Technical challenges of airborne LiDAR surveying technology in Malaysia

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Abstract. Light Detection and Ranging (LiDAR) is one of the most recent and useful active remote sensing tools; it provides accurate horizontal and vertical information by direct time measurement of a short laser pulse’s reflection on the Earth surface. The ability of LiDAR data to accurately characterize terrain has led many users in Malaysia, to employ this technology for various applications, including engineering and infrastructure, environment, disaster and natural resource management. However, there are some technical challenges faced by technology operators and users, particularly in Malaysia, in terms of data acquisition, processing and quality control. In this paper, some of the technical challenges, i.e. mismatches between LiDAR and ground land survey data, differences between coordinates derived from the primary GPS network 2000 and the CORS station, MyGeoid and NGVD height differences, changes in topographical features, LiDAR Data management and the lack of a standard for data acquisition and quality control in Malaysia, will be discussed.

1. Introduction
LiDAR is one of the most useful active remote sensing tools. It allows one to obtain accurate horizontal and vertical information from the surface of the Earth. This data is obtained by firing laser pulses from the scanner, calculating the time required for the emitted pulses to hit the object or surface and be reflected back to the scanner. This distance from scanner to object is then combined with the position and orientation of the laser to calculate the coordinates and elevation of the points. LiDAR technology has a wealth of benefits for many sectors and projects, including engineering, environmental research/protection, natural resource management and infrastructure planning, and this is particularly valuable in tropical countries like Malaysia with highly dense vegetation.

LiDAR technology is not new in Malaysia, but still there are some technical challenges faced by technology operators and users in Malaysia. The main objective of this paper is to highlight these challenges in the remote sensing community.

2. Methodology
The aerial LiDAR survey work was carried out by Ground Data Solutions R&D Sdn. Bhd. (GDS) who are pioneers in the industry and are an experienced airborne LiDAR survey service provider in the region. Beside the laser scanner to generate pulses, two pieces of equipment were used: (i) a GPS unit to determine the aircraft’s position in terms of latitude, longitude and altitude which are also known as the x, y and z coordinates and (ii) an Inertial Measurement Unit (IMU) to measures attitude (pitch/yaw/roll) of aircraft. All three pieces of data are then used to calculate the location that each
pulse lands at, which provides a LiDAR data point. The Figure 1 shows the flowchart of the overall procedure:

![Flowchart of the overall procedure](image)

**Figure 1.** Airborne LiDAR survey procedure

3. Results and Discussion

In this section, a few technical challenges in utilizing LiDAR survey technology in Malaysia will be discussed in detail. The LiDAR survey case studies that are discussed here were carried out by GDS.

3.1. Mismatches between LiDAR data and data from ground land survey

It is often difficult to overlay ground survey data with LiDAR survey data because the surveying were carried out using different methods when applying the coordinate systems and different control points. This leads to survey data having both horizontal and vertical mismatches. Often, the control points used by the earlier ground surveyors do not exist anymore when the survey data are to be used later.

As an example, a LiDAR and digital imagery survey was carried out for a proposed transmission line and power plant from Tanjung Tohor to Yong Peng in Johor. The project area consisted of the proposed transmission line, which encompassed a 26km long line with a width of 350m, a 27.19km line with a width of 200m and the power plant site with an area of 3.7km² (Figure 2).

![Survey area from Tanjung Tohor to Yong Peng in Johor](image)
High accuracy LiDAR data was captured by using an airborne LiDAR survey system with a RIEGL LMS-Q240 laser scanner. The LiDAR survey work was based on Continuously Operating Reference Stations (CORS) stations (Table 1). The LiDAR point cloud data acquired had an average point spacing of 1.84m for ground points, and 0.84m for all points together.

