Specular and diffuse object extraction from a LiDAR derived Digital Surface Model (DSM)

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Abstract. This paper intents to investigate the indifferent behaviour quantitatively of target objects of interest due to specular and diffuse reflectivity based on generated LiDAR DSM of the study site in Ampang, Kuala Lumpur. The LiDAR data to be used was initially checked for its reliability and accuracy. The point cloud LiDAR data was converted to raster to allow grid analysis of the next process of generating the DSM and DTM. Filtering and masking were made removing the features of interest (i.e. building and tree) and other unwanted above surface features. A normalised DSM and object segmentation approach were conducted on the trees and buildings separately. Error assessment and findings attained were highlighted and documented. The result of LiDAR verification certified that the data is reliable and useable. The RMSE obtained is within the tolerance value of horizontal and vertical accuracy (x,y,z) i.e. 0.159m, 0.211m 0.091m respectively. Building extraction inclusive of roof top based on slope and contour analysis undertaken indicate the capability of the approach while single tree extraction through aspect analysis appears to preserve the accuracy of the extraction accordingly. The paper has evaluated the suitable methods of extracting non-ground features and the effective segmentation of the LiDAR data.

1. Introduction

Over decades, LiDAR data is gradually becoming an important way to derive 3-D models [1]. LiDAR instruments used in 2012 were capable rapidly measure surface at rates greater than 300, 000 pulses per second [2]. The resulting product is a densely spaced network of highly accurate geo-referenced elevation points with respect to global geocentric system, often called a point cloud that can be used to generate 3-D representations of the Earth's surface and its features. The processing of 3-D LiDAR data is developing prominently as more advanced LiDAR sensors hit the market [3]. During data capturing, LiDAR beam hit the irregular surface and reflect back usually in two mechanisms; diffuse and specular. Both components are very useful in 3-D modelling especially for building and tree. Many approached had been published on 3-D modeling for building and tree's canopy using LiDAR data for instance; Demir *et al* [4], Aluir and Galvanin [5], Peter *et al* [6], Cheng *et al* [7] and Zhou *et al* [8]. From LiDAR data, user can detect and extract desired features for 3-D modeling purposes. More specifically, intensity and height information from LiDAR can be used with texture and region boundary information from imagery to improve detection accuracy [9]. This study intents to capitalize on the highly accurate LiDAR data through the generation of the DSM. Then objects (i.e. buildings and trees) behaving in specular and diffuse manner were extracted accordingly and quantitatively based upon segmentation and surface-based analysis.
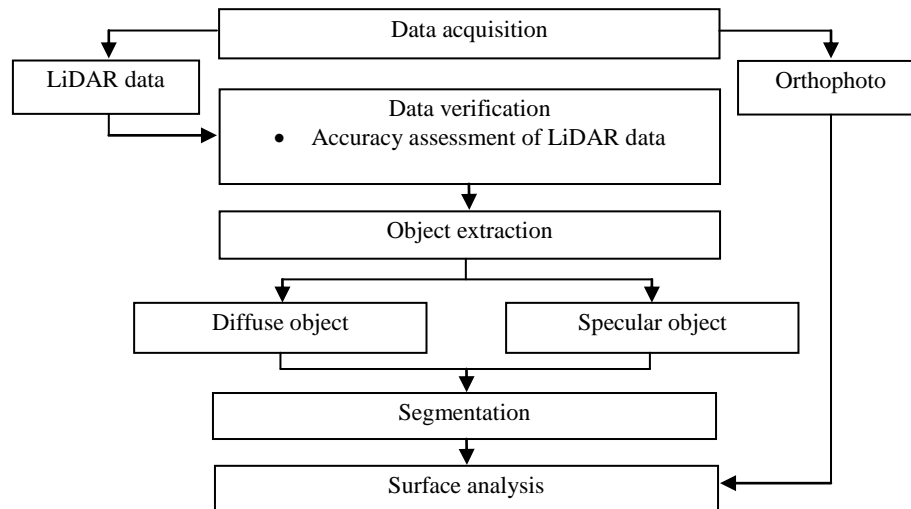
2. Materials and methods

The procedures in Figure 1 were followed accordingly in order to achieve the desired objectives of the study. The processes are data acquisition, data verification, specular and diffuse object extraction

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from DSM LiDAR data, object segmentation and surface analysis. The acquired LiDAR data were in form of DTM, DSM and ortho-photo. The study site that encompassed these datasets includes the area of Ampang in Wilayah Persekutuan Kuala Lumpur. This area is located geographically at 3° 13' 25" North, 101° 43' 49" East. The study area covers only a size of 1 km² and a major part of it covers buildings and trees which is in accordance with the emphasis of study.

