Application of air borne laser scanning and ortho-rectified photograph in geomorphological mapping works

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Abstract

The concentration of infrastructure and building construction demands over the last two decades in Malaysia, has encouraged developments over new areas of challenging terrains and encroachments into existing, otherwise stable, highland areas resulting in incidences of geotechnical instability and catastrophe. Over the years, many researchers including the government have ventured into slope hazard assessment exercise with major aims, i.e. to reduce landslide disaster or to facilitate the slope preventive works by prioritization of expenditure. Numerous slope systems with multiple hazard analytical tools have been developed. The preliminary stage of all these study required detailed field / geomorphological mapping to collect important information (i.e., failure information, geological discontinuity, distress information and etc.), for the analysis stage. Due to the nature of the tropic condition in Malaysia, sometimes the mapping works were made impossible due to the existence of the thick vegetation. Therefore, in some circumstances, important information were missed out and not collected.

With the advancement in technology of the current air borne laser survey, such limitation can be easily overcome. Hidden features i.e., failure scars, drainage basin, water ponding can be easy detected using air borne laser scanning. With the assistance from the air borne laser and application of GIS, some hydrological features including drainage path, potential water ponding, and saturated ground can also be determined. This information will facilitate the field surveillance teams to produce a better geomorphological map.

This paper highlights the application of air borne laser works inrelation of producing a geomorphological map for a slope hazard assessment study. The advantages of air borne laser survey for the production of geomorphological map and how does the air borne laser scanning works facilitate ground mapping works will also be detailed in this paper.

Keywords: Landslide, air borne LiDAR, geomorphological mapping, DEM, GIS.

1.0 INTRODUCTION

Landslide has resulted in significant losses in Malaysia. A basic tool for assessing regional landslide hazard is a landslide inventory map, which indicates the distribution of known landslide events, assists in understanding landslide processes, and can be used to estimate landslide susceptibility. Over the years, many researchers including the government have ventured into the slope hazard assessment exercise with major aims; to reduce landslide disaster or to facilitate the slope preventive works by prioritization of expenditure.

Understanding landslide process and being able to simplify it effectively rely on interpreting a number of contributing processes and activities. The greatest uncertainties in the process modelling of landslides arise from inadequacies in site characterization. These processes and activity i.e. water flow direction, slope angle, ground saturation etc. are significantly depending on the topographical conditions of the site. These processes require accurate terrain model and detailed geomorphological and geological information. The conventional approach for landslide assessment especially the large scale area based is mainly relying on aerial photograph interpretation and field mapping. Area which covered with thick forest often resulted in poor or inaccurate interpretation due to access difficulty.

2.0 GEOMORPHOLOGICAL MAPPING

Geomorphology looks at the processes that shape and alter the surface features of the land. By studying landforms, including their origin and patterns, scientists attempt to comprehend landscapes' history and dynamics. In so doing, they can better understand the types and extents of deposits directly beneath the existing levees through field observation, detailed mapping, and stratigraphic models (which study rock layers).

In the conventional large scale landslide hazard assessment exercise, aerial photograph interpretation (API) is used to interpret the geological settings of the area. The identification of potential landslide zones was visually judged based on morphological features: slope failures, scars, deposits, sagging and all kinds of topographical irregularities as well as the slope statistics that taken as evidence to delineate current and ancient landslide prone area. Differences in vegetation, moisture content, and soil or rock composition account for most tonal contrasts. On aerial photographs the boundary between coherent and unconsolidated material can be recognised, as well as the different lithologies. The lithological discrimination is made possible by the composite effect of tone, texture, landform, topography, drainage pattern and vegetation.

The APIs are often hampered by the presence of thick vegetation. Landslides are difficult to detect through API or field mapping. Therefore, the accuracy of conventional landslide hazard assessment is always questionable especially for areas with thick vegetation and complicated geology settings.

To overcome the limitation of API, often, ground mapping is carried out by geologist and geotechnical engineer. Field teams are sent to the study area for further verification on the API results. The ground mapping works will become difficult if the study area is covered by thick forest and bushes. Sometimes valuable important information might not be collected if the field teams are not able to assess the area in total.