Table 1. The coordinate derived from CORS

| Point ID | GDM2000 Coordinate | Ellipsoidal Height (m) |
|----------|---------------------|------------------------|
|          | Latitude (° '")     | Longitude (° '")       |                          |
| GAJA     | 2 07 20.24411       | 103 25 21.75286        | 60.2440                 |
| GDS01    | 2 00 26.99802       | 103 03 14.92476        | 19.7855                 |
| PRTS     | 1 58 53.06971       | 102 52 23.02074        | 15.6760                 |
| SPGR     | 1 48 38.14468       | 103 19 15.52189        | 34.2080                 |
| YPC12    | 2 04 48.25786       | 103 02 49.70747        | 9.2074                  |
| YPC26    | 2 01 52.79089       | 102 51 58.32420        | 17.2473                 |
| YPC35    | 2 03 04.92919       | 103 03 07.87669        | 12.9910                 |

Rigorous quality assurance and quality control procedures were implemented throughout the project from the ground surveys to the LiDAR sensor calibration to data processing. Ground survey work, which included GPS observation and physical investigation of the site, was performed in order to verify the accuracy and validity of the LiDAR data. It is important to note that for the purpose land acquisition, the ground survey was based on the boundary stone on Lot 12658 (PA 149057), with height based on Benchmark (BM) J1330. Coordinate derived from boundary mark in Cassini was transformed and projected to GDM2000 will be demonstrated in Table 2.

Table 2. Coordinates derived from boundary mark and height based on BM

| Point ID | GDM2000 Coordinate | Height (m) |
|----------|---------------------|------------|
|          | Latitude (° '")     | Longitude (° '") | RL NVGD height (m) |
| YPC12    | 2 04 48.352527      | 103 02 49.56157 | 4.704              |
| YPC26    | 2 01 52.798867      | 102 51 58.22873 | 13.510             |
| YPC35    | 2 03 05.00698       | 103 03 07.74407 | 8.421              |

The result shows that there are differences between coordinates that have been derived from LiDAR data and land survey works on the ground (Table 3).

Table 3. Difference between coordinates

| Point ID | GDM2000 Coordinate | Height (m)* |
|----------|---------------------|-------------|
|          | Northing (m)        | Easting (m)  | Height (m) |
| YPC12    | -2.927314           | 4.511552    | 0.272      |
| YPC26    | 0.068647            | 2.952145    | 0.337      |
| YPC35    | -2.40544            | 4.100905    | 0.260      |

*. The height values derived from CORS were converted from ellipsoidal height to orthometric height, using the MyGEOID geoid model.

The following Figure 3 demonstrates the same location captured with two different survey method.
Figure 3. The same location captured with two different survey methods: the image representing the LiDAR data and the digitized boundaries representing land survey data

In order to overcome this difficulty it is recommended that the coordinate system and control points used in the project should be the same. Furthermore, using the CORS network is highly recommended as it allows users to access long-range high accuracy network RTK corrections. In addition in some situations marked area that have been established by land surveys have been lost due to various reasons. If the CORS network is used, the lost control points could be re-established easily.

3.2. Differences between coordinates derived from the primary GPS network 2000 and the CORS station

The airborne LiDAR survey for the High Speed Rail project on March 2013 discovered that there were differences between coordinates derived from the Primary GPS Network 2000 and the CORS station (MERU, UPMS, BANT, JHJY, SPGR). Two different static networks were processed based on Primary GPS Network 2000. Network one was fixed to GP12 and GP18 and Network two was fixed to GP09, GP23, GP59 and GP12. Table 4 shows the coordinate established based on the CORS while the table 5 shows the established coordinate based on the primary GPS network 2000. Table 6 shows the differences between coordinates derived from Primary GPS Network 2000 and CORS station for network 1&2.

Table 4. Coordinate established based on CORS (MERU, UPMS, BANT, JHJY & SPGR)

| Point ID | Easting    | Northing   | Ellipsoidal height |
|----------|------------|------------|--------------------|
| GDS01    | 783818.055 | 346412.903 | 12.454             |
| GDS02    | 833153.670 | 292208.360 | 47.474             |
| GDS03    | 861583.865 | 249578.287 | 4.202              |
| GDS04    | 919357.553 | 237858.379 | 7.403              |
| GDS05    | 970766.832 | 210127.507 | 32.177             |
| GDS06    | 1019095.153| 181775.426 | 37.810             |

