HYPERSPATIAL RESOLUTION OF GROUND BASED REMOTE SENSING FOR NATURAL LIMESTONE CHARACTERIZATION: A CRITICAL INPUT FOR ROCK SLOPE HAZARD ASSESSMENT IN THE TROPICS

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ABSTRACT: An accurate and rapidly observed rock-cliff mapping is a step forward for a better hazard and risks assessment of natural limestone in the tropics. The use of advanced and modern mapping technology is crucial in assessing the stability and deformation of the rock slope. Rock-falls are typical geological disaster on steep slopes often resulted an impact to economic, human life and environmental issues. A combination of climatic, topographic and vegetation factors contributes to the initiation of rock-fall processes in a tropical environment. The rock-mass characteristics in particular the discontinuity properties, e.g. joints, bedding planes and fractures determine the possible unstable blocks leading to rock-fall activity. This collaborative research provides a better new insight into the use of very Long Range Terrestrial Laser Scanning (LRTLS) system captured at 1400 m and 4000 m to accurately map the rock slope characteristics of weathered tropical limestone. The method is also capable of extracting discontinuity orientations and positions on the rock face made it possible to reconstruct the rock-mass and identify hazardous blocks in the slope. Interestingly, we developed a methodological framework addressing the data preliminary-, collection-, processing- and analysis stage for rock-cliff stability assessment in the equatorial region. We critically discussed some practical and limitation issues on the use of LRTLS system to map and characterize the hazardous natural limestone in Batu Caves (Selangor, Malaysia) – an iconic touristic place characterized by 400 million years old limestone. The seamless integration of calibrated high-resolution digital color images with high-density LIDAR scan data allows an accurate characterization of rock-mass to improve the quality of rock slope stability analysis. Remarkably, this is a first attempt to objectively map the natural limestone and produce the rock-cliff derived hyperspatial resolution data for geomechanics, rockfall analysis and geotechnical risk assessment using a revolutionary, remotely advanced laser mapping technique in Malaysia.

1. INTRODUCTION

Terrestrial Laser Scanning (TLS), or also known as Terrestrial LIDAR is the most significant technology introduced in the mainstream topographic mapping (Shan and Toth, 2008). This equipment utilizes Light Detection and Ranging (LiDAR) technology providing an accurate geospatial data captured in a relatively very short time. It uses a visible to near infrared light emitted from a laser instrument that records the reflected light waves from its targets. This mapping technique utilizes the emission and return time of highly collimated electromagnetic radiation to compute the distance from the instrument optical centre to a reflecting target surface (Baltsavias, 1999).

The use of advanced and modern mapping technique has been widely used in various applications in Earth sciences including the rock slope investigations (Derron and Jaboyedoff, 2010). It is a direct, remote and reliable approach for investigating natural and man-made geological hazards. In rock slope instability, the TLS data is captured in the set form of points characterized in a three-dimensional coordinate system, allows the mapping and characterization of rock slopes. It provides us significant recent advance of detection the rock slope instabilities across a wide range of spatial and temporal scales. Abellán et al. (2014) highlighted the Terrestrial LIDAR as an effective sensor and superior in the term of range, accuracy, resolution and newly 3D visualization.

TLS LIDAR is a very promising technique to provide high resolution and accurate 3D surface information for geotechnical assessment, rock slope deformation and prediction rock failures. Major advantages lie on the rapid acquisition of rock slopes characteristic geometrically – particularly in the dangerous area or even inaccessible zones.

A promising key is also prominent in the capability of remotely obtaining the orientation of slope discontinuities in a complex environment. This data is a step forward for monitoring rock slopes, quantifying the rock type failures, modelling of rock slope deformation, and detecting any precursory of slope deformation for future prediction and mitigation purpose. This surveying technique is a great supplementary method to the current practice of geological mapping and stability assessment in Malaysia.