3.0 AIR BORNE LiDAR (Light Detection And Range) Survey

LiDAR is one of the best techniques to produce geomatic data for any geographical purposes. Air borne LiDAR mapping can provide more a comprehensive and precise topographic features than other conventional methods, such as aerial photographs interpretation and digital photogrammetry. Figure 1 shows the schematic diagram for the data capturing using LiDAR. This method relies on measuring the direction and time of sending and receiving coherent laser beams to the surveyed objects. This option has its own unique solutions to deliver close to ground data accuracy at an airborne speed with little effect from bad weather. It totally eliminates the Ground Control Point that need for imagery processing. At very high speed, the current LiDAR mapping technology can provide a very accurate terrain model to produce a contour map of terrain floor of any forest or cleared land to within 0.15m resolution. Three-dimensional spot heights are produced at 0.2m to 3m grids depending on flying height and skewing angle.

Modern airborne LiDAR scanner measures multiple returns for each laser pulse (refer Figure 2). Part of the laser pulse will bounce off from tree branches or foliage as several levels and the remainder from the ground. Sophisticated algorithms can filter the multiple returns and determine the time for the last return of laser pulse. The last signal return is more likely bounced off the ground surface. This capability is important when trying to map the ground topography beneath heavy vegetation and identify salient features in the ground, e.g. ground movement, ancient landslide failure scar, gully etc.

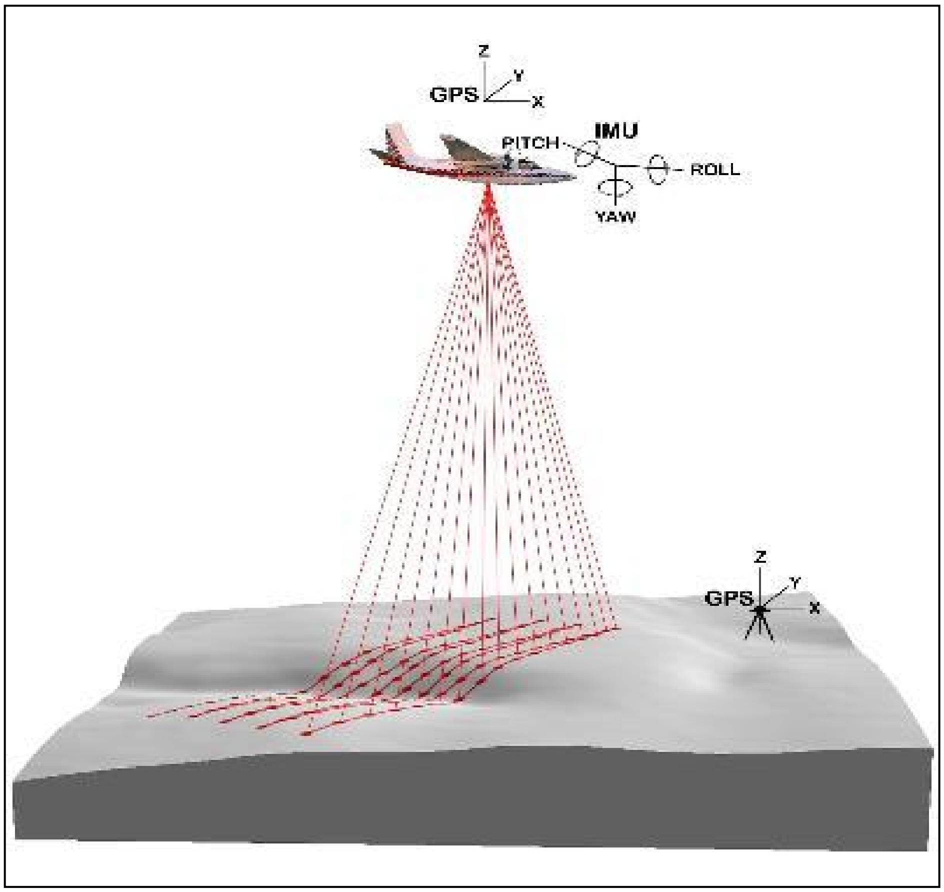

Figure 1: Illustration of how LiDAR sensing instrument captures elevation points

Therefore, air borne LiDAR survey has becoming popular terrain assessment tool among the environmentalists, soil scientists, engineers and geologist. The LiDAR returns are dense enough to interpolate close- gridded DEM beneath the vegetation and produce a series of useful and informative geomorphologic maps that can be analyzed in a GIS framework. This information will be used to assess various problems particularly for landslide assessment study.

