An Investigation of the Optimal Resolution for Landslide Monitoring Using Terrestrial Laser Scanner

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Key words: Terrestrial laser scanner, Resolution, Landslide, Deformation

SUMMARY

Landslide is one of the most devastating natural disasters for countries throughout the world which leads to life-threatening, properties and infrastructure damages. Hence, an effective technique is needed to monitor it thus, reducing the impact caused by this type of disaster. There are two approaches available for landslide deformation monitoring and they are point-based technique and area-based technique. Nowadays, Terrestrial Laser Scanning (TLS) technology is gaining popularity in monitoring and predicting the movement of the landslide body due to the capability of high speed data capture without requiring a direct contact with the monitored surface. Therefore, it is a suitable choice for monitoring unstable land slopes. It is undisputable that, proper project planning is needed before carrying out data collection for landslide monitoring. An important aspect that requires research is the optimum ground resolution of survey. This scan resolution mainly depends on the distance between the scanner and slope surface: cm to mm resolution. Besides that, the type resolution also depends on the minimum feature size that needs to be collected. Most researchers are using high resolution in this kind of application. The resolution of the digital terrain model (DTM) that can be generated for deformation analysis and the effort required for data handling are directly influenced by the point cloud density. Therefore, the objective of this study is to determine the optimal level of ground resolution for landslide deformation monitoring purpose. In the research, the data acquisition was conducted at a recent cut slope in Universiti Teknologi Malaysia (UTM), Skudai campus using Leica ScanStation C10. Five well-distributed control points, were established around the interest area for point clouds registration purpose. Two scan stations were used to cover the entire cut slope surface. Three types of resolution were utilized at each scan station and they are the low, the medium, and the high resolutions. After done with the data collection, the point clouds datasets were undergo the process of registration and vegetation filtering using Leica Cyclone software. After that, the registered point clouds datasets were analyzed using CloudCompare software. This study shows that the scanning resolution affects the generated displacement map especially the low resolution sample. Hence, it is concluded that high or higher scanning resolution is needed for landslide monitoring using TLS. In conclusion, this study demonstrates that TLS can be used to monitor the condition of the entire landslip slope surface.

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1. INTRODUCTION

According to Varnes (1978), landslides can be categorized into six types which are falls, slides, topples, flows, lateral spread and complex as shown in Table 1. Landslide is a general term referring to the various processes of downslope movements of earth materials under the influence of ground water, soil composition, gravity and human activities. Landslide is one of the major natural disasters for all countries over the world. It is life-threatening and causes property and infrastructure damages.

Table 1: Classification of landslide types (Varnes, 1978).

Type of Movement		Type of Material		
		Bedrock	Engineering Soils	
			Predominantly Coarse	Predominantly Fine
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slide	Rotational	Rock slide	Debris slide	Earth slide
	Translational			
Lateral Spreads		Rock spread	Debris spread	Earth spread
Flows		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
Complex (Combination of two or more principle type of movement)				

Nowadays, the method used for landslides data acquisition is slowly changing from the conventional method such as tacheometry and precise leveling to more efficient methods of using modern technology like Global Positioning System (GPS), Photogrammetry, Laser Scanner and Unmanned Aerial Vehicle (UAV) system. According to Abellan et al. (2006), Teza et al. (2007), Lingua et al. (2008), Miller et al. (2008), Sui et al. (2008), Sui et al. (2009), Kasperski et al. (2010), Bertacchini et al. (2012) and Jing (2012), Terrestrial Laser Scanning (TLS) is suitable for slope deformation and instability monitoring with the ability of providing dense three-dimensional (3D) point clouds in a short observing time without direct contact with the land slope surface. Furthermore, the accuracy of this technology is also acceptable for slope deformation monitoring with millimetre (mm) and centimetre (cm) level accuracy (Miller et al., 2008; Abellan et al., 2009; Barbarella et al., 2013).

