The sky is cloudy in most of the time all over a year, which is either not suitable for data acquisition or imposing too much requirements for re-flight to fill the cloud gaps. Figure 2 shows the statistics of de-facto flight hours of a survey plane for aerial photography in the second half year from 2007 to 2009. There are at least 240 hours of day-light time in a month. However, there is 68 hours of flight at most in August of 2008. In overall average, there are only 30 hours of flight time for a month.

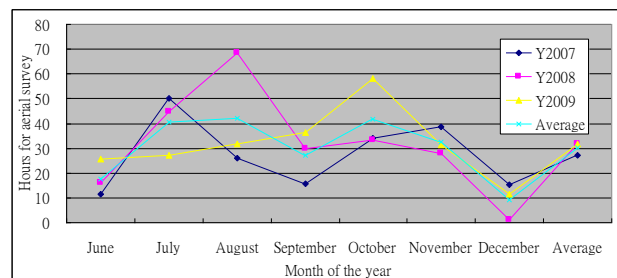


Figure 2 Statistics of flight hours of a survey plane from 2007 to 2008, showing that most of the time the sky is not suitable for aerial survey.

### 3.1.2 Terrain Relief:

Terrain relief is herewith defined as the altitude difference within one kilometre grid, which is approximated by a swath of LiDAR scans. Taiwan is a mountainous island with its highest point of Yushan range, Yushan, at 3,952 metres above sea level. Mountains account for 30% of its total area, hills and plateaus for 40%, and plains for the remaining 30%. As shown in Figure 3 and Table 1, a relief of more than 500m is distributed intensively in an elevation more than 500m and a relief of more than 1000m is distributed sparsely all over the high altitude area. In this high relief area, MPiA mode can not be applied to give a higher density and the spacing of flight lines has to be closely distributed. In addition, the area more than 200 meter in altitude is mostly covered by tropical and sub-tropical forests.

Table 1 Statistics of altitude and relief of Taiwan

Class	Altitude & Relief range (m)	Fraction of Altitude (%)	Fraction of Relief (%)
1	0~200	37.56	41.00
2	200~500	15.45	32.91
3	500~1000	14.98	24.83
4	1000~2000	20.15	1.25
5	2000~4000	11.86	0.01

### 3.2 Challenges due to human factors

It is spectacular but not uncommon in this world that legislative issue is a major limitation to the successful performance of a survey project. Because this LiDAR survey project is implemented under conditions of the law - "Special Statute For Reconstruction For Post-Typhoon Morakot Disaster", it is required to be ended before 31 August 2010 within the effective period of the Statue. Although Morakot Disaster almost became history, the tender was released as late as the middle of May 2010 due to necessary official procedures. The constraint for carrying out the project is obvious. In addition, human factors include inadequacy of platforms, limitations due to national security, air traffic clearance, and military training.

#### 3.2.1 Inadequacy of platforms:

Sarcastically, survey companies had fever for procuring airborne LiDAR sensors for bidding this national mapping program. Finally, a total of seven LiDAR sensors owned by five survey companies appeared in the small area of Taiwan. Comparably, it is not so easy to procure airplanes for aerial service companies. The situations become that sensors are too many and platforms are too few. Only three survey teams out of the five survey companies and three aerial service companies will be selected and awarded. It is really competitive.

#### 3.2.2 Delay of survey permit:

Military facilities or establishments should not be mapped by high resolution aerial sensors operated by civilians. It usually takes two to three months to obtain a survey permit before any aerial operation can be conducted. The limitation due to national security requirement is not avoidable in most of the countries in the world. Further issues are the arrangement of working environment and personnel. To assure the security of these high resolution data, little flexibility is allowed in

arranging or distributing the raw data for accelerating the processing procedures.

#### 3.2.3 Shortage of airspace:

As shown in Figure 1, the distance stretching east to west of Taiwan is only about 100km. Therefore, the sky is too crowded to adopt many airplanes in the air at the same time. In addition, military training is in top priority. In many areas, only weekends are available for civilian aerial survey.

