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Accuracy Assessment of LIDAR-Derived Elevation Value Over Vegetated Terrain in Tropical Region

Zamri Ismail[a*], Muhammad Zulkarnain Abdul Rahman[b], Mohd Radhie Mohd Salleh[b], Abdul Razak Mohd Yusof[b]

[a]*Photogrammetry & Laser Scanning Research Group*
[b]*TropicalMAP Research Group, Department of Geoinformation, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*

*Corresponding author: zamriismail@utm.my

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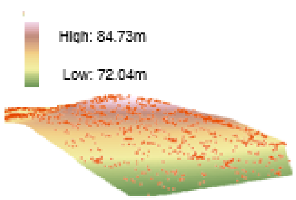
Graphical abstract



LiDAR point clouds (red dots) overlay with DTM generated from ground reference points

Abstract

Airborne LiDAR has been widely used to generate good quality of Digital Terrain Model (DTM). Normally, good quality of DTM would require high density and quality of airborne LiDAR data acquisition which increase the cost and processing time. This study focuses on investigating the capability of low density airborne LiDAR data captured by the Riegl system mounted on an aircraft. The LiDAR data sampling densities is about 2.2 points per m^2. The study area is covered by rubber trees with moderately dense understorey vegetation and mixed forest. The ground filtering procedure employs the adaptive triangulation irregular network (ATIN) technique. A reference DTM is generated using 76 ground reference points collected using total station. Based on this DTM the study area is divided into different classes of terrain slopes. The point clouds belong to non-terrain features are then used to calculate the relative percentage of crown cover. The overall root mean square error (RMSE) of elevation values obtained from airborne LiDAR data is 0.611 m. The slope of the study area is divided into class-1 (0-5 degrees), class-2 (5-10 degrees), class-3 (10-15 degrees) and class-4 (15-20 degrees). The results show that the slope class has high correlation (0.916) with the RMSE of the LiDAR ground points. The percentage of crown cover is divided into class-1 (60-70%), class-2 (70-80%), class-3 (80-90%) and class-4 (90-100%). The correlation between percentage of crown cover and RMSE of the LiDAR ground points is slightly lower than the slope class with the correlation coefficient of 0.663.

Keywords: Airborne LiDAR; accuracy; vegetation; slope

Abstrak

LiDAR bawaan udara telah digunakan secara meluas untuk menjana Model Rupa Bumi Digital (DTM) yang berkualti baik. Biasannya DTM yang baik akan memerlukan perolehan data LiDAR bawaan udara yang berkualiti dan padat yang akan meningkatkan kos serta masa pemprosesan. Kajian ini akan tertumpu kepada penelitian keupayaan data LiDAR bawaan udara berkepadatan rendah yang diperolehi dari sistem Riegl yang diletakkan pada kapal terbang. Penyampelan kepadatan data LiDAR adalah 2.2 titik per m^2. Kawasan kajian dilutupi oleh ladang getah dengan kepadatan tumbuhan lapisan bawah yang sederhana dan hutan campuran. Prosedur penurasan tanah menggunakan teknik *adaptive triangulation irregular network* (ATIN). DTM rujukan dijana menggunakan 76 titik rujukan bumi yang diperolehi menggunakan alat *total station*. Berdasarkan kepada DTM rujukan ini, kawasan kajian dipecahkan kepada kategori kecerunan yang berbeza. *Point clouds* yang telah dikelaskan kepada selain dari permukaan bumi digunakan untuk pengiraan litupan rimbunan pohon pokok secara relatif. Ralat Punca Min Kuasa Dua (RMSE) keseluruhan bagi nilai ketinggian yang diperolehi dari LiDAR bawaan udara ialah 0.611 m. Kecerunan kawasan kajian dibahagikan kepada kelas-1 (0-5 darjah), kelas-2 (5-10 darjah), kelas-3 (10-15 darjah) dan kelas-4 (15-20 darjah). Hasil kajian menunjukkan kelas kecerunan mempunyai korelasi (0.916) yang tinggi dengan RMSE titik bumi LiDAR bawaan udara. Peratusan litupan rimbunan pohon pokok dibahagikan kepada kelas-1 (60-70%), kelas-2 (70-80%), kelas-3 (80-90%) dan kelas-4 (90-100%). Korelasi diantara peratusan litupan rimbunan pohon pokok dan RMSE titik bumi LiDAR bawaan udara adalah sedikit rendah berbanding kelas kercerunan dengan pekali korelasi sebanyak 0.663.