2. STUDY AREA

The study area is located in Batu Caves, Selangor Malaysia. It is an iconic touristic place characterized by 400 million years old limestone (Figure 1). The area is a religious place and remained as a focal point for the Hindu community's yearly Thaipusam festival. Given the climatic, topographic and vegetation factors contributes to the initiation of rock-fall processes, the use of remote sensing technology in an active mode is urgently needed. An accurate rock-slope characteristic provides crucial input for stability assessment and deformation analysis.

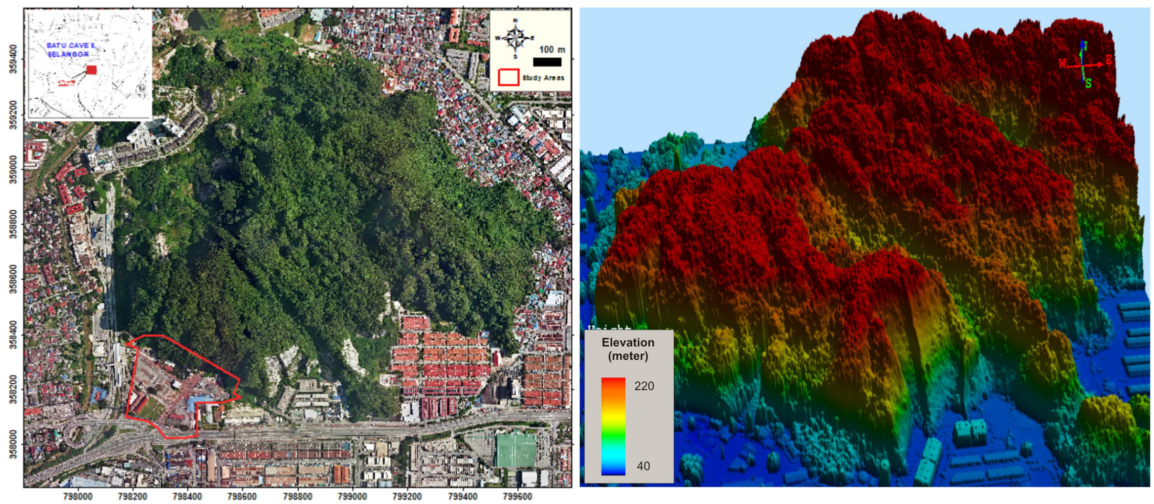

Figure 1: Study Area. Batu Caves, Selangor (Malaysia).

3. METHODOLOGY

3.1 Terrestrial Laser Scanning Campaign

In this research, a long range Terrestrial LIDAR namely RIEGL VZ 1000 was utilized and its specification is given in Table 1. We adopted a survey protocol for rock slope LIDAR mapping proposed by Lim et al. (2009) and the requirement of multi-stage survey routine as listed by Abellán et al. (2014). The methodological workflow – from the planning, field procedure, up to data processing is followed the widely accepted mapping procedure (Jaboyedoff et al. 2012). To our knowledge, this is a first reported study on the use of advanced and modern Terrestrial LIDAR system for mapping and characterizing the limestone rock slopes in Malaysia.

Table 1: Metadata for terrestrial laser scanning (TLS) RIEGL VZ1000 characteristics

Single point accuracy	8 mm at 450 m
Scan density (spot size)	6 mm at 40 m
Speed (pts/second)	122000
Accuracy	8 mm
Field of view (V x H deg)	100 x 360 deg
Weight	9.8 kg
Software	*Riegl software* RiScanPro

Figure 2 demonstrates the use of long range Terrestrial LIDAR system for rock slope mapping and characterization in the project site. Moreover high frequency GPS data is used to accurately geo-position the 3D point clouds, whereas the reflectorless total station is used to provide reference coordinate data for 3D point cloud registration in the areas of interest. The coordinate system used in this project is Cassini-Soldner Selangor. Generally a combination of these surveying methods is needed to achieve the results at unprecedented level of detail. At planning stage, the ideal scanning locations are very important to reduce the time and cost in the field. The geometrical area of interest and optimal field of view are key parameters to control the aforementioned issues. During the data collection, overlapping percentage between scanning area and respective features shall be taken into consideration. Site condition and its complexity must be critically evaluated from the beginning of data acquisition. At later stage; processing and analysis, the 3D registration method and its algorithm shall be addressed properly. LIDAR point cloud- and image-based analysis also required an expert knowledge as an additional input for a better characterization of rock slopes.

