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Application and Evolution of Airborne LiDAR Technology for Topographic Data Acquisition Practice in the Department of Survey and Mapping Malaysia

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Abstract **- The mapping industry is one of the areas that is always given attention to balance the rapid development of current technology. The application of Light Detection and Ranging (LiDAR) technology in the mapping industry opens up a wide dimension of discussion involving industry users as well as academics. LiDAR technology is now a common method for faster and higher quality topographic data collection than conventional topographic data collection methods. Observation data that is generally in the form of high-density point (point cloud) can also be applied in various uses, especially in the field of mapping and terrain analysis. Therefore, this paper will discuss related LiDAR technology including basic information or principles of LiDAR technology, the latest developments of LiDAR methods, and work processes involved from the point of view of the Department of Survey and Mapping Malaysia (JUPEM).**

Keywords—Component, formatting, style, styling, insert

I. INTRODUCTION

Light Detection and Ranging or known as LiDAR is a method to identify a specific point of object on the earth's surface based on the light reflected technique [1]. This technology is evolving and various innovations in terms of methods and equipment used to conduct the data acquisitions. Not only has that, despite the growth of geospatial knowledge, but LiDAR also becomes one of the sources in providing information in high accuracy [2]. In addition to providing data in high accuracy, LiDAR also assists in mapping the earth's surface rapidly through the collaboration of Global Positioning System (GPS) technology. The final output of LiDAR can also be interpreted into various applications to obtain information such as features classification, extraction, and modeling of DTM and DSM [3].

Department of Survey and Mapping Malaysia (JUPEM) has played a vigorous role in restructuring and managing the mapping activities in Malaysia for more than 20 years [4]. As the advisor to the national government, the department actively serves the nation's needs through the survey and topographic mapping activities throughout the country without limit. These activities are not only to cater for the national needs but also to support the social and environmental development of the nation. Therefore, it is JUPEM's responsibility to adopt all the evolution of LiDAR technologies and to look for opportunities to maximise the data potential for the nation's needs [5]. In order to discuss in detail regarding the application and evolution of airborne LiDAR technology for topographic data acquisition practice in JUPEM, this manuscript is divided into three (3) sections namely (i) LiDAR technologies, (ii) evolution of LiDAR technology in JUPEM, and (iii) LiDAR data application.

II. LIDAR TECHNOLOGIES

Light Detection and Ranging (LiDAR) has become an accurate method of capturing high-density point data for a three-dimensional (3D) based topographic surface [6]. Yan et

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al. [7] stated that the 3D coordinates of the target object are obtained from several mechanisms including (i) the difference in beam time and laser reversal, (ii) the angle of the laser beam transmitted, and (iii) the location of the detector as in Fig. 1. LiDAR technology is now applied in various measurement platforms such as terrestrial laser scanning (TLS), airborne laser scanning (ALS), mobile laser scanner (MLS), and even spaceborne [8].

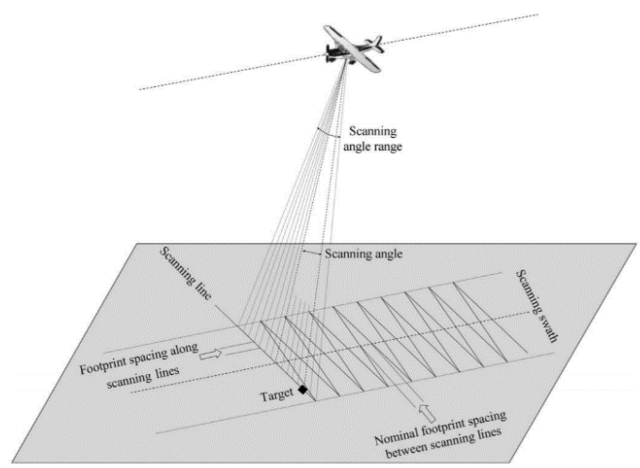

Fig. 1. LiDAR coordination mechanisms [9].

A. *Airborne LiDAR Positioning Fundamental*

In general, airborne LiDAR/ALS technology methods contain several components such as aircraft for aerial acquisition techniques, sensors, Global Navigation Satellite System (GNSS) receivers, inertial measurement unit (IMU), and computer hardware [10] as in Fig. 2. In addition, most aviation missions are also equipped with digital cameras to supply terrain images. The resulting LiDAR data will supply some important inputs such as x, y, and z coordinate values, intensity values, and the red, green, and blue bands better known as RGB bands [11].

