Unveiling topographical changes using LiDAR mapping capability: case study of Belaga in Sarawak, East-Malaysia

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Abstract. The use of Light Detection and Ranging (LiDAR) remote sensing technology to scan and map landscapes has proven to be one of the most popular techniques to accurately map topography. Thus, LiDAR technology is the ultimate method of unveiling the surface feature under dense vegetation, and, this paper intends to emphasize the diverse techniques that can be utilized to elucidate topographical changes over the study area, using multi-temporal airborne full waveform LiDAR datasets collected in 2012 and 2014. Full waveform LiDAR data offers access to an almost unlimited number of returns per shot, which enables the user to explore in detail topographical changes, such as vegetation growth measurement. The study also found out topography changes at the study area due to earthwork activities contributing to soil consolidation, soil erosion and runoff, requiring cautious monitoring. The implications of this study not only concurs with numerous investigations undertaken by prominent researchers to improve decision making, but also corroborates once again that investigations employing multi-temporal LiDAR data to unveil topography changes in vegetated terrains, produce more detailed and accurate results than most other remote sensing data.

1. Introduction
The relentless reshaping and changing of the earth surface that results from nature and human activities triggers topographic variations, causing hazard, environment and ecological problems, land and farming degradation, etc. Several studies have emphasized the suitability of remote sensing techniques to map topography [1] [2] [3] [4]. However, this earth surface mapping using remote sensing techniques has not always yielded the expected outcome; either some features were difficult to detect [5], or low spatial resolution was obstructing the detection and identification of features reliably [6]. In densely vegetated terrain; the mapping via spectral signatures of the surface features below the vegetation may be unreliable [7]. In particular, the effective mapping of features such as hills, creeks, valley and rivers may be impossible because exposure of the surface beneath the vegetation canopy may be limited [7] [8] [9].

Unlike other remote sensing techniques, LiDAR remote sensing technology is unique in the field of topography change mapping, as it is able to measure features under vegetation, by scanning the target with laser pulses and recording backscattered information highly effectively and accurately [10][11][12].

In this study, the change detection was measured using LiDAR datasets collected in 2012 & 2014 to produce meaningful outputs depicting the topographic changes in Belaga. However, the mapping of topography under dense vegetation still remains a daunting task, because of the dense forest canopy. Figure 1 and Figure 2 below show the overlap areas of two projects in Belaga, Sarawak collected in 2012 and 2014. This study area mostly comprises of dense jungle.
2. Materials and methodology

2.1. Datasets
The two sets of spatial data used in this study are airborne full waveform LiDAR and imagery data captured on 12th February 2012 and 8th September 2014. According to the American Society of Remote Sensing Society (ASPRS) [14], when using LiDAR-derived elevation data, it is essential to specify the accuracy expected for all final products being delivered. Vertical accuracy is assessed in the z dimension only and different methods are used for non-vegetated and vegetated terrain [15]. LiDAR data vertical accuracy should always be reviewed in terms of the potential harm that could be done to the public health and safety [14]. Examples for ten common vertical accuracy classes and other quality criteria for digital elevation data can be obtained from ASPRS's Positional Accuracy Standards for Digital Geospatial Data [15].
To determine the accuracy of different datasets, the elevation points of both datasets were compared with established control points. The standard deviation, RMSE, and accuracy at 95% confidence level are computed based on equation 1, 2, and 3 respectively. Table 1 lists the properties of the data used in this study.

\[
\text{Standard Deviation} = \sqrt{\frac{\sum_{i=1}^{n}(z_i - \bar{z})^2}{n-1}}
\]

(1)

\[
\text{RMSE}_z = \frac{\sum_{i=1}^{n}(z_{i\text{sur}} - \bar{z}_{LIDAR})^2}{n}
\]

(2)

\[
\text{Vertical Accuracy at 95\% Confidence Level} = \text{RMSE}_z \times 1.96
\]

(3)

where \(z_i\) is the \(i^{th}\) error in the specified direction, \(\bar{z}\) is the mean error in the specified direction, \(n\) is the number of checkpoints tested and \(i\) is an integer ranging from 1 to \(n\).

