

Integrating airborne LiDAR dataset and photographic images towards the construction of 3D building model

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Abstract. A 3D building model of man-made objects is an important tool for various applications such as urban planning, flood mapping and telecommunication. The reconstruction of 3D building models remains difficult. No universal algorithms exist that can extract all objects in an image successfully. At present, advances in remote sensing such as airborne LiDAR (Light Detection and Ranging) technology have changed the conventional method of topographic mapping and increased the interest of these valued datasets towards 3D building model construction. Airborne LiDAR has proven accordingly that it can provide three dimensional (3D) information of the Earth surface with high accuracy. In this study, with the availability of open source software such as Sketch Up, LiDAR datasets and photographic images could be integrated towards the construction of a 3D building model. In order to realize the work an area comprising residential areas situated at Putrajaya in the Klang Valley region, Malaysia, covering an area of two square kilometer was chosen. The accuracy of the derived 3D building model is assessed quantitatively. It is found that the difference between the vertical height (z) of the 3D building models derived from LiDAR dataset and ground survey is approximately ± 0.09 centimeter (cm). For the horizontal component (RMSE_{xy}), the accuracy estimates derived for the 3D building models were ± 0.31 m. The result also shows that the qualitative assessment of the 3D building models constructed seems feasible for the depiction in the standard of LOD 3 (Level of details).

1. Introduction

3D building models have long been useful and required in a variety of applications and act as an important in geographic information systems, for urban planning applications, virtual tourism, analysis of urban climate and traffic planning due to its capabilities in showing real-world features and phenomena in three dimensions. 3D is a new level of spatial data in a “digital world” [1].

Currently, traditional method of ground survey to gather building information towards the creation of 3D models in urban areas requires enormous time; is very costly and labor intensive. As an alternative to deriving building parameters manually, airborne LiDAR datasets are made available and the fusion of these datasets with aerial image towards 3D building construction seems feasible.

LiDAR technology enables large area to be surveyed with three dimension (3D) or (x, y, z) information for the construction of Digital Surface Model (DSM) with high accuracy in a short delivery time, with vertical accuracies reported of less than 15 centimetres [2]. LiDAR integrates

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three matured technologies: a rugged compact laser scanner, a highly accurate Inertial Navigation System (INS) and the Global Positioning System (GPS) [3] as depicted in Figure 1.

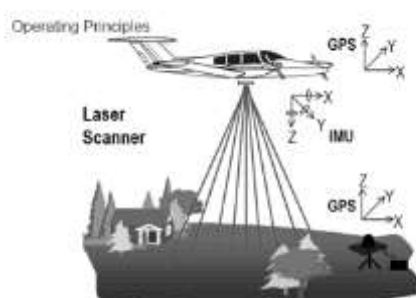


Figure 1. Airborne LiDAR [15].

Integrating these subsystems into a single instrument, a 3D data point cloud is collected. It is possible to rapidly produce an accurate DSM of the terrain beneath the flight path of the aircraft with samples the surface of an urban site in 3 dimensional [4]. Certainly, this technology has become an accurate, cost-effective for collecting topographic elevation data LiDAR DSM for large areas which will eventually benefits a diversity of applications namely, forest [5], architecture, town planners, telecommunications and city councils with high accuracy in a short delivery time [6].

2. Study area and data

The study area chosen for the study is within the Klang valley situated at Putrajaya, Malaysia. The choices of study area are based on the following criteria; the area exhibits a variation in topography (height) and experiencing rapid development especially for residential areas.

The LiDAR data tile for the study area consists of 2 x 1 km was extracted from the original dataset with a grid spacing of less than 1m interval. The LiDAR datasets were acquired using British Nomad 2 aircraft with first class infrared laser sensor (Optech System) in 2010. The LiDAR DSM and photographic image are shown in Figure 2 and Figure 3 respectively.



Figure 2. LiDAR DSM .