However, one of the aspects that require attention in the data acquisition is the optimum scan resolution (Miller et al., 2008; Monserrat and Crosetto, 2008). So, a high-quality project planning is required ensure the balance between the time used for data collection and the quality of the captured data. In addition, the resolution of the DTM that can be generated for deformation analysis is directly influenced by the point cloud density. Hence, the aim of this study is to investigate the optimum scan resolution for land slope deformation detection. Three types of scan resolution are applied in this study in order to examine the suitability of different types of scan resolution in deformation detection. The method of "point cloud to point cloud" comparison is used to calculate the deformation.

2. STUDY AREA

The area for this study is the cut hill slope besides the new building for Faculty of Biosciences and Medical Engineering (Block T02) in Universiti Teknologi Malaysia (UTM), Skudai. The dimension of the land slope is about 80m × 25m. This area is chosen because there are some signs of ground erosion on the slope surface. Figure 2 shows the study area.

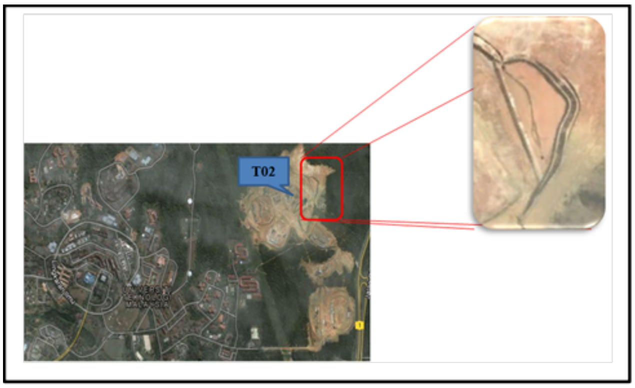


Figure 2: Location of the study area in UTM, Skudai.

3. TECHNIQUE FOR DATA COLLECTION

In this experiment, three different types of resolution were used. They were low (0.2m horizontal and vertical spacing at 100m), medium (0.1m horizontal and vertical spacing at 100m) and high (0.05m horizontal and vertical spacing at 100m) resolutions. These resolutions are preset in the Leica ScanStation C10 scanner software. The highest (0.02m horizontal and vertical spacing at 100m) resolution available in the scanner was not chosen because this resolution required a long observation time for collecting the point clouds. Concurrently, this experiment was conducted with three different scan distances which are 100m, 130m and 160m approximately. A length of approximately 30m between two observation stations was chosen based on the requirement of minimum length for the traverse line as stated in Tuan Sulong (2007).

The type of network consisting of the check points on the cut slope surface is a relative network. This is because all the check points were located inside the area of interest and this area is considered unstable. On the other hand, an absolute network is applied using the control points and observation stations which were outside of the interest area. Furthermore, all the control points were well-distributed around the deformation area. Figure 3 shows the overview of the distribution of the control points and check points on the land slope. In Figure 3, the control points are shown in red triangles while the check points are shown in light blue hexagon.

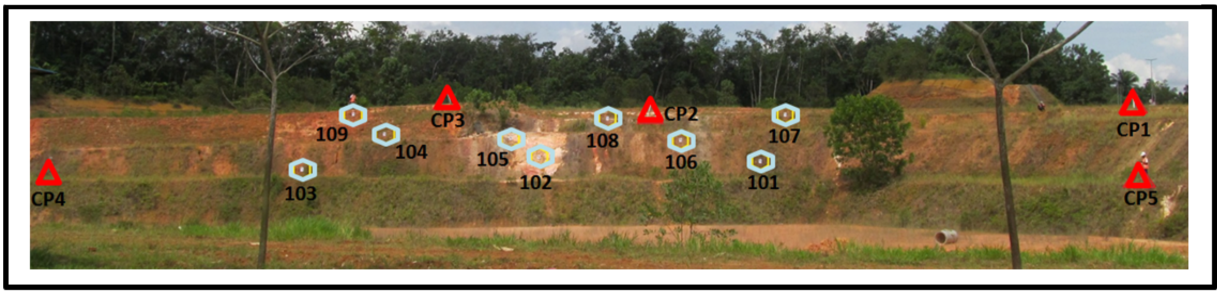


Figure 3: The distribution of the control points and check points on the land slope.