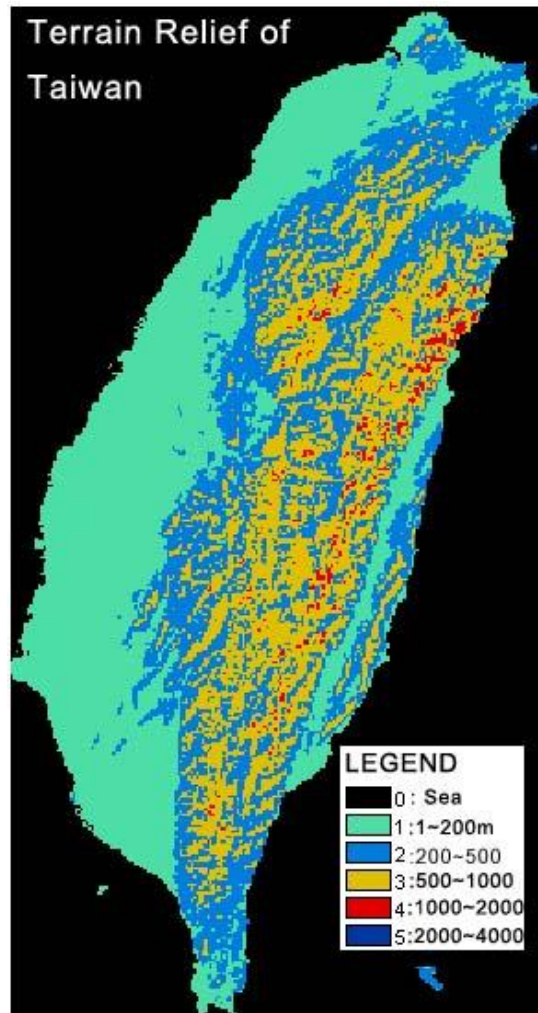


Figure 3 Terrain relief map of Taiwan showing height variations in 1000 grid.

## 4. KEY FOR SUCCESS

So many competitors are finally worked together for the program, including three LiDAR survey teams and one team for quality check. They have to cooperate to make a success of such a challenging project. Geologists are waiting for the LiDAR output for geohazard studies.

The mis-matching of margins of survey blocks have to be solved by different survey teams. And, the third party check is not doing a police work and should be more a role for coordinating between parties and acting as a platform for sharing experiences. Flaws found during quality check or criticism should be expressed in a constructive and open-minded atmosphere. No one should possess an attitude to fail

the job. All parties have a mutual obligation to go for the best. Sharing and optimising resources and experience would add high value. One outcome of the good cooperation is that the experience gained can be translated into adjustment of survey parameters in order to optimise data quality.

All the professionals involved should keep in mind the main goal of delivering the best quality to the client, given the specifications. Parties should be willing to apply the highest professional expertise and invest in timely delivery of products, both in terms of human and financial resources.

## 5. STATUS

The parties involved in this program, monthly meetings, and types of flaws are described in this paragraph.

### 5.1 The parties

The client is the Central Geological Survey of Taiwan. Three prime contractors of LiDAR survey are all local companies in Taiwan including Chung-Shing Survey Company, Realworld Engineering Consultant Incorporation, and Geoforce Technology Company. The team for conducting third party check is also a prime contractor to Central Geological Survey. This quality check contract was awarded to a team organized by Department of Geomatics, National Cheng Kung University. A fourth prime contractor of LiDAR survey will join the family by the beginning of May 2011. LiDAR Sensors employed include Leica ALS60, Optech ALTM Pegasus, and Riegl Q680i. All the sensors have capability of Multi-Pulse in Air (MPiA) though most of time it is not applicable when the terrain relief is high.

Each survey team has to complete about 2500 square km per year (Figure 1). Because they are working on adjacent survey blocks, sometime sorties simultaneously on the air are not possible. Nevertheless, a maximum of three systems have been operating simultaneously during periods of optimal weather conditions.

Flying height and pulse rate are to be optimized by point density and completeness of coverage. And, this varies with LiDAR sensors. Flying height varies between 1,200 and 2,700m, flight speed between 90 and 110 knots, and pulse rate between 50 and 100 kHz.

Each survey team has to take care of flight plan, sorties, post processing, point cloud editing, DEM/DSM generation, orthorectification, as well as ground surveys for adjustment and controls. All LiDAR survey teams deliver the Lidar data to the third party team, where all the products undergo a thorough quality check procedure prior to delivery to Central Geological Survey.

### 5.2 Monthly meetings

Central Geological Survey hosts monthly meetings to monitor the progress of all parties. Flaws found by the third party team and issues encountered by all three survey teams are raised for discussion. Experiences are shared. Some experiences are translated into survey parameters. For example, in the requirement of flight parameters, point density of the first echoes was assigned as 1 point per  $m^2$  in single flight lines in high mountains above 800m. Terrain relief and wind effect

tends to make the survey density becomes higher whereas it is still prone to gaps between strips. Therefore, the resolution made in a meeting changes this to “at least 1.5 points per  $m^2$  above 800m” without the phrase “in single flight lines”.

### 5.3 Types of flaws

All the deliverables of map-sheets in the first year (Figure 1) is scheduled to be completed by the end of May 2011. More than 100 air sorties have been carried out before February. Total coverage completed is 7300 square  $km^2$ . The grand average of point density is more than 3.0 points per  $m^2$ .