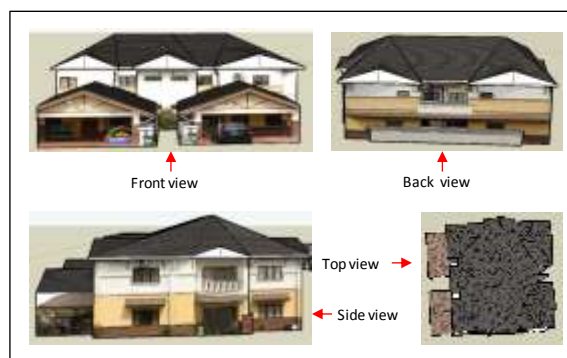


Figure 3. Photographic image.

2.1. Control points and field vector line

Figure 4 shows control points and vector lines were established within the study area which acts as reference points for the quantitative assessment. Forty two (42) well-defined points (control points) were observed using Global Positioning System (GPS) and tachometric surveying method in the determination of the control points within the survey area (Putrajaya). For the horizontal accuracy (RMSE_{xy}) assessment, the different at known position (x, y) for the building edges on LiDAR DSM are investigated. Forty (40) points was established to represent vector line is identified to compute RMSE_{xy}.

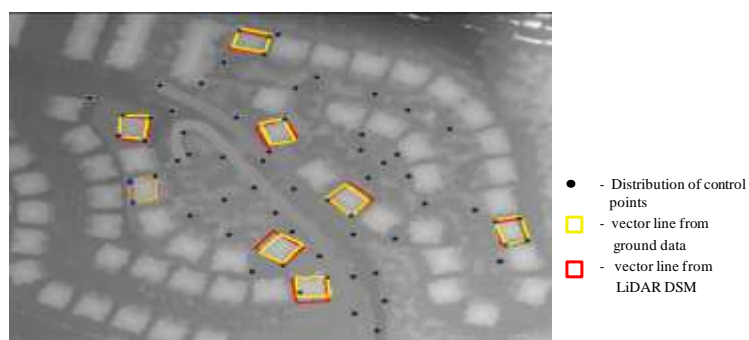


Figure 4. The location of control points and vector lines on Light Detection And Ranging DSM.

3. Methodology

The step taken to accomplish the task in the reconstruction of 3D building models is shown in Figure 5. The result also shows the 3D building models from standard LOD 3 (Level of details)[7].

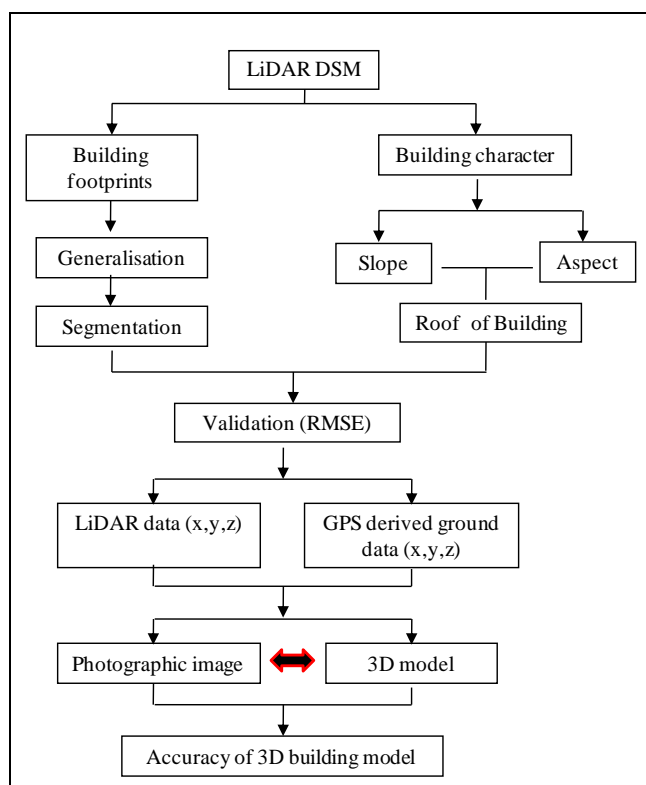


Figure 5. Workflow for reconstruction of 3D building models.