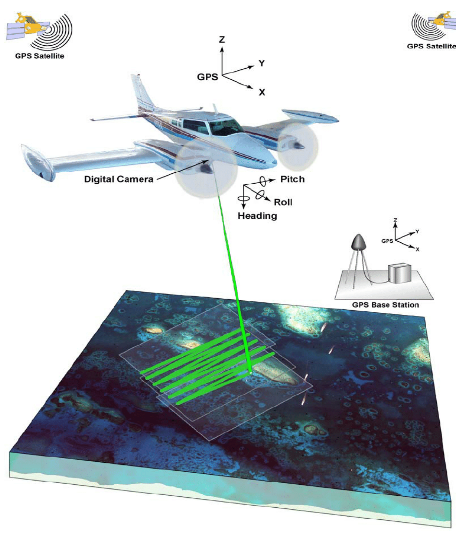

Fig. 2. ALS LiDAR components [12].

LiDAR is an active remote sensing technique that uses the concept of laser target light tuning and analysis of reflected light [13]. By identifying the time of light reflection for each pulse returning to the sensor, the position and height of the object can be measured in elevated accuracy based on the basic formula as in Eq. (1) [14].

$$D = r * t/2 \tag{1}$$

D = Distance from sensor to target object

R = Rate of light speed 3×10^8 m / s

t = The time taken for the pulse to return to the sensor

2 = Process of light going and returning to the sensor

B. *Advantages of LiDAR Technology*

For the ALS method, the aircraft flight mission along with the scanning process targets the area by creating a network of flight lines in a grid pattern [8]. The use of a laser beam that does not require sunlight because it is actively sensing and can be carried out either during the day or night which is very suitable for survey work especially for engineering purposes [15]. The production of high-resolution and accurate data allows more efficient mapping activities to be carried out for various purposes such as development planning, 3D representation of man-made structures (modeling roads, bridges, buildings), and others.

The density of points cloud produced depends on various aspects such as flight altitude, aircraft speed, type of detector, and so on. The use of TLS can record higher density points compared to ALS because the distance between the detector and the object is closer [8]. Typically, LiDAR point formats are produced in various formats such as LASer (.las) format and American Standard Code for Information Interchange (ASCII). The file will then be processed using certain software to produce an output that can be used in various applications.

III. Evolution of LiDAR Technology in JUPEM

The use of LiDAR in JUPEM started in 2002 using the OPTECH ALTM 30/70 (ALS) and CYRAX 2500 (TLS) devices. In 2013 and 2014, LiDAR data acquisition activities were conducted in the Federal Territory of Kuala Lumpur and for the acquisition of SmartKADASTER data [4]. LiDAR activities accelerated and were widely used in JUPEM from 2016 to 2019 where a lot of data processing was done by private companies that had started investing in the purchase of LiDAR sensors. The National Institute of Land and Survey (INSTUN) also contributes to the growth of LiDAR activities by organising LiDAR-related courses for interested individuals and groups. A chronological summary of the evolution of LiDAR technology adaptation at the JUPEM can be seen in Table I.

On top of that, JUPEM is a LiDAR subject-matter expert (SME) for government agencies involved in any project related to LiDAR data acquisition [16]. Apart from JUPEM, there are also government and non-government agencies that are also involved in the processing of this data. Government agencies such as the Department of Mineral and Geoscience Malaysia (JMG) and the Department of Irrigation and Drainage (DID) are also not left behind in LiDAR activities, as JUPEM officers participate in providing mapping advisory services. Apart of become an SME, JUPEM is also appointed as LiDAR data auditor by the National Audit Department as an entity that checks and balances the implementation of this activity, especially within government agencies.

Table I. LiDAR technology adaptation at the JUPEM.

Year	Activities	LiDAR Tech
2002	Purchasing OPTECH ALTM 30/70	ALS
2004	Purchasing CYRAX 2500	TLS
2013	LiDAR data acquisition for Malaysian Centre for Geospatial Data Infrastructure (MaCGDI)	ALS
2014	Kuala Lumpur (KL) and Putrajaya's LiDAR data acquisition (SmartKADASTER Phase 1)	ALS, TLS, MLS
2015	Purchasing Faro Focus 3D	TLS
2016	Kelantan's LiDAR data acquisition	ALS
2016	Terengganu's LiDAR data acquisition	ALS
2017	Purchasing Faro Focus M series	TLS
2018	Terengganu's LiDAR data acquisition	ALS
2018	Kelantan's LiDAR data acquisition	ALS
2019	Terengganu's LiDAR data acquisition	ALS
2019	Kota Belud's LiDAR data acquisition	ALS
2020	Greater KL to Seremban's LiDAR data acquisition (SmartKADASTER Phase 2)	ALS, TLS, MLS

IV. LiDAR Acquisition Practice in JUPEM

There are two main phases that need to be carried out to make sure the LiDAR's final output is fit for specific purposes. The phases involved are the data acquisition phase and the processing phase.