During the field campaigns, we also used a combination of GPS-RTK and Reflectorless Total Station. TLS survey is practically done at the higher place and far from the area of interest in such a way that it can capture a wide range of data with relatively short time and low number of scanning stations. As mentioned earlier, the tool is capable of capturing the data up to the 1400 m and can be located anywhere with clear line of sight. The preliminary scan – done in a relatively few minutes over the entire rock cliffs can be used to evaluate the critical areas of interest.

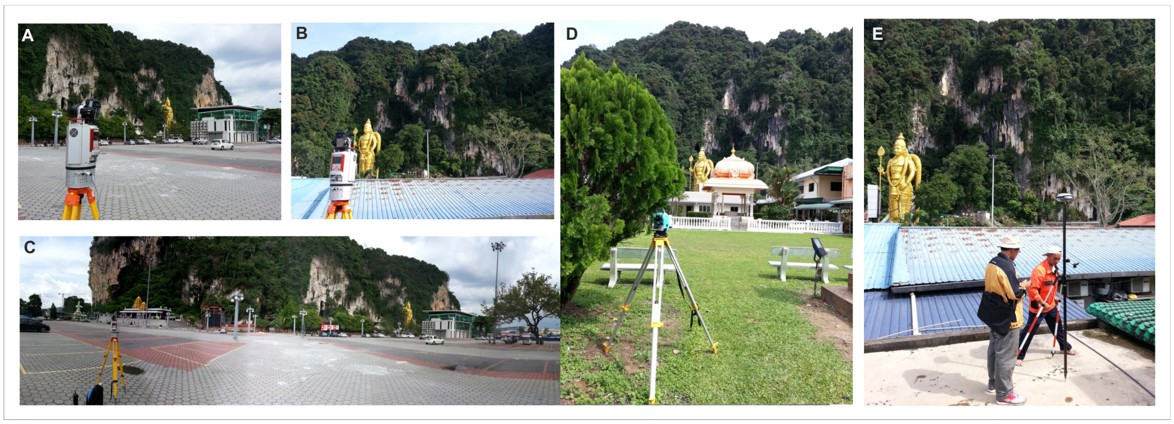

Figure 2: Geospatial field campaign in Batu Caves, Selangor, Malaysia. A to C) Terrestrial Laser Scanner, RIEGL VZ1000, D) Reflectorless Total Station, E) Real-Time Kinematic GPS data acquisition over the study area.

3.2 Control Surveying using GPS-RTK and Total Station

To provide accurate control stations (horizontally and vertically) for the Terrestrial Laser Scanning instrument, Real Time Kinematic GPS (RTK GPS) technique was used with the ability to achieve centimeter accuracy level. To obtain such accuracy, GPS corrections were required and this was succeeded using MyRTKnet service, provided by the Department of Surveying and Mapping Malaysia (DSMM). MyRTKnet is a system that provides GPS corrections computed from multiple reference stations established by DSMM. All the corrections are sent to the DSMM processing center and then broadcast to the users via internet, typically using wireless connections. The accuracy of MyRTKnet issued by DSMM is 4 and 6 cm for the horizontal and vertical components, respectively (at 95% confidence levels). In this study, a satellite receiver Ashtech ProMark 800 was used to perform RTK GPS and receiving corrections from MyRTKnet.