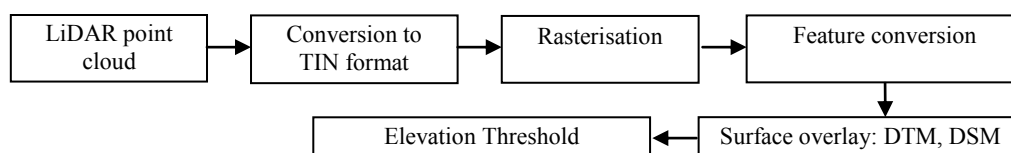**Figure 1.** Flowchart of the methodology.

2.1. Data verification

In order to verify the acquired LiDAR data, an accuracy assessment was conducted. The contemporary method of assessing Airborne LiDAR quality data is to leverage a minimum of 25 isolated ground control points (GCP) at strategically important locations throughout a project [10]. In this study, 27 ground truth observation points have been chosen to verify whether the LiDAR data used is reliable and accurate. The horizontal and elevation values of the checkpoints are compared to the LiDAR data horizontal and elevation values. The differences are used to calculate the Root Mean Square Error (RMSE) of the data. RMSE is the square root of the average of the squared elevation differences between data set elevation values and checkpoint elevation values for identical points. Horizontal accuracy required usually up to 20-30cm RMSE while high accuracy claimed for vertical (elevation) accuracy is 10-15 cm RMSE [11].
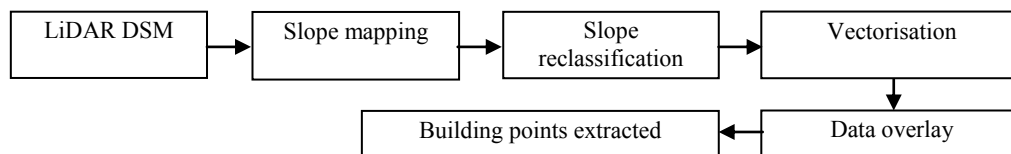
$$RMSE = \pm \sqrt{\frac{\sum (LiDAR_z - Checkpoint_z)^2}{n}}$$

2.2. Extraction of diffuse and specular objects

The LiDAR data that has been acquired were generated into surface models comprising of Digital Terrain Model (DTM) and Digital Surface Model (DSM). These generated data products were converted to TIN for raster conversion. From raster form, these data were then converted to features in polygon form to applying the threshold to the difference elevation. From the difference in elevation made, DTM points were removed while points of non-ground feature were extracted. After that, LiDAR points of non-ground features were used in the object segmentation stage to distinguish diffuse (trees) object and specular (building) object. Figure 2 and Figure 3 illustrated the process of diffuse and specular object extraction utilized within the ArcGIS application tools.

Figure 2. Workflow of data processing for diffuse and specular object extraction.

| LiDAR DSM | → | Slope mapping | → | Slope reclassification | → | Vectorisation |

| Building points extracted | ← | Data overlay |

Figure 3. Workflow of data processing for building points extraction.

2.3. Object Segmentation

Segmentation is a critical pre-processing step in a number of autonomous perception tasks [12]. It was for instance shown by Douillard *et al* [12], that prior segmentation improves 3-D data such as classification, dynamic object tracking and path planning. The first step of boundary extraction was performing image segmentation towards normalised DSM raster imagery based on the elevation threshold to eliminate the unwanted features [13]. In order to performing segmentation process, slope analysis was conducted to the DSM to analyse the slope changes so that the different features could be separated. The rate of change (delta) of the surface in the horizontal (dz/dx) and vertical (dz/dy) directions from the centre cell determines the slope [14]. The basic algorithm used to calculate the slope is equation (1). However, slope is commonly measured in degrees, which uses the algorithm (2):

$$\text{slope\_radians} = \text{ATAN} (\sqrt{ ([dz/dx]^2 + [dz/dy]^2) }) \tag{1}$$
$$\text{slope\_degrees} = \text{ATAN} (\sqrt{ ([dz/dx]^2 + [dz/dy]^2) }) * 57.29578 \tag{2}$$