Table 1. Properties of the LiDAR and imagery datasets.

| Properties                              | 2012                  | 2014                  |
|----------------------------------------|-----------------------|-----------------------|
| Scanner Type                           | Riegl LMS-Q560        | Riegl LMS-Q560        |
| Forward Speed                          | 100 kph / 62 mph      | 100 kph / 62 mph      |
| Flying Height Above Ground Level (AGL) | 600 m                 | 600 m                 |
| Max AGL Setting                        | 850 m                 | 850 m                 |
| Scanning Angle                         | 52.9°                 | 45°                   |
| Swath Width                            | 597 m                 | 349 m                 |
| Vertical Accuracy at 95% Confidence Level | 0.096 m              | 0.057 m              |
| Average All Point Spacing              | 0.2 m                 | 0.3 m                 |
| All Point Density                      | 11 points/m²          | 8 points/m²           |
| Average Ground Point Spacing           | 1.5 m                 | 1.8 m                 |
| Ground Point Density                   | 0.4 points/m²         | 0.2 points/m²         |
| Imagery Raw Pixel Size                 | 0.1 m                 | 0.1 m                 |

2.2. Methodology

The multi-temporal airborne full waveform LiDAR data was captured using a Riegl LMS-Q560 scanner. The data was acquired in two different years on 12th February 2012 and on 8th September 2014 in Belaga, Sarawak. The flying heights of the sensor were on average 600 m AGL, which produced a laser swath width of 349 m for 45° and 597 m for 52.9° field of view setting for laser. The flightlines were designed with a 30% overlap between adjacent flightlines for the camera.

TerraSolid and ArcGIS software were used to conduct the data processing and analysis. First, the data from the laser, IMU and GPS sensors were processed to produce a raw point cloud. LiDAR point clouds were generated using the ITRF00 datum and UTM Zone49 map projection. Then, the points were classified into ground and non-ground points [16]. This included detailed ground editing to correct the errors in the automatic classification processes to improve the ground model. Then, the ground points were used to generate a DTM. Still imagery was collected simultaneously with LiDAR data with a 60% forward overlap and 30% side overlap to ensure sufficient imagery coverage.
Orthophoto mosaics were generated using trajectory data produced from GPS and IMU data, DTM keypoints and the imagery with a 0.1 m resolution. Statistical and geostatistical analysis were performed as described next.

3. Results and analysis

3.1. Validation of LiDAR dataset
Multi-temporal LiDAR datasets were captured in 2012 and 2014 in Belaga, Sarawak. These two sets of data were processed using the ASPRS standard of vertical accuracy as mentioned in the section 2.1. The vertical accuracy of each LiDAR dataset in Table 1 shows that the data is sufficiently accurate to be used in this study. However, to ensure agreement between both datasets, and to confirm that any variation in the datasets is due to topographical changes and not attributable to data production issues, the datasets were validated using cross sections of point clouds in built-up areas. Some buildings can be considered as static structures for verification. Figure 3 shows an example for the point cloud cross sections for both datasets along a building that matched in both datasets. The point cloud of 2012 (red) and point cloud 2014 (blue) match each other in the ground areas around and on the roofs of buildings which were confirmed to be unchanged in these 2 years.

3.2 Growth measurement with multi-temporal LiDAR data

3.1.1. Canopy height model from LiDAR data. Canopy height models (CHM) derived from LiDAR data are widely recognised as an excellent tool for understanding and managing forest ecosystems. Here, a CHM was generated by subtracting the digital surface model of the first return (DSM) with the digital terrain model (DTM) of the ground points. These CHM were used to illustrate canopy changes of the selected area, which was completely heavily vegetated (figure 4). The black line indicates the cross-section profile that was used throughout this analysis. Figure 5 (a) and (b) illustrate CHMs for 2012 and 2014 respectively.