All the control points and one observation station were established with aluminum pipe and concrete block. However, the remaining 5 observation stations were marked with nail on the tar surface of the parking space opposite the land slope. These control points are used for registration purpose. On the other hand, the observations points are established on the tar and concrete surface opposite the land slope. Figure 4 shows the overall layout of the control points, check points and observation stations.

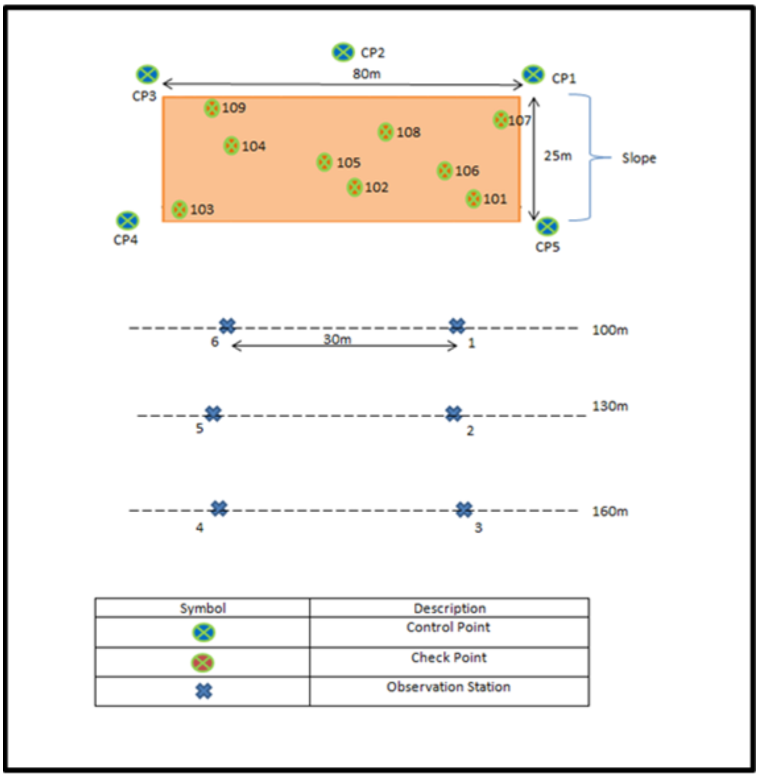


Figure 4: Overall layout of the control points, check points and observation stations.

The Balck and White (B&W) targets with special designed aluminum plate holders were placed on the control point when data collection was carried out using Leica ScanStation C10 scanner. Besides that, this type of target was also used as check point and they were planted on the surface of the land slope. Figure 5 shows the type of targets used for control points and check points.

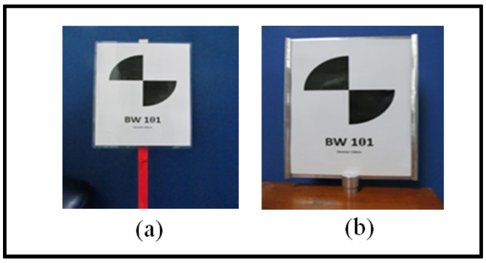


Figure 5: Type of targets used for (a) check points and (b) control points.

After setting up all the control points and check points, the Leica ScanStation C10 scanner was used to scan the slope surface from two scan stations as shown in Figure 6 (a). The scans were carried out using windowing method where the boundary of scan area is directly defined in the interface of the instrument. Furthermore, the highest scan resolution was used to scan all the control points and check points individually. These scanning processes were repeated for the other two scan distances.

After that, a nominated reflectorless Total Station Topcon ES-105 (Figure 6 (b)) was used to collect the measurements for all the control points and check points. This process validates the quality of the scanned data. Before starting the data collection using reflectorless Total Station, the differential field test (DFT) was carried out to check the condition of the instrument. Two epochs of data were collected in this experiment with an interval of two months.

Figure 6: (a) Leica Scan Station C10 is used to scan the land slope surface and (b) reflectorless Total Station Topcon ES-105 is used for validation.