Kata kunci: LiDAR bawaan udara; ketepatan; tumbuh-tumbuhan; cerun

■1.0 INTRODUCTION

Light Detection and Ranging (LiDAR) technology is an active remote sensing technique that provides direct range measurements between the laser scanner and the Earth's surface. It was reported that such distance measurements that are mapped into 3D point clouds could provide up to sub-meter vertical accuracy.[1] Hence, this technology has emerged as a promising method for acquiring digital elevation data effectively and accurately as compared to conventional methods. It has been shown that the technology is approaching towards a fully automated procedure in generating digital elevation model and pushes researchers to pay more attention to link this technology to its related applications.[2] Inevitably, this situation has forced scientists or users who intend to incorporate a DTM into their study to carefully consider the sources of DTM with a clear idea on the impact of the errors on the applications.

One of the most debated issues of DTM generated from LiDAR is the height's accuracy. In general most of related applications require high accuracy of DTM for example as stated by the American Society of Photogrammetry and Remote Sensing (ASPRS) in the guidelines of DTM accuracy for different applications such as marine navigation and security, storm water and flood plain management in flat terrain, management of wetlands and other ecologically sensitive flat areas, infrastructure management of dense urban areas and special engineering applications.[3] Similar issues also pointed in forest management and town planning.[4]

Intensive investigations on the applicability of LiDAR technology in producing high accuracy of DTM have been done in developed or temperate countries. Similar efforts are still demanded for tropical region, especially in Malaysia. Previous studies have shown that the accuracy of DTM is determined by several groups of factors, in which the geographic environment i.e. land-cover type and terrain slope has become one of the important factors.[5,6,7,8]

The quality of DTM generated using LiDAR data in a fluvial area of the Netherlands by comparing the results to the DTM obtained from reference data collected over area covered by low grass and pavement.[9] The reported root mean square errors (RMSEs) are between 0.7 m and 0.14 m. One research has conducted experiments on LiDAR data collected over North Carolina during leaf-off condition, which covers different land-cover categories.[10] Generated DEM was compared to the 1,225 survey points, it was found that the RMSE varies in accordance to different land-cover types (i.e. low grass: 0.145 m, high grass: 0.163 m, scrub: 0.361 m, pine: 0.276 m and pavement: 0.226 m). A similar research conducted to investigate DEM generated using LiDAR data captured over forested area in Galicia, Spain.[8] The study area was divided into four zones: 1) non- wooded, 2) wooded canopy less than 60%, 3) wooded canopy more than 60%, and 4) building. The DEM was verified based on 40 control points and the RMSE values are 0.12 m, 0.27 m, 0.22 m, and 0.14 m for zone 1, zone 2, zone 3, and zone 4 respectively. Another research used the minimum height values obtained from the last returns of airborne LiDAR data to generate DEM.[11] The DEM was compared with 17 ground control points and the resulting RMSE values are 0.17 m and 3.99 m for short vegetation and deciduous on steeper slopes respectively. Next, various slopes and reported the RMSE errors for each five (5) slope classes as follows; 0.60 m (0-2°), 0.65 m (2-4°), 0.88 m (4-6°), 0.93 m(6-8°), 0.89 m (8-10°).[12] Slope has a significant effect on LiDAR accuracy and mean RMSE value for slopes greater than 10 degree are roughly twice than those for slopes lower than 10 degree.[13] The RMSE value for area with 25 degree of slope gradient will be twice compare to flat area.[14] For understanding purpose, Figure 1 can be used to explain the effect of slope in introducing the errors. We see that even though sample (a) is from a tree such as tree crown, the ground slope means that return (b) (ground) is at a higher altitude, and so return (a) might be identified as a ground point during filtering of these points.[15] Some of the filtering algorithm confusing in determining the ground point when the slope is high.