Figure 3. (a) Cross section of buildings in the study area and (b) Point cloud of the buildings and surrounding ground for 2012 in red and 2014 in blue.
Based on the CHM of both years, the areas in red show higher tree heights, while yellow areas indicate areas of grass or low-lying shrubs. Figure 5 (c) shows the cross-section profile for both CHMs, indicating increases of canopy height along the cross section line. However, decreases of canopy height were also detected along the cross section. Therefore, by analyzing the differences between both CHMs (figure 6), the areas which experienced decreases (green) and increases (yellow to red) of canopy height can be identified easily. Areas digitized in blue show a few locations with decrease in canopy height, probably due to fallen trees or parts of trees. Orthophoto images of these blue areas of both years, figure 6 (b) and (c) shows the appearance of "black holes" due to some sort of disappearance of vegetation. The areas in red show high increase in canopy probably due to neighbouring higher trees increasing their canopy sideways. This can particularly be seen with areas...
digitized in magenta. Therefore, the use of LiDAR multi-temporal data is able to provide indicative CHM changes.

![Image](a)

**Figure 6.** The changes in canopy height. (a) CHM difference, (b) Orthophoto image of 2012, (c) Orthophoto image of 2014.

3.1.2. *Individual tree height growth.* The LiDAR technology is well suited for acquisition of highly detailed forest structure information, and can provide more detailed information relating to the individual tree growth. Individual tree height and canopy diameter growth can be measured by taking cross sections of the tree point cloud profile. Randomly, five sample individual trees were identified to measure their growth as shown in figure 7.
Figure 7. Sample of individual tree. (a) Orthophoto image and (b) Point cloud.

Figure 8 shows the measurement of individual tree heights from five sample trees from the study area. The red and blue points indicate the point cloud in 2012, 2014. The height was measured from ground to the top of the tree crown for both years, using their respective point clouds. From the measurement, all five sample trees showed growth over the two years estimated to be ranging from approximately 0.61 to 1.35m. The canopy diameter of the sample trees can also be seen to have increased in the two years. It can be inferred that trees A, B, & C were faster growing than D & E within this time interval.

Figure 8. The height of each individual tree was measured from point cloud cross-sectional profile.
3.3 Comparison of area elevation changes

Figure 9 shows the respective orthophoto images and DEM for 2012 and 2014. Visual inspection of these orthophoto images and the generated DEM shows that there were significant changes in the DEM surface during these two years.

Figure 9. Study area for elevation changes, with the DEM generated from the LiDAR data. (a) Orthophoto image in 2012, (b) Orthophoto image in 2014, (c) DEM of 2012 data and (d) DEM of 2014 data.

Most of the changes are believed to be due to earthworks activities causing movement, compaction and expansion of soil. Soil erosion would be of particular concern. These earthworks activities can be analyzed by monitoring changes in the terrain. Raster data is used in this surface analysis, which is one of the more efficient methods to identify areas that have been significantly cut and filled. This analysis is based on changes in the surface elevation between 2012 and 2014 surfaces, which will identify the areas that have been affected by track construction, such that there is surface material loss, compaction, gain or expansion.

Figure 10 shows the area elevation changes, which are determined by comparing the difference between the 2012 and 2014 raster grids. The areas in blue indicate significant soil gain or expansion between 1 to 5.72 m. The areas in red and orange indicate significant soil loss or compaction between -1 to -6.07 m. The green and yellow areas show little elevation change, and cover approximately 60 percent of the study area.
3.4 LiDAR for earthwork monitoring

LiDAR technology offers highly accurate elevation data with highly detailed and clear imagery allowing for identification of features and vegetation. These are useful for monitoring an area expected to undergo elevation changes initiated by earthwork activities. The changes can be analyzed using cross sections of the point cloud and visualization of the orthophoto mosaic images, as shown in figure 11. The mosaic image figure 11 (a) shows the area underwent construction during the data acquisition in 2012; while in figure 11 (b), the road construction seems to be complete. Figure 11 (c) shows the cross section of the road using both sets of data, which clearly indicate that in two years, terrain changes have occurred. In particular, there has been excavation work to lower ground levels by approximately 3 m for the road section shown.