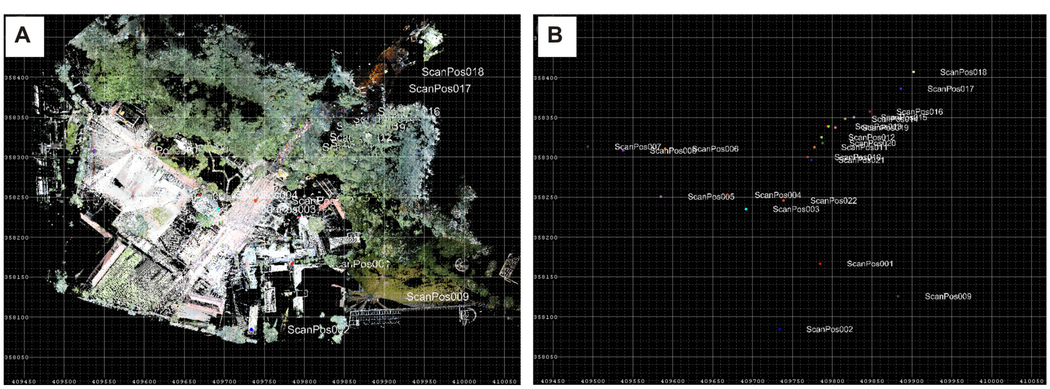

Figure 3: An overview of Terrestrial Laser Scanning stations. A) Georegistered TLS point cloud. B) 25 location of TLS scanning stations over the Batu Caves, Selangor.

For some of the control stations that were not capable to receive GPS signals and failed to achieve RTK GPS positioning mode due to poor satellite availability and obstructions, a Total Station (TS) was used. The TS connected between stations using distance and angle measurements. Note that the coordinates for these stations were derived from the closest stations that were already observed by RTK GPS method. A Nikon Nivo Total Station was used for this purpose with the accuracy of ± (2 + 2 ppm x distance) mm.

4. RESULTS AND ANALYSIS

A total of 260 million point clouds captured using a very long range terrestrial laser scanner, RIEGL VZ1000 resulted in an accurate and reliable survey data in particular the rock faces of limestone. The terrestrial laser scanning data was observed in a relatively very short of time compared to the conventional surveying methods. Figure 4 shows derivatives of TLS data for rock slope. One of important remarks is the extraction of discontinuity and joint extracted purely from TLS data. The output provides crucial geological indicator for a better assessment of rock stability. A detailed rock slope characteristic is revealed by hyperspatial TLS data in Batu Caves, Selangor. Examples of common and peculiar characteristic of natural rocky limestone are shown in Figure 5.