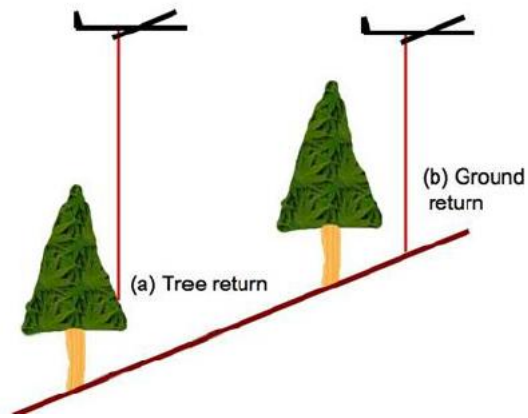


Figure 1 Slope effects towards the accuracy of LiDAR data.[15]

According to the Figure 2, although there are no elevation errors in observation, the horizontal error may introduce "apparent" error in the elevation value from a user's perspective.[14] They also suggest that any point with 100 cm horizontal error on a 10° slope can be up to 18 cm of elevation error.

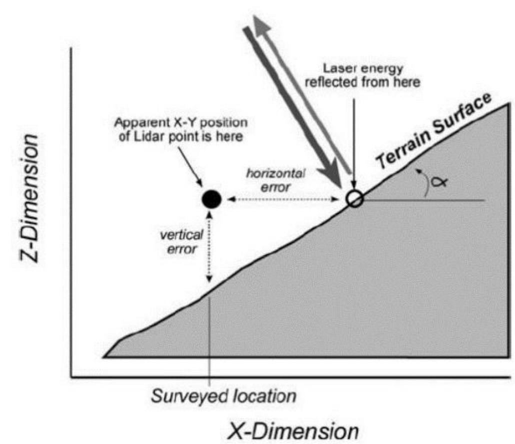


Figure 2 Illustration for the effects of terrain slope on observable elevation error[14]

The objective of this study is to investigate the specific influence of geographic environment factor on the accuracy of a LiDAR data such as slope gradient and canopy density. This information will provide a great understanding on how much both factors contribute to the total error of LiDAR data and the right direction to improve DTM generation especially through point cloud classification process.

2.0 MATERIAL AND METHODS

2.1 Description of the Data and Study Area

The study area is located in the south-west of Bentong District, State of Pahang, Malaysia (see Figure 3). The total study area is about 400 m^2 and it is characterized by irregular topography with slope gradient range between 0˚ and 20˚. The study area is mainly covered by rubber trees with moderately dense understorey vegetation and mixed forest (Figure 4).

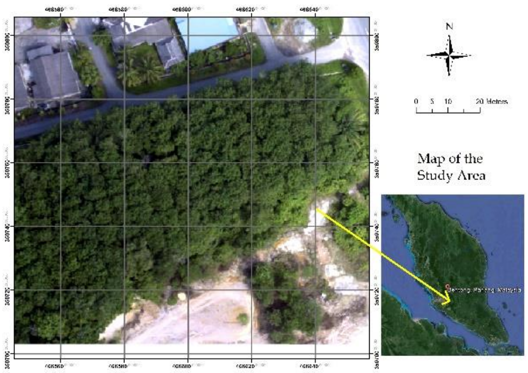
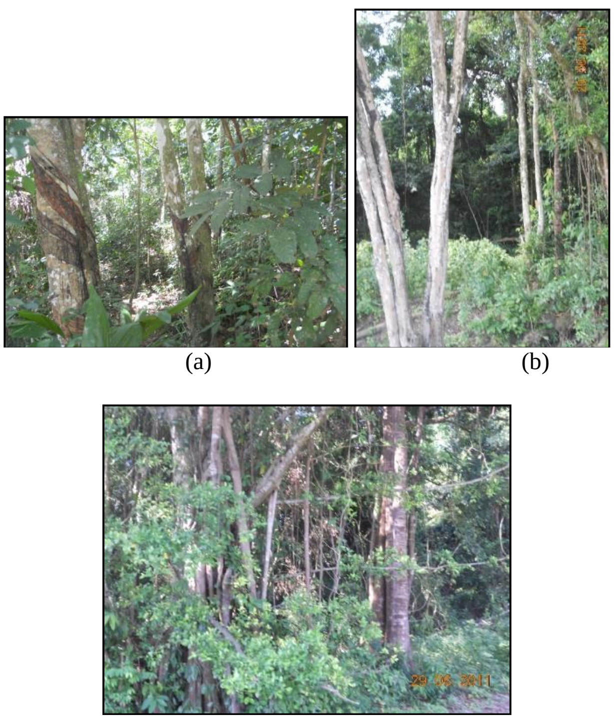