4. DATA PROCESSING

The raw point clouds dataset collected by TLS were registered together into a single coordinate system using Leica Cyclone (v. 7.3.3) software. The process of point clouds registration is done by picking up at least three common targets in both point clouds datasets. After that, this is followed by basic editing and manual vegetation filtering in order to trim the point clouds which are not belong to the interest area together with vegetation. Then, the datasets were exported in .pts format in order to process in CloudCompare (v. 2.5.0) software.

CloudCompare software is open source software. It is capable for either direct “point cloud to point cloud” comparison or “point cloud to surface” comparison. In this software, the first epoch of dataset was set as the ‘Model’ which referred as reference cloud while the second epoch of dataset was set as ‘Data’ which referred as the dataset that will be registered. These two epochs of point clouds datasets were registered together through coarse and fine registration. The process of coarse registration was performed by choosing at least three homologous points in both datasets. In this case, the control points near the slope were used. However, the fine registration was performed through using Iterative Closest Point (ICP) algorithm in order to minimize the mean squared distance between the point clouds in both epochs.

After completing the process of coarse and fine registration, both datasets from two epochs were analysed by applying the “cloud to cloud” computation technique in order to calculate the deformation of the land slope. This “cloud to cloud” computation technique calculates the nearest neighborhood distance between two epochs using a kind of Hausdorff distance algorithm. According to Girardeau-Montaut et al. (2005), the Hausdorff distance is the distance computed between the nearest points of two point clouds.

5. RESULTS AND ANALYSIS

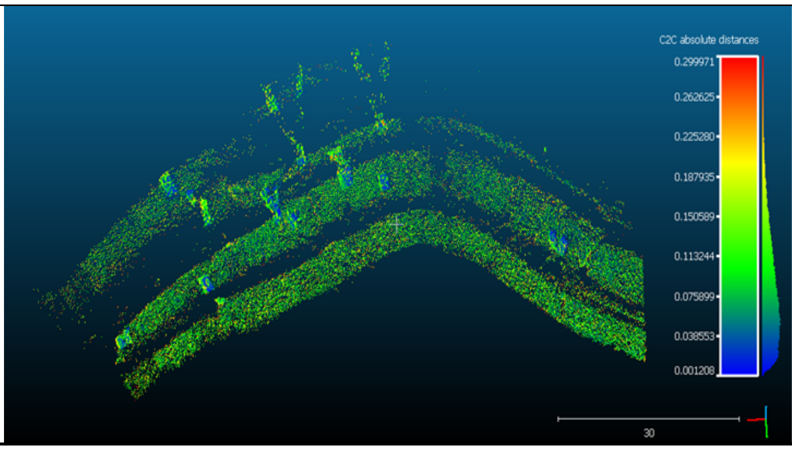
To obtain the results, the stability of the control points and check points is analyzed. At the same time, nine sets of displacement map are produced which are corresponding to three different scan resolutions and three different scan distances. These displacement maps were generated using CloudCompare open source software.

5.1 The colour-coded displacement maps

There are nine colour-coded displacement maps generated through using CloudCompare software and they are shown in Table 2, Table 3 and Table 4. These displacement maps were computed without applying proper vegetation filtering. As a result, this factor has contributed to a certain amount of faulty displacement detected between two epochs which caused by vegetation re-growths. On the other hand, the unusual high faulty displacement also showed at the border of the cut slope. The cause was the difference in the data value at the scan border between the two epochs. So, these faulty displacements should not be considered as the cut slope displacement. Hence, the average of the displacement detected in all the displacement maps is at cm level.

The mean values for the detected displacement with respect to different scan resolutions were provided in the Table 2, Table 3 and Table 4. From the results for the mean, it can be concluded that the mean of the displacement is proportional to the scan distance. Besides that, the suitability of scan resolution for each type of scan distance can be deduced from Figure 7. In this case, the mean value of the displacement for the high resolution is taken as the bench mark for comparison. This is because most researchers used high scan resolution for landslide monitoring. Hence, it can be concluded that both low and medium scan resolution is not suitable for scan distance which is more than 100m for land slope deformation detection.

Table 2: The generated displacement map and the mean value for displacement with respect to the three different scan resolutions at 100m of scan distance.