Next, an aspect analysis was done using the aspect algorithm. Taking the rate of change in both x and y direction for cell 'e', aspect is calculated using equation (3):

$$\text{aspect} = 57.29578 * \text{atan2} ([dz/dy], -[dz/dx]) \tag{3}$$

Aspect identifies the steepest downslope direction from each cell to its neighbours. It can be thought of as slope direction or the compass direction a hill faces [14]. The value of each cell in an aspect dataset indicates the direction the cell's slope faces and flat areas having no down slope direction. The aspect value is then converted to compass direction values (0–360 degrees), according to the following rule [14]:

> if aspect < 0, cell = 90.0 - aspect
> else if aspect > 90.0, cell = 360.0 - aspect + 90.0
> else, cell = 90.0 – aspect

3. Results and analysis

The results and analysis of this study is arranged according to the processes described in the preceding sections; beginning with justifying the reliability of LiDAR data and ending with the accuracy assessment of the extracted process.
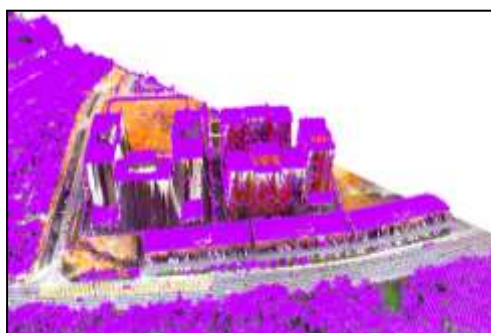
3.1. Data verification

Altogether 27 checkpoints survey were conducted by GPS point positioning throughout the project area. The horizontal and elevation values of the checkpoints were compared against the LiDAR data values. The differences are the residuals that would determine the size of the RMSE to be computed latter. The result from an accuracy assessment of LiDAR data is shown in Table 1. Horizontal accuracy required usually up to 20-30cm RMSE while high accuracy claimed for vertical (elevation) accuracy is 10-15 cm RMSE [11]. The LiDAR data obtained for this study has RMSE less than the specified LiDAR accuracy and thus these data meets accuracy specification. So, as far as these LiDAR data are concerned, the data can be used for any purposes and for appropriate analysis.

Table 1. The result of RMSE for DSM and DTM LiDAR data used in the study.
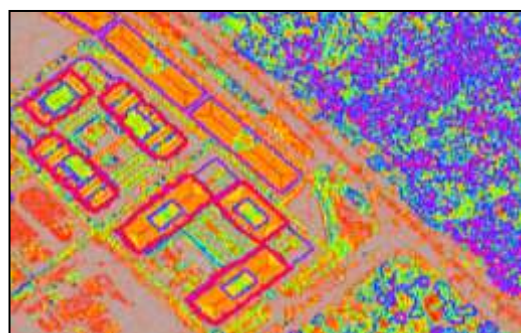
RMSE ($\pm$ m)	Easting (m)	Northing (m)	Elevation (m)
DSM and DTM	$\pm$ 0.159	$\pm$ 0.211	$\pm$ 0.091

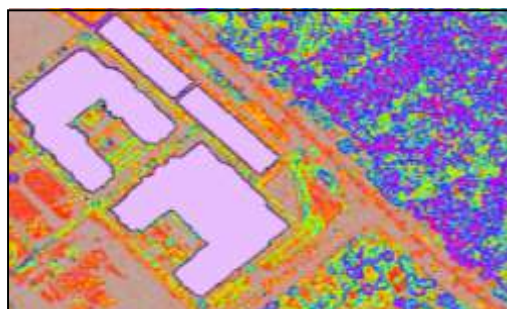*3.2. Diffuse and specular object extraction*