Figure 3 Study area in Bentong District, State of Pahang, Malaysia



(a) (b)

(c)

Figure 4 Example of photographs taken over study site covered by rubber trees (a) and (b) with understorey vegetation (c)

The LiDAR data were (Figure 5) collected on January 2009 using an REIGL laser scanner mounted on a British Nomad aircraft. The data were delivered in the classified LAS format of three-dimensional point cloud. The average LiDAR data sampling density across the area is about 2.2 points per meter m^2. The total area covered by the LiDAR campaign is approximately 14000 ha.

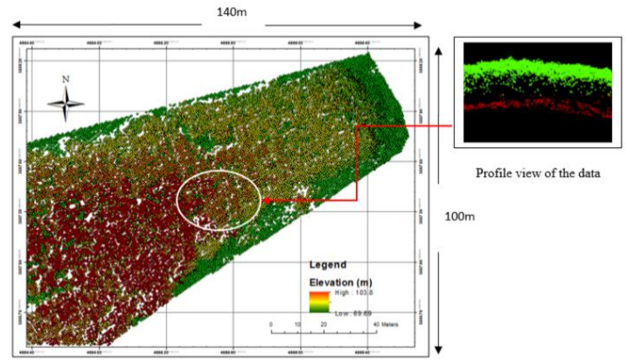


Figure 5 Raw LiDAR point clouds used for this study

In this study the ground data is used to validate the elevation value obtained from point clouds labelled as ground. Furthermore the slope map will also be generated based on a thorough and dense field collected elevation data. The ground elevation measurement ware carried out using a Nikon Total Station with an optical levelling technique. In total there is about 87 surveyed ground reference points (GRP) were collected in July and August 2012. The measurement points were distributed at a distance between 10 and 15 meter from each other.

2.2 Ground Filtering Airborne LiDAR Data

The ground filtering is performed using the adaptive TIN densification (ATIN) approach that is embedded in the TerraScan software.[16] Users are required to define the suitable value for four parameters to extract the ground points: 1) maximum building size, 2) iteration angle, 3) terrain angle, and 4) iteration distance.[17] The method collects ground points by first selecting local low points and iteratively generating triangulated surface models. Since there is no building in the chosen study site, the maximum building size is set to the 5 m, which is the minimum accepted size of building. It assumes that in any 10 by 10 m of area there will be at least one laser hit on the ground. The method develops an initial ground model from the selected low points. Triangles of this initial model are mostly below the ground and only the vertices touching the ground. Next, the routine push the model upwards by iteratively adding new laser points to it, in which each added point shapes the model closely to the ground surface. The iteration parameter determine how closed a point must be to a triangle plane, so that the point can be accepted as ground point and added to the model. Iteration angle is the maximum angle between a point, its projection on a triangle plane and the closest triangle vertex. Iteration distance is used to constraint the iteration from making a big jump when triangles are large. Terrain angle and iteration angle are set to 15° and 4° respectively and iteration distance is set to 0.5 m.

2.3 Generation of Digital Terrain Model (DTM)

In the phase of DTM generation, the ground points collected in the field are interpolated with a 1.0 m spatial resolution using Kriging interpolation method. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values.[18,19] It is based on the regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the z-values is statistically homogeneous throughout the surface. Figure 6 shows filled contours for the area produced by the Kriging interpolation method.

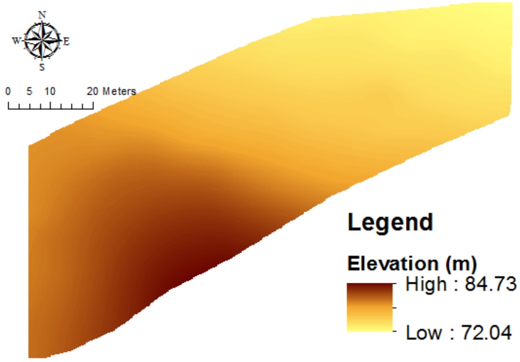


Figure 6 DTM generated from Ground Control Points (GCP)

2.4 Percentage of Canopy Density

The percentage of canopy density is calculated based on the non-ground points and the total number of points of airborne LiDAR data over a specific area determined by spatial resolution (Figure 7). The canopy density distribution is generated with 5.0 m spatial resolution by applying Equation 1.

$$Canopy\ density = \frac{Non\text{-}ground\ points}{Total\ points} \times 100 \quad (1)$$

where *canopy density* is the percentage of canopy density, *non-ground points* is the laser points classified as non-ground and *total points* in the total points in a specific area. The canopy density of the study area is classified into four classes as shown in Table 1.