Scan Resolution	Displacement Map	Mean (m)
Low		0.0863

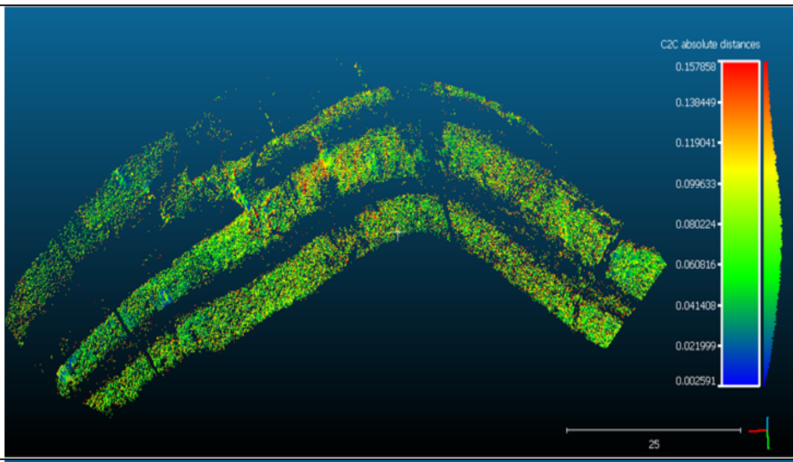
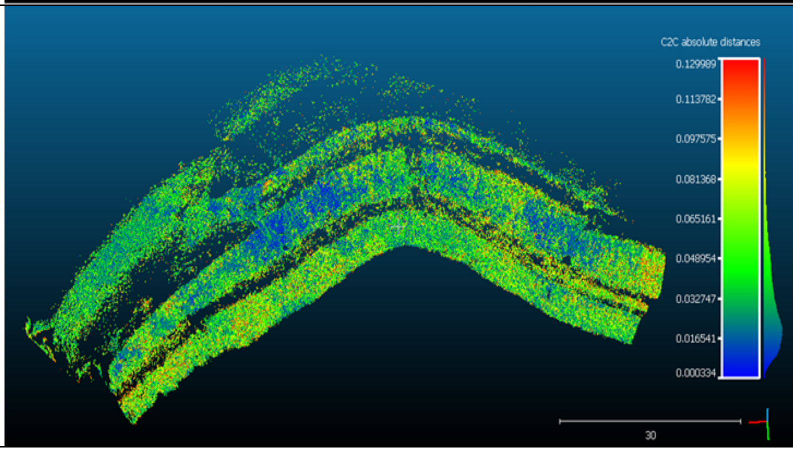
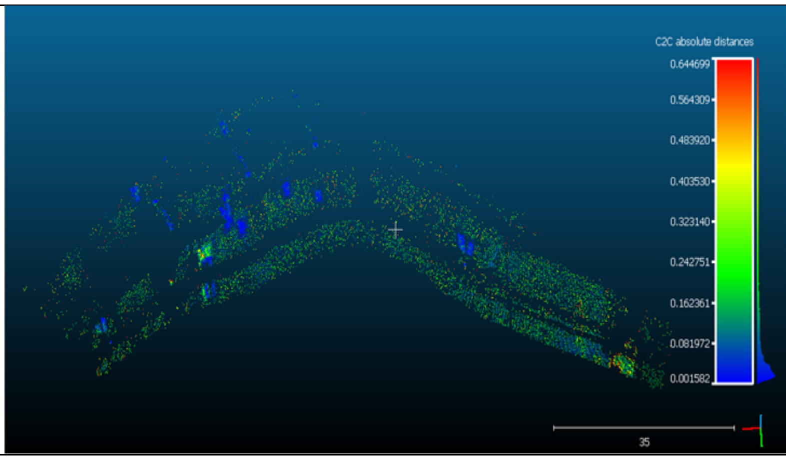
Medium		0.0769
High		0.0341

Table 3: The generated displacement map and the mean value for displacement with respect to three different scan resolutions at 130m of scan distance.