Specular object extraction is referring to the building extraction of LiDAR point clouds while diffuse object is trees. Figure 4a shows the non-ground, i.e. the building based on the techniques mentioned earlier whilst Figure 4b depicts the slope map of non-ground. Notice the capability of the approached utilized in identifying and distinguishing the building from other features. In Figure 4a, DSM was removed the DTM that call a generation of normalised DSM for non-ground extraction. Once the non-ground was extracted, an evaluation of building region and tree was made. Building region and tree were separated using slope analysis. The slope function is run on an elevation dataset. Figure 4b illustrates the steeper slopes are shaded red on the output slope raster. It used to identify sharp changes in value especially for building detection while boundary of buildings was determined through normalised DSM and slope algorithm as stated in Figure 5a. The LiDAR point cloud fall on the boundary were then extracted to separate from trees and other features as shown perceptively in 3-D viewing in Figure 5b.
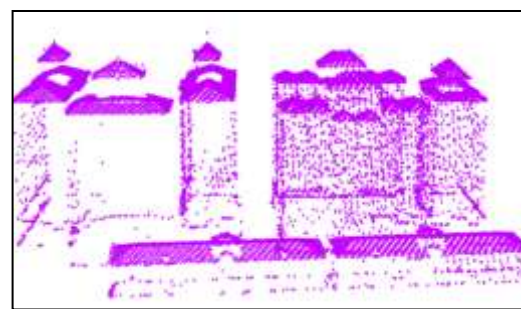

Figure 4a. Non-ground extraction.

Figure 4b. Slope map of normalised DSM.

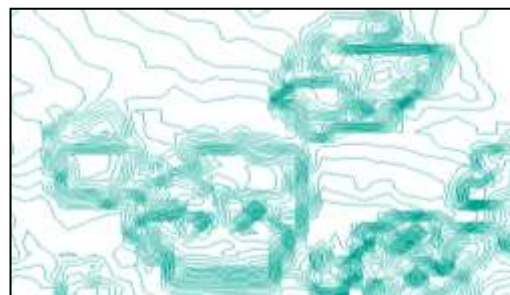**Figure 5a.** Building boundary (plan view).

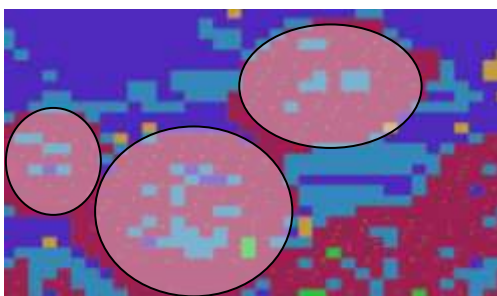

Figure 5b. Building extraction (3-D view).

Once the specular objects (buildings) were extracted, 3-D city mapping and 3-D building reconstruction could be done in the best and accurate visual. The extraction of single tree was defined as diffuse object extraction where slope analysis, contour and aspect map were generated from LiDAR point clouds data. LiDAR point cloud of object tree was extracted based on slope, contour and aspect analysis. Slope raster in Figure 6a illustrates the steeper slopes in red colour. The result of 1m contour interval which shows that single tree has around shape of contour as shown in Figure 6b. Figure 7a shows the tree being the diffuse object that was extracted based upon the approach specified. A normalised DSM depicted region that could be distinguished as being tree. This region was segmented as shown in Figure 7b.
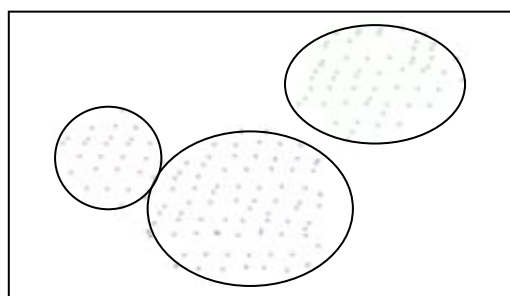
Figure 6a. Slope raster illustrates the steeper slopes that shaded red were determined as trees.

Figure 6b. Contour interval at 1m of LiDAR point clouds.

Figure 7a. In aspect map, LiDAR point clouds of tree fall in the red area.

Figure 7b. Single tree extraction.

4. Conclusion

This study has described the capability and potential of LiDAR data in feature extraction. Features such as building and tree, which are normally specular and diffuse, tend to act differently on LiDAR pulses. Using these LiDAR initial pulses and the generated LiDAR DSM and DEM/DTM derived from it could be giving an alternative and better approach of extracting these features. The characteristics of building and tree features due to their specular and diffuse behaviour make the extraction a bit complex. This study however, had been able to utilize the segmentation approach together with surface analysis especially slope and aspect analysis to extract the building and tree features accordingly using the LiDAR DSM and DTM, which were initially verified and proven of its reliability.

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