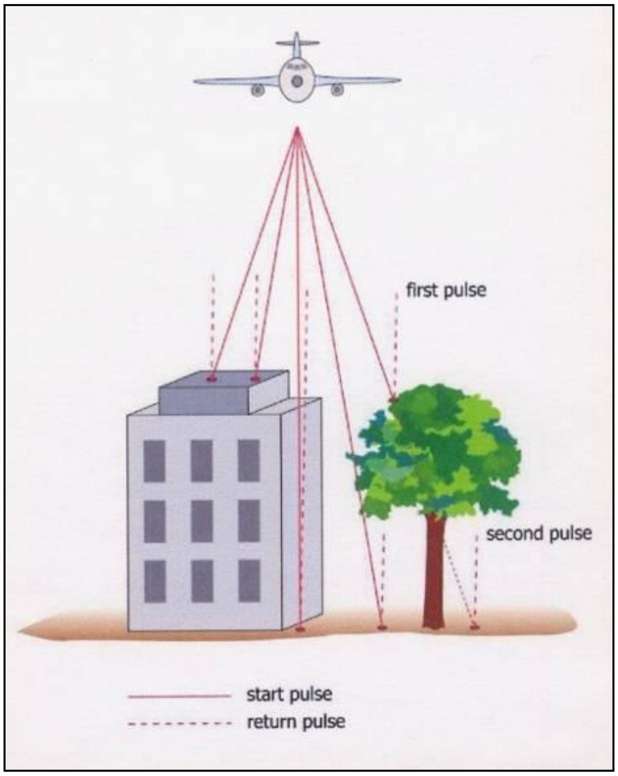

Figure 2: Illustration of the multiple reflection of laser pulse

4.0 USEFUL GEOMORPHOLOGIC FEATURES FROM LIDAR SURVEY

The ability of LiDAR in producing dense digital terrain model (DTM), digital elevation model (DEM) and filtering the canopy layers has resulted easy and accurate geomorphological mapping works. Figure 3 shows a processed LiDAR 3-D model where some interesting features such as slope failures, culvert location and paddy field can be clearly identified. The ortho-rectified photographs taken during LiDAR works also provide visualised images in facilitating LiDAR processing works and interpretation works pertaining to vegetation and land cover. The model can be used as the preliminary guide map in field geomorphological mapping works. Field team can prioritize the mapping works based on the preliminary findings from the terrain map produce from LiDAR survey.

There are several useful “hidden” geomorphologic features i.e., hidden topography, landslide scars etc., can be retrieved from LiDAR works. These hidden features are detailed in this paper. The availability of these features contributes significantly in landslide assessment study. Both processed and unprocessed LiDAR data can be used in interpreting these features.

4.1 WATER PONDING

The unprocessed LiDAR raw data can be used to locate the areas with water ponding. The distributing of LiDAR raw point cloud data indicates the x,y,z coordinates of the returned laser pulses. Area with no data points (hole) indicates difficulty in pulse return due to the absorption of laser pulse by the water. Figure 4 shows a typical raw point cloud data for a road with water ponding.