Scan Resolution	Displacement Map	Mean (m)
Low		0.0968

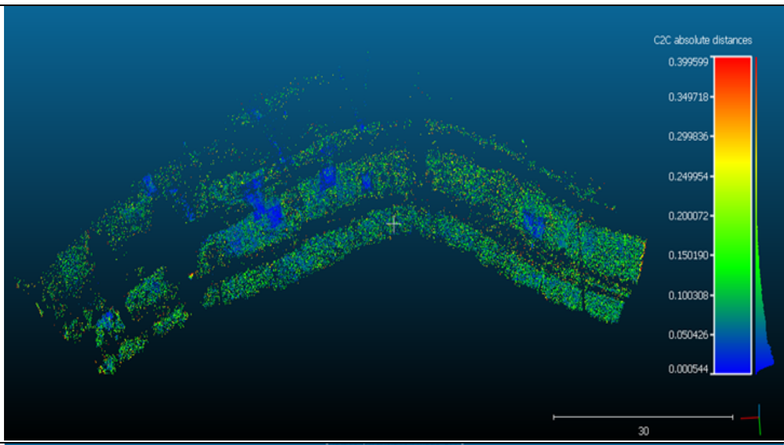
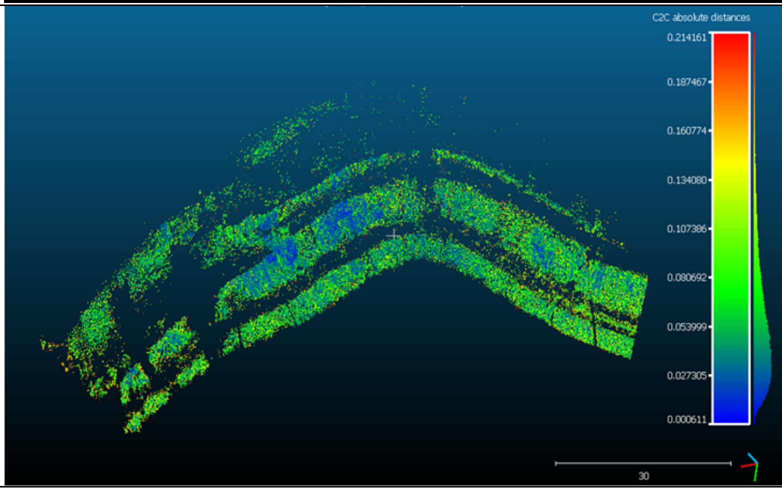
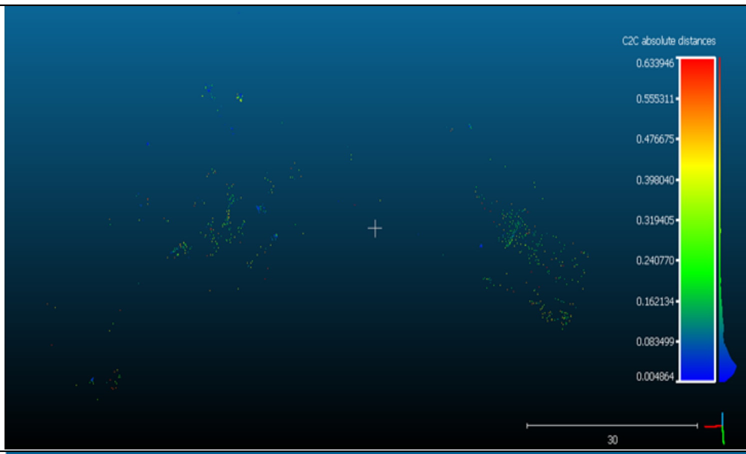
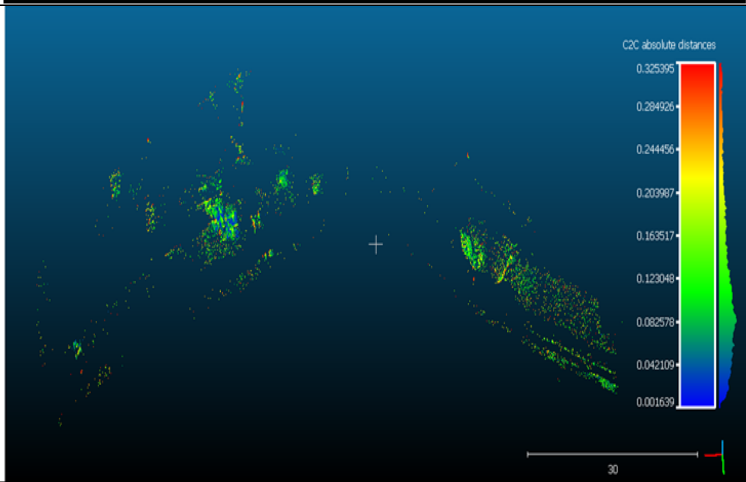
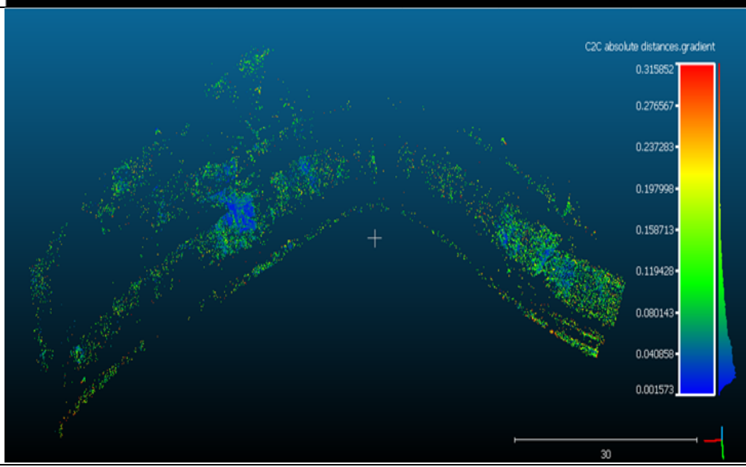
Medium		0.0782
High		0.0587