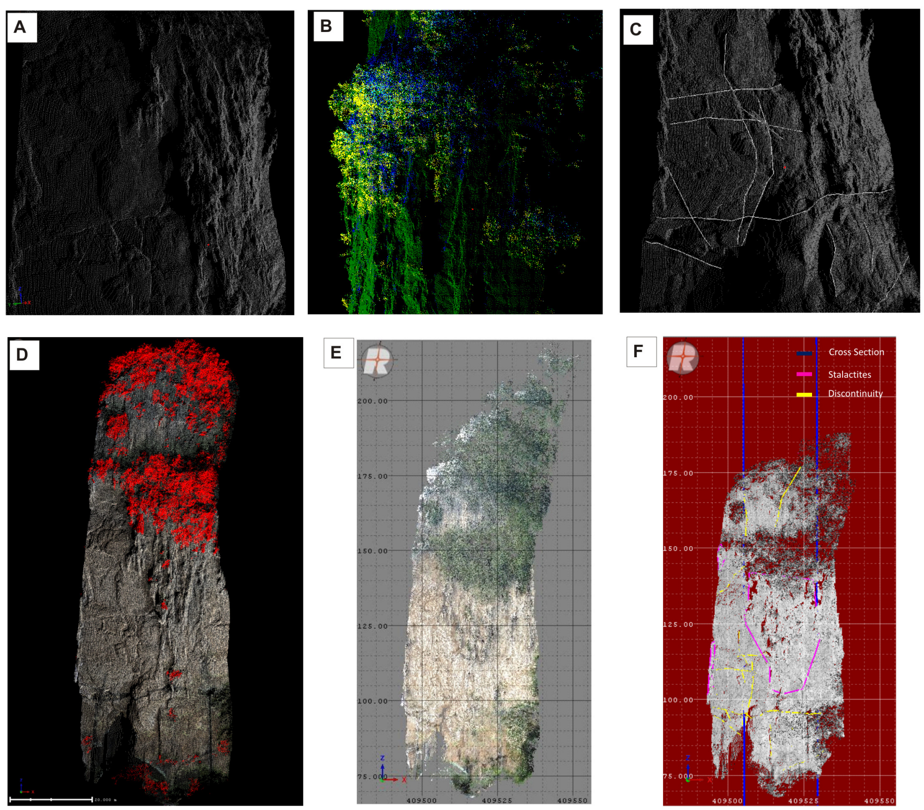

Figure 4: TLS-derived rockface data and analysis. A) 3D point cloud data. B) Multiple target or echoes. C) Discontinuity and joint extracted from TLS data. D) Vegetated area in red. E) F) One of standard data delivery for assessing the geological rock mass represented as a colorized point cloud and filtered data, respectively with indication of geological features leading to the rock stability study.

Interestingly, it recorded a very detailed rock mass characterization beyond than the normal eye-level. Coupling with reference stations setup using GPS-RTK and Reflectorless Total Station, TLS data was geo-registered and geo-rectified properly. Moreover, with its potential to record multiple echoes, the filtering computational was performed to extract the rock features beneath the dense vegetation. A combination of additional data, e.g. 11 million point clouds of airborne laser scanning data and 15 cm very high resolution aerial images, the primary data for geological interpretation and rock-cliff boundary was carefully generated and fully utilized.

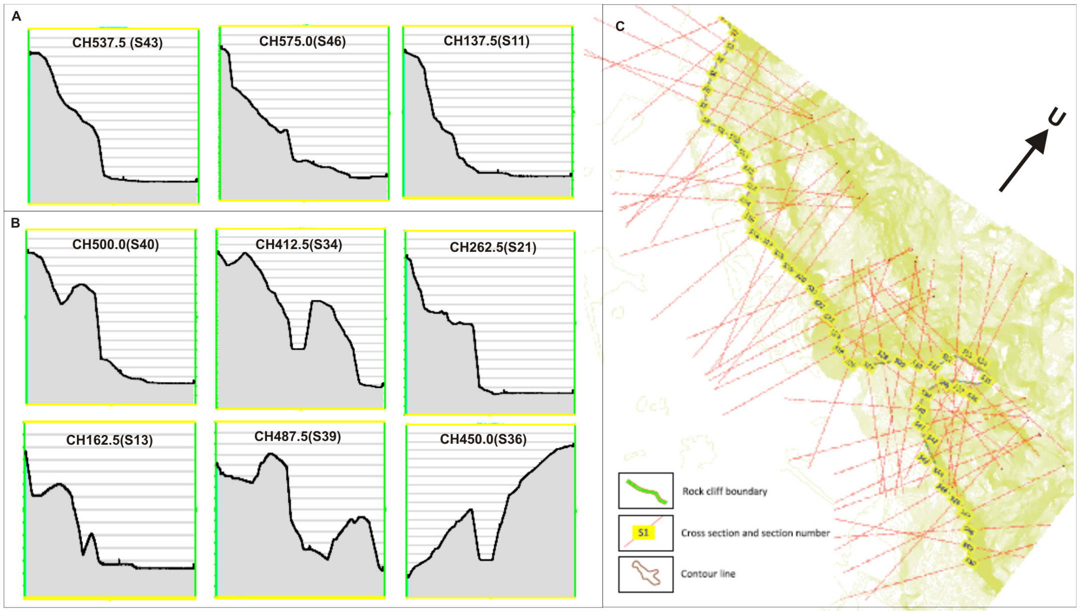

Figure 5: Rock slope characteristics revealed by hyperspatial TLS data (Batu Caves, Selangor). A) Usual geometric terrain of rock slope. B) Peculiar characteristic of natural rocky limestone. C) An entire of cross sections coupled with rock cliff boundary and contour line used for geological and geotechnical assessment.