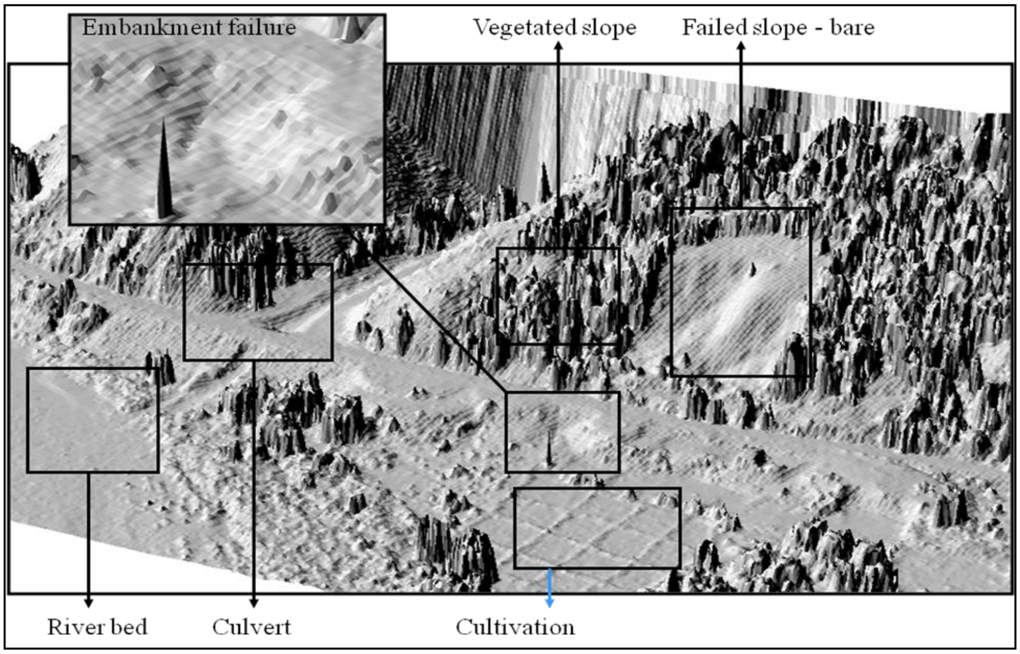

Figure3: 3-D model generated from LiDAR showing some important geomorphologic features

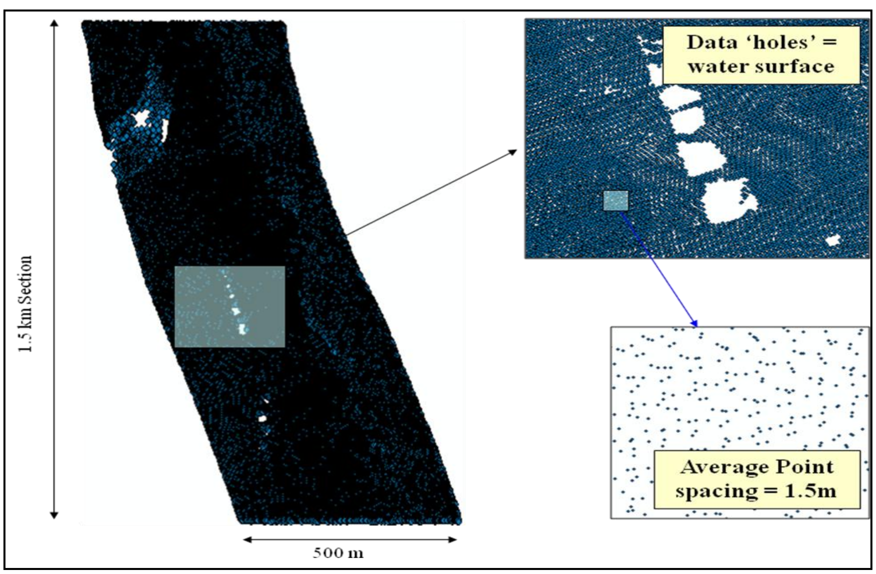

Figure 4: Illustration of the data "holes" due to water ponding in LiDAR raw point cloud

4.2 HIDDEN LANDSLIDE SCAR AND TOPOGRAPHY

The capability of stripping the canopy in LiDAR processing technology can help engineers and geologists in identifying landslide scar and ancient landslide in the thick forest areas (refer Figure 5). Although API can be used for this similar assessment, the accuracy of API is only limited to large scale landslide. Locating these features will not be easy if the assessment is merely based on API. The advantages of such technologies are obvious when dealing with inaccessible thick tropical forest like Malaysia.