The differences between coordinates derived from Primary GPS Network 2000 and CORS station is shown in Table 6. Again, it is recommended that CORS is used to avoid the differences between coordinates derived from Primary GPS Network 2000.
Table 5. Coordinate established based on Primary GPS Network 2000

| Point ID | Network 1(GP12 &GP18) | Network 2(GP09,GP23,GP59&GP12) |
|----------|----------------------|----------------------------------|
|          | Easting | Northing | Ellipsoidal height | Easting | Northing | Ellipsoidal height |
| GDS01    | 783818.090 | 346412.910 | 12.771 | 783818.073 | 346412.892 | 12.667 |
| GDS02    | 833153.677 | 292208.347 | 47.744 | 833153.608 | 292208.372 | 47.752 |
| GDS03    | 861583.781 | 249578.319 | 4.495  | 861583.797 | 249578.321 | 4.495  |
| GDS04    | 919357.435 | 237858.342 | 7.713  | 919357.428 | 237858.406 | 7.689  |
| GDS05    | 970766.894 | 210127.411 | 32.441 | 970766.813 | 210127.512 | 32.459 |
| GDS06    | 1019095.410 | 181775.317 | 38.136 | 1019095.388 | 181775.433 | 38.147 |

Table 6. Differences between coordinates derived from Primary GPS Network 2000 and CORS station for network 1 & 2

| Point ID | Network 1 | Network 2 |
|----------|-----------|-----------|
|          | Easting | Northing | Ellipsoidal height | Easting | Northing | Ellipsoidal height |
| GDS01    | -0.035  | -0.007  | -0.317          | -0.018  | 0.011  | -0.213          |
| GDS02    | -0.007  | 0.013   | -0.270          | 0.062   | -0.012 | -0.278          |
| GDS03    | 0.084   | -0.032  | -0.293          | 0.068   | -0.034 | -0.293          |
| GDS04    | 0.118   | 0.037   | -0.310          | 0.125   | -0.027 | -0.286          |
| GDS05    | -0.062  | 0.096   | -0.264          | 0.019   | -0.005 | -0.282          |
| GDS06    | -0.257  | 0.109   | -0.326          | -0.235  | -0.007 | -0.337          |

3.3. MyGeoid and NGVD height differences

One of the issues in LiDAR survey is familiarity of LiDAR data users on the Malaysia vertical datum. The geodetic reference frame for Peninsular Malaysia has been realized through the setting-up of the Malaysia Active GPS System (MASS) in 1999. Peninsular Malaysia used the National Geodetic Vertical Datum (NGVD) that was established in 1995 for its height reference. In 2005, the Department of Survey and Mapping Malaysia (JUPEM) has launched Malaysia Geoid Model (MyGEOID) to provide public users with a complete infrastructure that can be utilized. Sometimes, government departments, government-linked companies (GLCs) and other clients either do not specify at all or specify very old GEOID models for the survey services that they have tendered out. Based on our experience, these old models are less accurate than MYGEOID, leading to low orthometric elevation accuracy over long distances.

For example, a LiDAR survey was carried out for civil and structural engineering consultancy services for the proposed railway network linking Samalaju industrial Park – Bintulu – Mukah – Tanjung Manis, Sarawak project on August 2014 (see Figure 4).

Figure 4. Study area
For this project, LiDAR survey works based on CORS (BELA, BIN1, KAPI, MUKA and NIAH) and orthometric height were based on MyGEOID geoid model while for land acquisition, ground survey work was based on bench mark (SS3944). Based on analysis, it shows that the difference was more than 0.1m at road survey (Figure 5). It is recommended to use MyGeoid which is the best suited national geoid model.

![Figure 5](image)

**Figure 5.** Vertical difference on road surface between LiDAR and ground survey were (a) 0.5843m (b) 0.1360m

### 3.4. Changes in topographical features

Airborne LiDAR is creating new possibilities for change detection [1] [2]. For this example, 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 (Figure 6). 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 change detection was measured using LiDAR datasets collected in 2012 & 2014 to produce meaningful outputs depicting the topographic changes in Belaga.

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. These changes that occur are due to erosion and earthwork activities, which can provide estimates of cut and fill for earthworks calculations (Figure 7). It is recommended that topographical maps are updated every 2 years.

### 3.5. LiDAR standard

The use of LiDAR data for different applications has increased significantly in the past few years. At present moment, there is still a lack of comprehensive standards and procedures for LiDAR mapping in Malaysia. There are nonetheless some LiDAR standards available that are published by international organizations such as the American Society for Photogrammetry and Remote Sensing (ASPRS) and the Land Information Organization of New Zealand National Aerial LiDAR Base Specification (which is defines a consistent set of minimum products to ensure compatibility across projects and regions in New Zealand). These standards however define different vertical/horizontal accuracies, point density, etc.