![Figure 10. Interpolated surfaces of area elevation changes.](image)

![Figure 11. Images of road construction (a) 2012, (b) 2014, (c) Cross section of point cloud in 2012 (green) and 2014 (white).](image)
3.5 Earthwork calculation

In most preliminary project planning and design, LiDAR derived DEM and digital imagery is necessary to identify favourable alignments, evaluate alternative routes and create final design drawings that optimize alignments and grades for the selected alternative. The elevations of the same area (figure 11) for both years can be seen in figure 12 (a) and (b). There were minor changes in the elevation between 3.5 to -3.5 m as represented in figure 12 (c).

![Figure 11](image1.png)

![Figure 12](image2.png)

**Figure 12.** Elevation changes. (a) Elevation during road construction in 2012, (b) Elevation in 2014, (c) Elevation changes over 2 years.

GIS can also estimate the cut and fill that is required for the desired area. By using the same area (120 m) of the road, this study produced an estimate of cut and fill of the road segment. The road segment was divided into 12 sections of road, 3 m wide by 10 m long (figure 13). Table 2 shows the estimate of cut and fill for each section.

![Figure 13](image3.png)

**Figure 13.** 12 section of road.
Table 2. Estimate of cut and fill.

| Section | Cut (m³) | Fill (m³) | Total material disposed (m³) |
|---------|----------|-----------|----------------------------|
| 1       | 0.9726   | 1.5848    | -0.6122                    |
| 2       | 0.0000   | 10.3208   | -10.3208                   |
| 3       | 0.0000   | 17.3907   | -17.3907                   |
| 4       | 4.9899   | 4.9836    | 0.0063                     |
| 5       | 21.5851  | 0.0000    | 21.5851                    |
| 6       | 27.3640  | 0.0000    | 27.3640                    |
| 7       | 24.5926  | 0.0000    | 24.5926                    |
| 8       | 28.4032  | 0.0000    | 28.4032                    |
| 9       | 31.8958  | 0.0000    | 31.8958                    |
| 10      | 28.3945  | 0.0000    | 28.3945                    |
| 11      | 4.8144   | 9.6253    | -4.8109                    |
| 12      | 0.1337   | 3.3214    | -3.1877                    |

Total 173.1458 47.2266 125.9192

Thus, for this 120 m road section, a total of 125.9192 m³ of soil is estimated to have been disposed of. However, while ArcGIS software has been used for these analyses, past experience has shown that software specific to the analysis required, can more efficiently and accurately use the LiDAR data for the purpose of the analysis. Examples of such software include MX Road for Road Design and PLSCADD for Transmission Line Design.

4. Conclusion

When using multi-temporal full waveform datasets to do change analysis, it is important to ensure agreement between both datasets to ensure any change is due to topography changes and not mapping accuracy issues. Static structures, such as unchanged buildings were used to confirm agreement between datasets and showed no difference between 2012 and 2014 datasets.

There is a wide range of analyses that can be performed using multi-temporal LiDAR data, but this study focused on a few topographical changes that have occurred in the study area in two years. For densely vegetated areas, LiDAR was able to demonstrate its unique ability to analyze vegetation growth and elevation through tropical rainforest canopy. Individual tree growths were measured and the canopy height model (CHM) generated for each year and the changes between the two datasets were compared. The study also analyzed the elevation changes of both datasets, due to erosion and earthwork activities which can provide estimates of cut and fill for earthworks calculations. Thus, this paper demonstrates some of the useful change detection analyses that can be performed for multi-temporal full waveform LiDAR data, and more analyses should be explored in future.

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