Figure 5: Landslide scar under thick vegetation

Area topography is an important tool in landslide assessment works. A high resolution topography allows a better understanding of the landslide causal factors and processes i.e. water surface runoff, slope saturation and slope geometry. Topography produced by API is sometimes inaccurate especially at a relatively small area with thick vegetation covers. Often, some important "hidden" information was missed out and not collected even with field mapping works by the engineers. Figure 6 shows a hidden topography of a slope. This "hidden" topography is covered by thick vegetation and hard to be visualised during field mapping works.

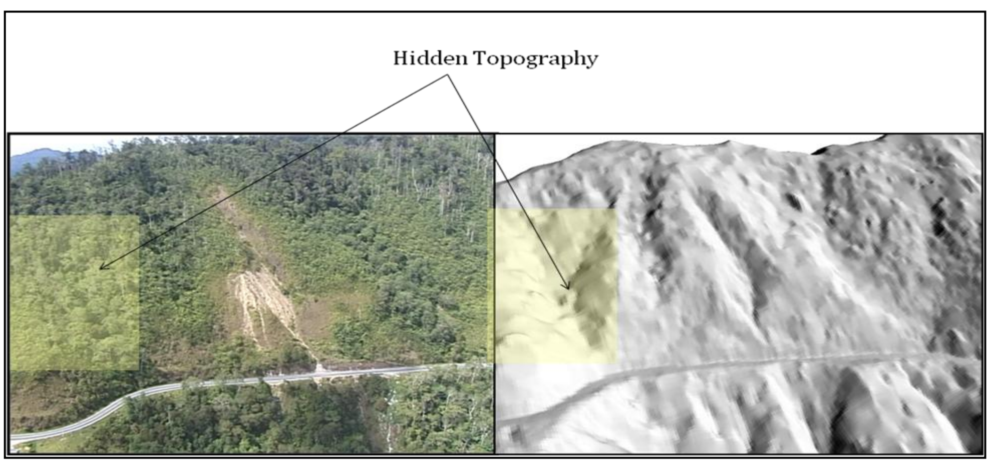

Figure 6: "Hidden" topography retrieved from LiDAR 3-D terrain model

4.3 POTENTIAL DEBRIS FLOW

Debris flow is a natural hazard and occurs naturally at streams where side slopes are steep and the catchment is large, usually in mountainous terrain. Debris flow is usually triggered by intense and prolonged rainfall, initiated by debris avalanches which blocked the stream flow. The criteria in identifying locations of potential debris flow can be summarized as follows:-

- Type of debris flow (mud/granular)
- Estimated volume involved
- Density of debris flow
- Inclination of slope
- Impact velocity
- Geometry of the blocked channel area
- Subsoil conditions

Some of these geotechnical and hydrological processes required an accurate terrain model. Figure 7 shows an active debris flow location. The bare-earth DEM clearly shows the channelized characteristic of the topography of the debris flow failure location.