Table 1 The classification of canopy classes over study area

Class	Canopy Density (%)
1	60 – 70
2	70 – 80
3	80 – 90
4	90 - 100

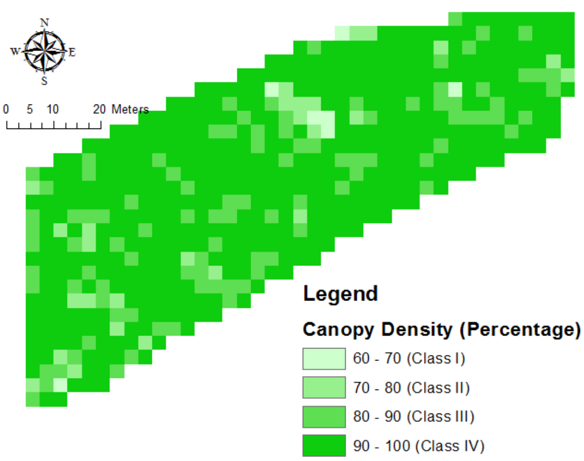


Figure 7 Canopy density map of study area

2.5 Generation of Slope Map

The slope map is generated using DTM of field collected data (Figure 8). The slope map is classified into four slope gradient classes i.e. class-1 (0-5°), class-2 (5-10°), class-3 (10-15°) and class-4 (15-20°) as shown in Table 2.

Table 2 The classification of slope classes over study area

Class	Slope range (Degrees)
1	0 - 5
2	5 – 10
3	10 – 15
4	15 - 20

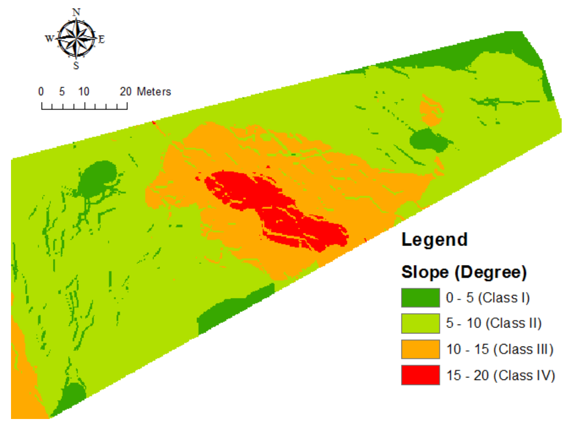


Figure 8 Slope map of study area generated from Ground Control Points (GCP)

2.6 Accuracy assessment of LiDAR derived ground points

The accuracy assessment step is carried out by comparing the elevation values obtained from the points clouds classified as ground with the DTM generated using field collected elevation data. The comparison will be based on the value of Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Mean Bias Error (MBE) presented in Equation 2 to Equation 4.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z_{LiDAR_i} - Z_{DTM_i})^2}{n}} \quad (2)$$

$$MAE = \frac{\sum_{i=1}^{n}|Z_{LiDAR_i} - Z_{DTM_i}|}{n} \quad (3)$$

$$MBE = \frac{\sum_{i=1}^{n}(Z_{LiDAR_i} - Z_{DTM_i})}{n} \quad (4)$$

where n is the number of samples, Z_{LiDAR} is the terrain elevation obtained from the ground point clouds, Z_{DTM} is terrain elevation value obtained from the DTM (or interpolated field collected elevation measurements).

3.0 RESULTS AND DISCUSSION

3.1 The Effect of Terrain Slope on Airborne LiDAR Elevation

Previous study have demonstrated that the accuracy of derived DTM to be greater in areas of steeper slopes when using modeled statistical method.[12,20,21,22] In our study RMSE value indicated the accuracy of point clouds elevation generally increased as slope gradient increased. Table 3 shows the result obtained from this study while Figure 9, 10, and 11 shows the graph plotting based on that result.