Referring to Figure 5, Airborne LiDAR point clouds were firstly converted into a DSM to retrieve the x, y and z informations are the first step of the process. In this study, three (3) processes were carried out to construct of 3D building models namely extraction of building footprints, generalization and segmentation. Hence, with derived slope and aspect from Airborne LiDAR DSM represent a good way for the detection of building roof points. The generalisation proses of building footprint are shown in Figure 6 below.

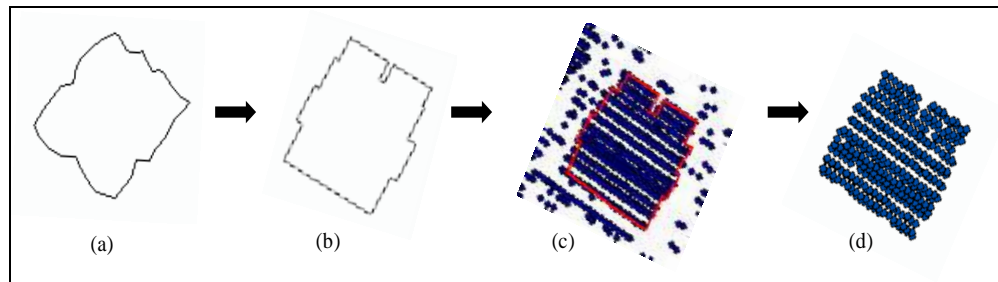


Figure 6. (a) Original building footprint, (b) generalized building, (c) clipped and (d) segmented point cloud.

The Douglas Pucker algorithm [8] has been applied to reduce line being performed by removing intermediate vertices in generalization process (Figure 6(a)). The removal of intermediate vertices was done by selecting the minimum subsequence of the original vertices and using the outer vertices to create the generalized line. The generalized building footprints were necessary for application of the segmented point cloud (Figure 6(b)). If a segment is not known to be part of a building it can describe other objects like trees or cars [9]. The point cloud clipped (Figure 6(c)) from the generalized building footprint, were then segmented and converted to ASCII format. In the segmentation process the points reflected by each of the faces are grouped into a segment which identified by a number or a colour, (Figure 6(d)).

The generalization and segmentation of building footprints combined with the slope and aspect of building classification in order to produce 3D models [10]. In general, slope is the angle between a 3D triangle formed by three random points on the surface of a 3D model and the horizontal plane while aspect is the downslope direction of the triangle between three random points on the surface of a 3D model. As a result, the roofs of a building can be detected and then will be calculated from LIDAR points falling onto it. Meanwhile, LiDAR DSM (x,y,z) were used to construct the 3D building models, the height values with ground data (tacheometric) are being calculated.

The output of the created is a LoD 0 3D model with valid accuracies (Table 1). It is because the 3D data in GIS contain x, y and z [11]. This results in a LoD 1 model by implementing detection of footprint and reconstruction of a roof shape in LOD 2. Unlike natural landscape features, buildings created by humans are relatively regular. Moreover, man-made structures are better represented in 3D of vector models [1]. 3D geometric shapes are normally constructed by existing GIS, AutoCAD, and photogrammetry methods. In this study, 3D geometric shapes of buildings are edited and extracted from SketchUp with the selected location via geo-location function of SketchUp interface where the building models is obtained based on height and width of LiDAR DSM. Afterwards, these 3D building models exported as COLLADA files [12]. Finally, the COLLADA files converted in ArcGIS 10. Figure 7 shows the reconstruction of 3D buildings using SketchUp software [13] in LOD 3 using photographic image.

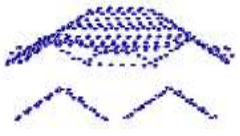







Description of information	LiDAR DATASET (x,y,z) (3D view)	Construction of 3D model (Sketch Up)	Photographic image
Front			
Back			
Side			
Top			

Figure 7. Reconstruction of 3D modeling integrated with photographic image and Light Detection And Ranging dataset.