A. Data Acquisition Phase

For the LiDAR data acquisition, a survey of the work area must be done first. It is important to plan and provide a good GNSS control network to ensure that the accuracy of the data received meets the required specifications. Once the GNSS control network has been designed, static measurements for the GPS base station or ground control point (GCP) can be performed. A large number of control points are better for the production of quality LiDAR data [17]. The first procedure that needs to be done is to install the system components on the aircraft followed by flight calibration. Flight calibration should be performed to ensure that the system installation does not experience any complications during an actual flight [18].

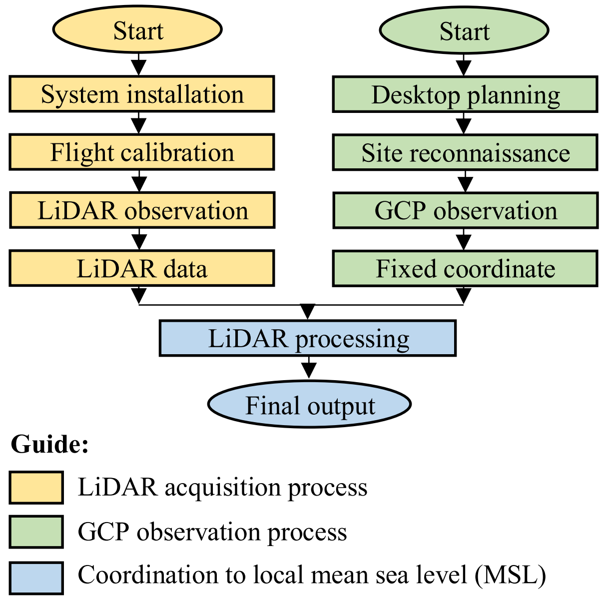

Fig. 3. LiDAR data acquisition work procedure.

For checking purposes, GCP should be made at the appropriate location of the area of interest (AOI). The GCP distribution must cover the entire work area [17] with the appropriate GNSS network. Each GCP will be observed for 4 to 8 hours to get good and stable data results. The coordinate values (x, y, z) of GCP will be compared to the values obtained from LiDAR. For the groundwork of the GCP, the Surveyor must be registered with the Land Surveyors Board (LJT), however, for the unregistered Surveyor, the groundwork of GCP can still be done but must through the registered party to ensure standard GCP control is guaranteed. The selection of appropriate sensors is also an important aspect before the mission is launched. This is because each sensor has different capabilities and it affects the final result of LiDAR point cloud density. The flow of the LiDAR data acquisition work procedure is as shown in Fig. 3.

B. Processing Phase

Once the field data acquisition has been done, the LiDAR data processing phase will be implemented. Some important reviews need to be carried out including high specification hardware, software capabilities, and so on [19]. High-performance computers are important because of the enormous size of the LiDAR data captured especially when it involves large areas. Usually, the raw data received from the sensor is in *.BIL* format before it is converted to standard point cloud format which is *.LAS* format. After that, the data classification will be conducted according to the classification number that has been set by the International Society for Photogrammetry and Remote Sensing (ISPRS). Among the frequently used software is TerraSolid software. The software uses the Adaptive Triangulated Irregular Network (ATIN) algorithm to process the filtration of the Earth's LiDAR points [20]. Other software such as LiDAR360 and ALDPAT also use the ATIN algorithm due to its potential for providing high-quality results.