Table 3 The RMSE, MAE, and MBE based on slope classes

Slope Class	*RMSE (m)*	*MAE (m)*	*MBE (m)*
1	0.599	0.544	-0.0096
2	0.581	0.564	-0.0009
3	0.691	0.650	-0.0056
4	0.799	0.774	-0.0231

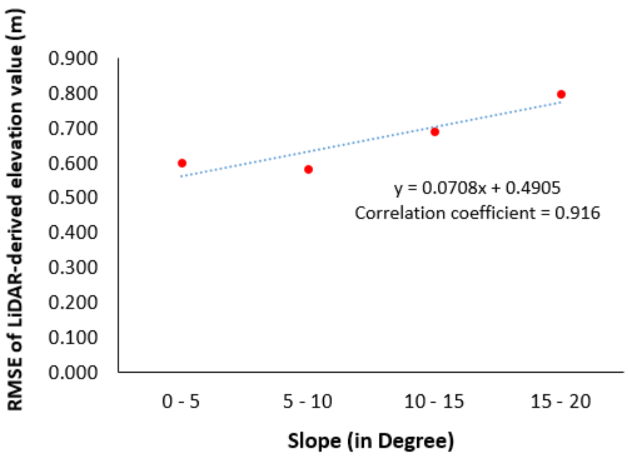


Figure 9 Relationship between RMSE of LiDAR-derived elevation and slope classes

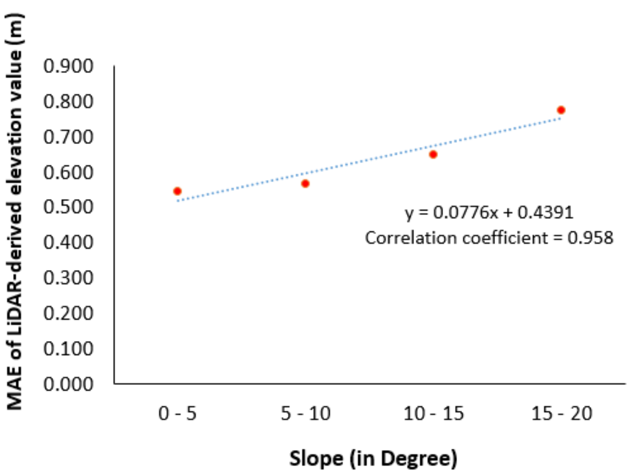


Figure 10 Relationship between MAE and slope classes

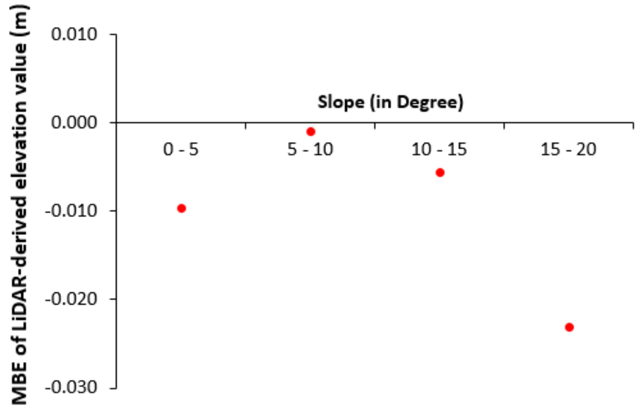


Figure 11 Value of MBE for different slope classes

The RMSE at slopes over than 10 was twice that found when slopes were less than 5. This finding is similar to several previous research where observed errors on slopes more than 20 to be twice that found on relatively flat area.[14,23]

The correlation coefficient calculated for point clouds RMS error and slope was 0.916 which can be considered as high positive correlation where it indicates as values of slope increase, values for RMSE also increase. Another research also shows slope is correlated to the elevation error of LiDAR-derived DTM by getting 0.996 and 0.981 for the value of correlation coefficient.[24]

3.2 The Effect of Canopy Density on Airborne LiDAR Elevation

In order to evaluate the effect of crown cover density on DTM accuracy, the raw LiDAR data were classified into four (4) classess of percentage (Table 1). RMSE values result are shown in Table 4 while Figure 12, 13, and 14 shows the graph plotting fro that result. The accuracy of crown cover varied with crown cover classes and the differences are statistically significant. The best result were obtained for canopy class 1 (60–70%) with RMSE errors of 0.567m. The higest error is 0.629m for the crown cover class no 3 (80-90% density).