A DEM with high accuracy and high resolution will be a tool for the interpretation of geohazards by geologists. Therefore, intensive labours have been deployed to closely check the flaws of point cloud editing. Examples of major types of flaws are given here. These flaws are due for correction by the LiDAR survey teams.

- (1) Outliers are not filtered (Figure 4): Outliers including low points, high points, and other possible noises should be identified and filtered before go further for other point editing.
- (2) Points of buildings are not filtered (Figure 4).
- (3) Points of bridges, elevated roads, culverts, and underpass are not filtered (Figure 5).
- (4) Points of temporary piles of earth, garbage, and others are not filtered (Figure 6).
- (5) Points of vegetations are not filtered (Figure 7).
- (6) Points sparsely distributed on mountain top are filtered off. This will result in a flat mountain top (Figure 8).
- (7) Points of dike, solid earth embankment, balk between paddy fields or ponds, and natural levee are filtered off (Figure 9).
- (8) Points of hydraulic facilities e.g. watergates are filtered (Figure 10).



Figure 4 Points of outlier and building are not filtered.

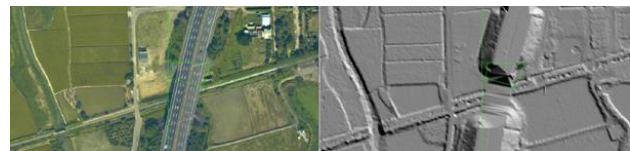


Figure 5 Points of elevated roads are not filtered



Figure 6 Points of temporary piles are not filtered.

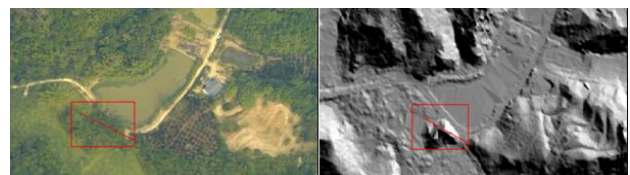


Figure 7 Points of vegetation are not filtered.

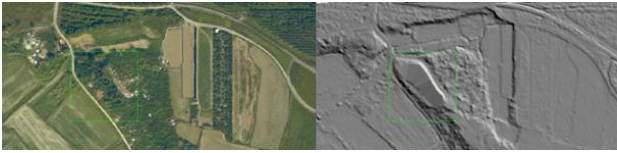


Figure 8 Points of mountain top are filtered.

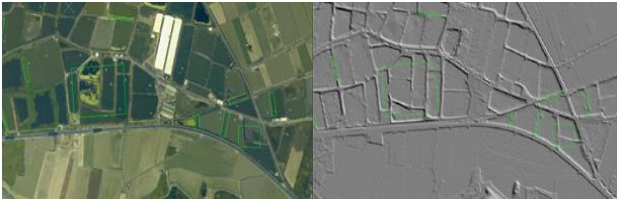
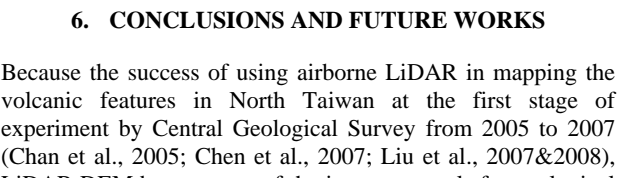


Figure 9 Points of balk between fish ponds are filtered.



## 6. CONCLUSIONS AND FUTURE WORKS

Because the success of using airborne LiDAR in mapping the volcanic features in North Taiwan at the first stage of experiment by Central Geological Survey from 2005 to 2007 (Chan et al., 2005; Chen et al., 2007; Liu et al., 2007&2008), LiDAR DEM became one of the important tools for geological people to interpret geological features. This results in the proposal by Central Geological Survey after the Morakot Disaster. A national program for disaster mapping is thus initiated and launched. As mentioned in the introduction, the LiDAR survey is only a part of the national geohazard mapping program. When the LiDAR products are delivered to Central Geological Survey, geologists will continue to explore their applications. In addition, a second phase succeeding this Morakot LiDAR project has been initiated to complete a full coverage of Taiwan with LiDAR data.

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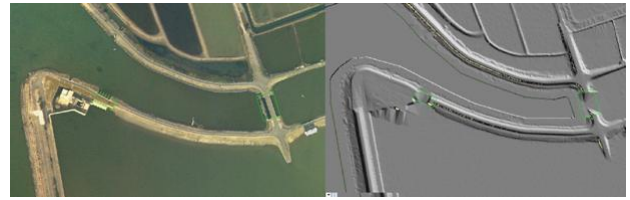


Figure 10 Points of water gate are filtered.

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