Besides, the development of current technology is seen to have a positive impact on the classification of LiDAR point cloud where the use of Artificial Intelligence (AI) technology is seen as very helpful in the process of classification. Principles such as Random Forest, Artificial Neural Network, and Support Vector machine implemented in software for LiDAR data processing help in providing fast and high-quality results [21]. These technologies are not only able to classify high-quality earth points, but are also able to classify man-made objects such as buildings, lamp posts, and trees in detail. Based on the classification conducted, output such as Digital Surface Model (DSM) and Digital Terrain Model (DTM) will be able to be produced [22]. Every output produced should be checked for quality to ensure there are no errors such as spikes, void areas, and others [23]. Once a detailed checking has been made, corrections to the data should be applied. This is because the production of good contours is highly dependent on the quality of DTM data produced. Continuity from DTM data, extraction of features such as water body features, roads, and so on can be done according to the needs of an agency. Each data generated needs to go through a process of quality checking of features to ensure that the findings obtained are accurate and as close as possible to the surface of the terrain in the field [22]. Framework for the generation of DTM based on JUPEM practices can be seen in Fig. 4. Some examples of the final results generated from the LiDAR data are shown in Fig. 5.

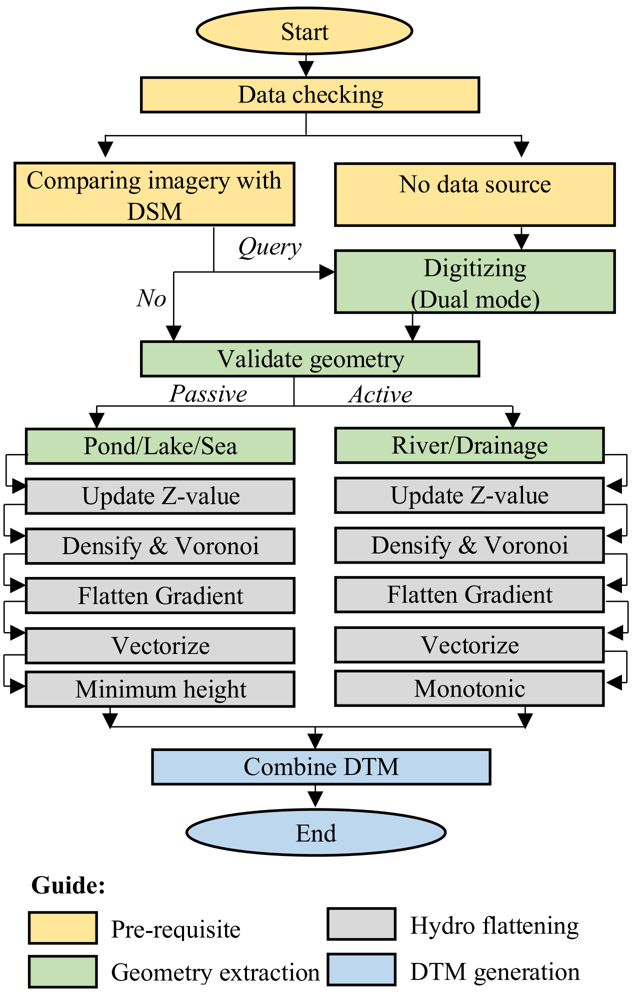

Fig. 4. DTM generation framework.