Table 4: The generated displacement map and the mean value for displacement with respect to three different scan resolutions at 160m of scan distance.

Scan Resolution	Displacement Map	Mean (m)

<table>
<tr><td>Low</td><td>
</td><td>0.1335</td></tr>
<tr><td>Medium</td><td>
</td><td>0.1227</td></tr>
<tr><td>High</td><td>
</td><td>0.0729</td></tr>
</table>

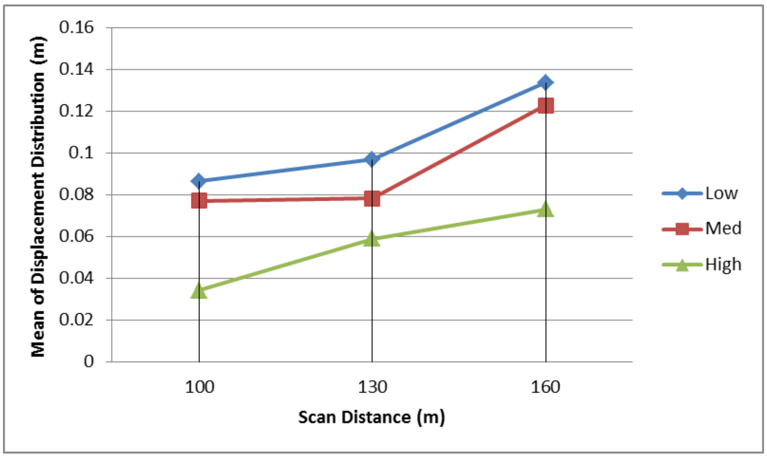


Figure 7: Plot for mean of displacement distribution versus scan distance for three different scan resolutions.

6. CONCLUSION

Based on the results obtained from the first experiment, it can be concluded that the scan resolution affects the sensitivity of landslide deformation detection. Based on the results obtained in this study, it can be concluded that the high or higher resolution is needed for landslide monitoring using TLS. Furthermore, this research also confirms that TLS can be used for landslide deformation survey with the accuracy between mm and cm level. Undoubtedly, a better result can be obtained if effective vegetation filter could be applied before the deformation computation analysis.

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