Table 4 RMSE, MAE, and MBE based on canopy classes

Canopy Class	*RMSE (m)*	*MAE (m)*	*MBE* (m)
1	0.5675	0.563	-0.0299
2	0.5998	0.594	-0.0063
3	0.6292	0.610	-0.0016
4	0.6009	0.566	-0.0017

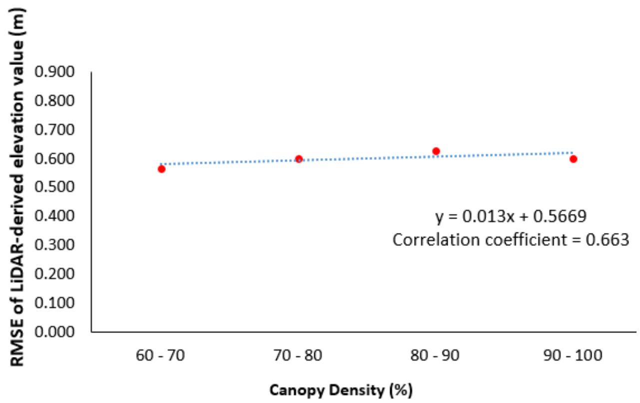


Figure 12 Relationship between RMSE and canopy density classes

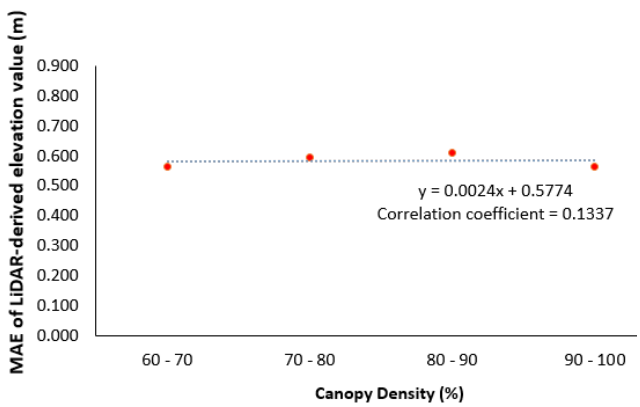


Figure 13 Relationship between MAE and canopy density classes

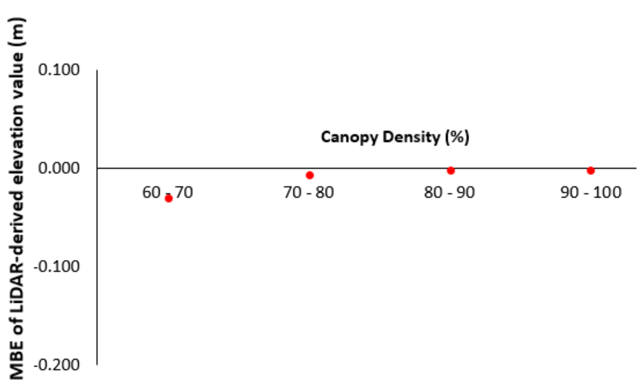


Figure 14 Value of MBE for different canopy density classes

The correlation coefficient calculated for point clouds RMS error and canopy cover density was 0.663 which can be considered as positive correlation. Generally, the RMSE values will increases by increasing the density of the canopy.

■4.0 CONCLUSION

This study demonstrates that airborne LiDAR data with a considerably low point density can be used to generate DTM over steep area covered with moderately dense vegetation in Malaysia. In this investigation, the overall RMSE of point clouds elevation is 0.611 m. Slope and canopy have influence on the point cloud elevation, which means the higher the slope with dense canopy cover the high error of point clouds obtained. This can be seen from the result where the RMSE is higher by increasing the slope and across the high dense of canopy density. Slope also can be consider as more influence factor on the error in point clouds elevation. This has been proven by comparing the correlation coefficient for both of the factor where slope is highly correlated in introducing the error to the point clouds compare to canopy. However, this level of accuracy more adequate for initial planning activities such as identifying new electrical tower station, potential area for a new highway and to find a best spot for telecommunication station. Based on this study, the result obtained can be used in improving the ground filtering process.

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