3D buildings constructed in this study were assessed quantitatively. Quantitative assessment includes the computation of Root Mean Square Errors (RMSE) of well define measurements such as building heights, dimensions and the displacement in the horizontal component with respect to known ground surveyed points [2]. The quantitative assessment for the vertical component (RMSE_z) is computed based on Equation 1 [14].

$$\text{RMSE}_Z = \pm \sqrt{\sum_{i=1}^{i=n} \frac{(Z_i - Z_i^*)^2}{n}} \quad (1)$$

where n is the number of check points; Z_i^* is the is height derived from LiDAR DSM at control point i and Z_i is the control point height at the same position on the ground. For the horizontal components, Equation 2 will be utilized for distinct or well defined points on the LiDAR DSM and control point such as representing the building edges.

$$\text{RMSE}_{(x,y)} = \pm \sqrt{\sum_{i=1}^{i=n} \left(\frac{(X_i - X_i^*)^2 + (Y_i - Y_i^*)^2}{n} \right)} \quad (2)$$

where n is the number of check points; X_i and Y_i are the coordinates of the control points i derived from LiDAR DSM, X_i^* and, Y_i^* are the coordinates of control points at the same position on the ground.

4. Results and discussion

The result for the vertical and horizontal component (RMSE_z and RMSE_{xy}) for the evaluated dataset is shown in Table 1.

Table 1. RMSE_z and RMSE_{xy} for the LiDAR datasets with ground data.

	RMSEz	RMSExy
LiDAR data (\pm m)	0.09	0.31

Referring to Table 1, it is shown that the accuracy for the LiDAR dataset in the vertical component (RMSEz) is ± 0.09 m and it is within the acceptable limit stated by the manufacturer (10-30 cm) and verifies the findings reported by various researchers [4,15]. For the horizontal component (RMSExy), the accuracy estimates derived from the dataset is ± 0.31 m. Referring to the accuracy stated by the manufacturer, LiDAR dataset seems to be sufficient in supporting the construction of 3D model, both in the horizontal and vertical specifications stated. However, it should be pointed out that, LiDAR is designed for the creation of accurate digital surface model (height of ground and above-surface features), the image of features on the LiDAR DSM are not distinct to certain extent throughout the dataset.

5. Conclusion

The development of 3D city model has raised great attention in term of data sources, method to generate the 3D building model. The data source and 3D model generation are the current issues on 3D city model development. Understanding the accuracy of the dataset in used for any applications is crucial, as errors propagate through processes. In this research, the step taken towards for construction of 3D building models using Airborne LiDAR datasets are shown. LiDAR data have become the major sources for high accuracy 3D (dimensional) digital models representations. LiDAR technology has been accepted in most of the mega engineering projects in Malaysia as the technology could supply accurate Digital Surface Model in short delivery time. Compared to traditional methods, LiDAR seems to be an effective way for terrain data collection, especially for wide area with reasonable cost and time consuming [10].

The integration of Airborne LiDAR and photographic image is achieved into LoD 3 in 3D building model development using of Sketch Up software is contributes in terms of updating the building model in 3D building model data. Meanwhile, in term of accuracy assessment, the vertical accuracy of the derived models (LiDAR data with ground data) is ± 0.09 m while the accuracy for the horizontal component is ± 0.31 m. It is clearly shown that, the accuracy of the LiDAR dataset is within the centimetre range as specified by the manufacturer [2,4], which suitable for planning works towards creation of 3D city models.

The prototype of 3D building model developed from integration of Airborne LiDAR technology and photographic image can be used for mapping purpose and it has a potential to moves forward from 2D mapping into 3D mapping. Airborne LiDAR technology is an active remote sensing and has become an effective solution in acquiring dense and accurate 3D data of the earth topography [16].

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