It is important to establish a basic framework of standards for LiDAR data acquisition and processing for LiDAR users in Malaysia. This framework should be used to build a national LiDAR dataset that support all applications and maximize the amount of LiDAR data available for re-use.
Furthermore it must meet the minimum requirements of the department of survey and mapping Malaysia (JUPEM) regulation.

**Figure 6.** (a) Overlap area which depicts parts of the northern section of Belaga. (b) Overlap area which depicts the southern section of Belaga.

**Figure 7.** Images of road construction (a) 2012, (b) 2014, (c) Cross section of point cloud in 2012 (Green) and 2014 (White).

3.6. LiDAR Data management

LiDAR survey is very popular and has made great significant improvements in Malaysia. However, managing and serving LiDAR data is becoming a rising problem. A crucial problem still exists when working with these data sources in terms of how quickly one can access and represent a 3D set of
point clouds into different datasets due to the very large storage requirements of LiDAR datasets [3][4] as well as storing and sharing of this data. LiDAR management systems, should facilitate storing and sharing of LiDAR data in an effective manner. As an example, Dielmo is an online solutions to host, present, use and manage geodata on the Internet which includes 2D Web portals as well as geospatial map services to display any GIS, LiDAR, or raster data online. It is recommended to have an effective and secure data management system for LiDAR data.

3.7. In Summary

Six technical challenges have been studied and reviewed in this paper. Each challenge has led to different recommendations. There were the mismatches between LiDAR data and data from ground land survey (Easting 0.093 m, Northing -0.7540 m) caused by differences between coordinates that have been derived from LiDAR data and land survey works on the ground. Another challenge was identified during High Speed Rail project: differences between coordinates derived from the primary GPS network 2000 and the CORS station with approximately 0.28m differences. The next study showed the height differences on road surface between LiDAR and ground survey due to the differences between MyGeoid and NGVD height. In another study, analysis of multi-temporal LiDAR dataset allowed for the identification of the topographical features that might have changed due to erosion and earthwork activities which can also provide estimates of cut and fill for earthworks calculations. Lastly, there is a lack of comprehensive LiDAR standards in terms of data acquisition and quality control in Malaysia as well as scarcity of data management systems.

4. Conclusion

In the Malaysia geospatial market, airborne LiDAR technology is not new and use of this technology is growing very fast. The ability of LiDAR data to accurately characterize terrain has led many organizations in Malaysia to utilize this technology for various applications. However, there are still a few challenges in terms of data acquisition, processing and quality control in Malaysia as discussed in this paper. It is recommended that JUPEM’s latest guidelines be adapted by professional surveyors, including land surveyors as well as LiDAR surveyors. Furthermore, the use of the CORS network is highly recommended, as long as it is fully available and consistent in one’s project area before embarking on a project.

Further work should be conducted to minimize the differences between established and converted coordinates by using appropriate and accurate conversion’s parameters. Additionally, creating a standard for LiDAR data acquisition and quality control in Malaysia is necessary. Lastly, having an effective and secure data management system for LiDAR data is essential.

Reference

[1] Barber D M, Holland D and Mills J 2008 Change detection for topographic mapping using three-dimensional data structures Int. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 37 B4 1177–82

[2] Xu H, Cheng L, Li M, Chen Y and Zhong L 2015 Using Octrees to Detect Changes to Buildings and Trees in the Urban Environment from Airborne LiDAR Data Remote Sens. 7 9682-04

[3] Schön B, Bertolotto M, Laefer D F & Morrish S February 25-28 2009 Storage, manipulation, and visualization of lidar data In Presented at the 3rd Int. Workshop, 3D-ARCH’2009: 3D Virtual Reconstruction and Visualization of Complex Architectures, Trento, Italy International Society of Photogrammetry and Remote Sensing

[4] Lewis P, Elhinney C P M, and McCarthy T 2012 LiDAR data management pipeline; from spatial database population to web-application visualization In Proc. of the 3rd Int. Conf. on Computing for Geospatial Research and Applications (COM.Geo ’12) (New York: ACM) article 16