For a detailed analysis of rock stability and rock-fall modelling, the 50 sections along 625 m chainages were produced and analysed at 12.5 m cross-section. Such impressive laser data made the limestone slope cross section characteristics are possible, and critically link to the key slope cross section across the Sri Maha Mariamman Temple in Batu Caves. Several plots were selected to evaluate the potential of TLS to compute the dip/orientation from the laser data particularly the one above the eye-level. Data collection from the field was performed in one of the validation plots (see Figure 6). We evaluated the consistency of dip/ orientation output generated by RiScanPRo and SPLIT-FX (Table 2). Interestingly the results of dip/orientation computational are very much similar with the one computed in the RiScanPro software. Further validation tests and field campaigns are needed to provide a series of quantitative results over the larger area.

The results are very promising given the large potential of immense 3D laser data in the geotechnical and geological risk assessment. This research provides the new insight into the use of TLS mapping technique for mapping and characterizing the limestone in the tropics. To the knowledge of author, this is a first study carried out by utilizing the advanced and modern topographic laser scanning system for mapping limestone rockfaces and extracting the important features related to geological structures and instability of rock mass in Malaysia.

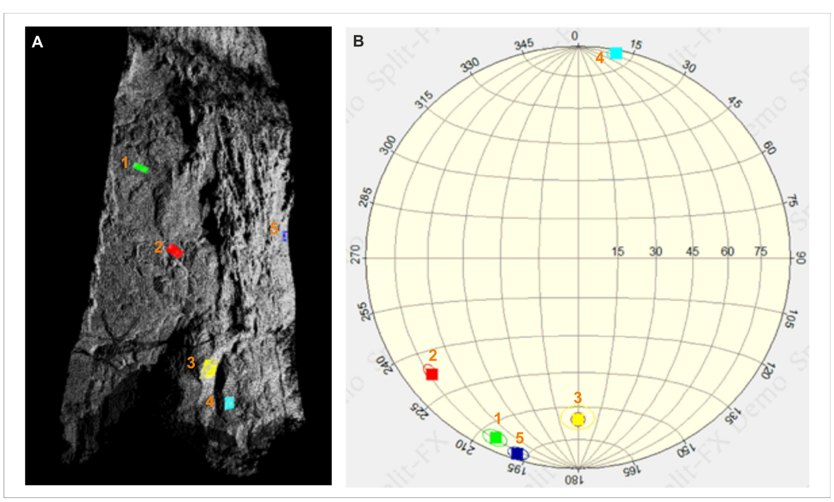

Figure 6: Validation plots: Dip/orientation computed from RiScanPro and SPLIT-FX. See text for an explanation.

Table 2: Quantitative assessment of dip- angle and orientation derived from hyperspatial Terrestrial LIDAR data

	RiScanPro		Split-FX	
	Dip Angle (deg)	Dip Orientation (deg)	Dip Angle (deg)	Dip Orientation (deg)
1	84.11	24.24	82.80	24.30
2	75.80	49.92	76.70	51.20
3	66.26	0.49	65.80	0.00
4	88.095	190.98	88.10	190.60
5	87.55	15.27	86.70	17.00

5. CONCLUSION

The emergence of Terrestrial Laser Scanning (TLS) data for investigating geomorphic processes and activities has improved our ability to map, monitor and model the topographic terrain signature and geological features leading to instability of rock mass. This study explicitly unveiled that TLS can be a very important new data source and mapping tool to characterize unstable limestone even in a complex environment. The increased prevalence of modern TLS system and advanced point cloud processing had led the ways to improve future rock-fall or hazard maps and subsequently reduce potential risk. Ground remote sensing, in particular the very long range TLS technology is a critical and supportive geospatial tool for better understanding of geological phenomenon in a dynamic environment.

The increasing availability, quality and affordability of TLS data have triggered this study and are potentially applied in different limestone areas including the one covered by the dense vegetation. This study proved the high possibilities of TLS data to identify map and characterize the rock-cliffs, their important features and subsequently provide valuable data input for geotechnical and geological risk assessment in Malaysia. The use of advanced and modern surveying tool is crucial in rock slope characterization, mapping and monitoring project. It is also promising tool to characterize complex landslides along the transportation route in a mountainous region (Razak et al. 2014) In a conclusion, this paper illustrates superior mapping technique for rock stability in terms of accuracy, reliability, consistency, time acquisition and cost-and-benefits in Malaysia.

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