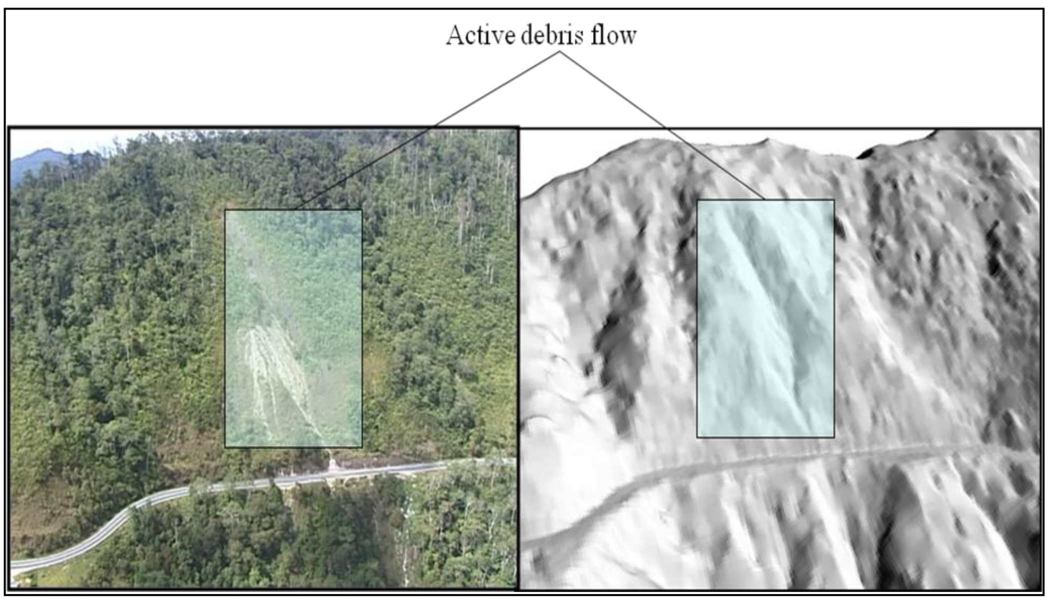

Figure 7: Active debris flow location

Geographical Information System (GIS) has becoming popular in landslide hazard assessment works. The potential channelized debris flow (CDF) can be identified using simple factor overlay approach in GIS environment. Important CDF contributing spatial layers generated i.e., flow accumulation, slope angle etc., from high resolution DEM from LiDAR can be overlaid to produce CDF susceptibility map. Figure 8 shows a 3-D CDF susceptibility map.

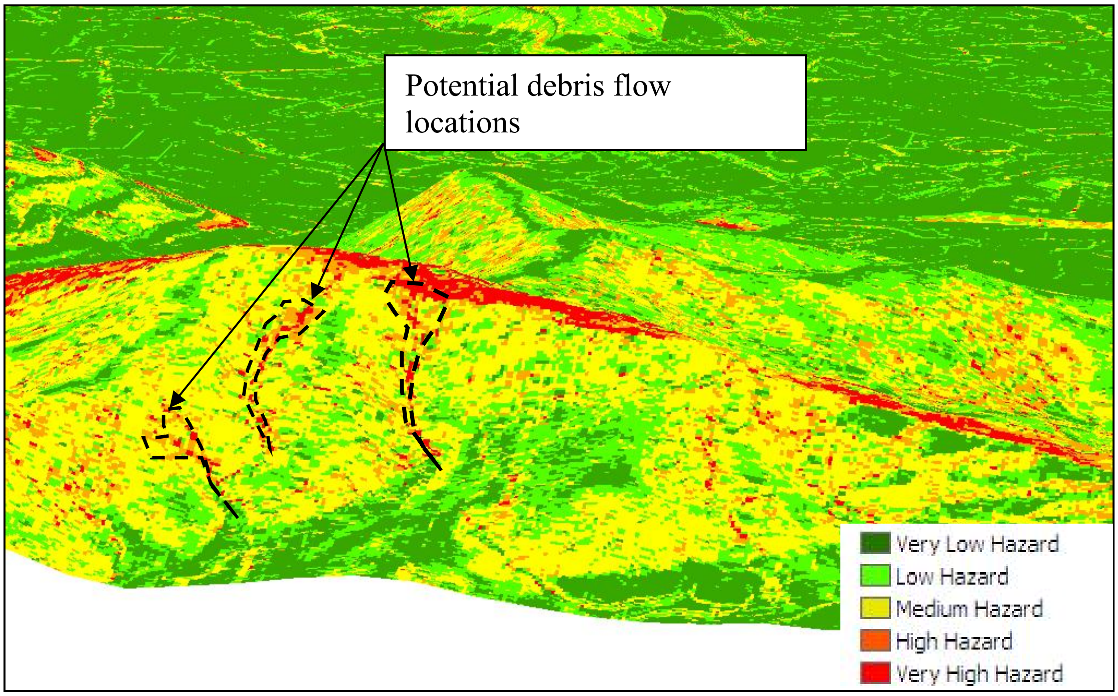

Figure 8: Potential channelized debris flow locations indicated on a landslide hazard map produce in GIS environment.

4.4 CONCLUSION

A high-resolution LiDAR allowed an efficient reconnaissance level on landslide hazard assessment to be conducted in forest, where dense vegetation makes traditional geomorphological mapping and aerial photograph interpretation virtually impossible. The canopy removal capability in LiDAR technology can help engineers and geologists to understand better the geotechnical, geological and hydrological characteristics of a landslide location.

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