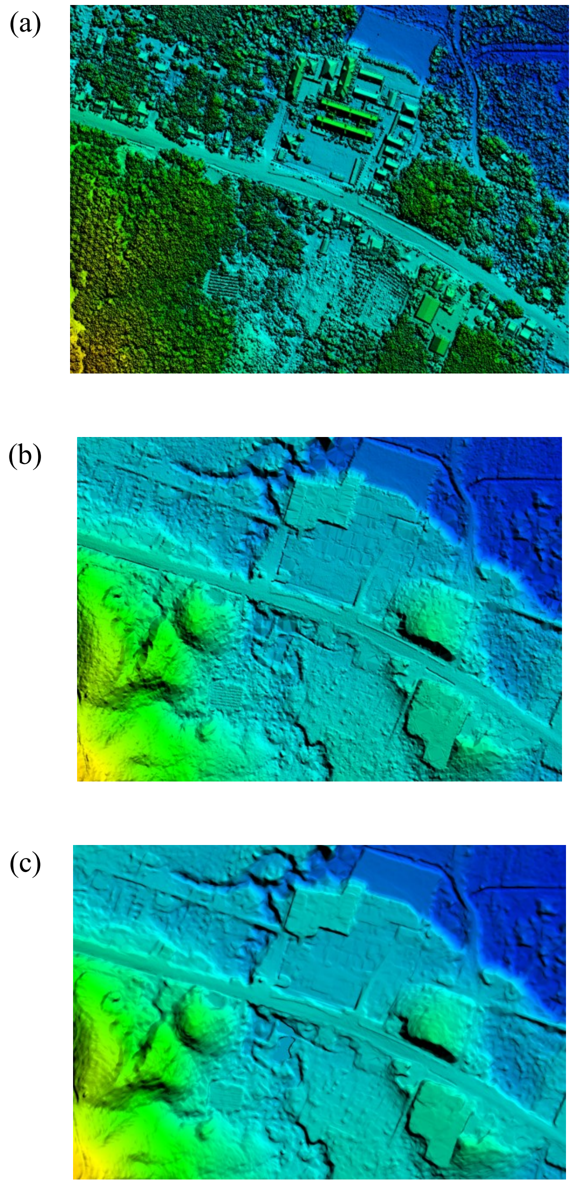

Fig. 5. Generated digital model (a) DSM, (b) DEM and (c) DTM.

V. LiDAR Data Application

Apart from capturing and processing LiDAR data, JUPEM also implemented the captured data into some applications for internal and public use. Big Data Analytics (BDA) and SmartKADASTER Interactive Portal (SKiP) are examples of applications that manipulate the LiDAR data for greater use.

A. Big Data Analytics (BDA)

Big Data Analytics or BDA is an application that focuses on big data mapping for geospatial management by focusing on hydro mapping as a business case. This project was started in 2019 which focused on the issue of river pollution in Sungai Tebrau, Johor. The concept is applied to geospatial data management or environmental control. This application is developed as a tool to generate reports or statistics for the use of JUPEM as well as related departments or agencies in daily management and decision making. It is also able to combine, analyse, and manipulate the data and information obtained from JUPEM as well as external departments or agencies to produce the desired analysis.

The application of LiDAR data within BDA is through the manipulation of elevation information from DSM and DTM. This elevation information is an important asset to integrate with the Department of Statistics Malaysia (DOSM) statistical information. The probabilistic methods are used to calculate the population based on the DOSM parameter by fusion building footprint with terrain data. The formula used to identify the number of population for single structure building (such as terrace house and bungalow unit) is as in Eq. (2).

$$P_1 = \left(\frac{DSM - DTM}{3}\right) * 4 \qquad (2)$$

P₁ = Number of population for single building

DSM = Digital Surface Model elevation

DTM = Digital Terrain Model elevation

3 = 3 meters vertical height for each floor

4 = 4 occupants per unit based on average household statistic by DOSM [24]

The formula is used to identify the population for multi-storey buildings (such as apartment and condominium unit) as in Eq. (3).

$$P_2 = \left(\left(\frac{DSM - DTM}{3}\right) * 4\right) * 8 \qquad (3)$$

P_2 = Number of population for multi-storey building

DSM = Digital Surface Model elevation

DTM = Digital Terrain Model elevation

3 = 3 meters vertical height for each floor

4 = 4 occupants per unit based on average household statistic by DOSM [24]

8 = Average of 8 unit per floor for multi-storey building

B. SmartKADASTER Interactive Portal (SKiP)

SmartKADASTER Interactive Portal or SKiP is an interactive portal that gathers cadastral data, mapping, and GIS information integrated into an accurate database and used for national planning and development. The main purpose of the project is to establish a multi-purpose cadastral based spatial analysis platform. The spatial analysis can be performed in 2D or 3D interface according to the user's preference [4]. Through the combination of various data includes cadastral information (National Digital Cadastral Survey Database (NDCDB) lots and administration boundaries), mapping data (DSM and DTM), environmental model or mesh-model, and three-dimensional (3D) building model with various Level of Details (LOD) stages (LOD 1 to LOD 4), it opens a new dimension for geo-enabled data manipulation. By using LiDAR-based data such as DTM and DSM, multiple geospatial analyses can be conducted within SKiP such as flood simulation, viewshed, slope query, and so on.

The geospatial data must be fully utilised to move forward with the Industrial Revolution 4.0 (IR 4.0). Therefore, the combination of LiDAR technologies that were implemented within SKiP was not only to consolidate the final output but also to make sure it is supporting smart cities enablement in Malaysia. For example, the generation of the mesh-model not only uses the ALS data but also considers the MLS data. These perfected each other and stretches magnificent productivity with the combination of aerial and mobile captured point clouds. Besides that, the combination of ALS imagery with a Multi-view Oblique (MVO) system that offers nadir-imagery for SKiP data capture enhances the base-map used. This is because, through the combination of ALS imagery and MVO imagery, true-orthophoto imagery can be delivered. The differences between orthophoto and true-orthophoto can be seen in Fig. 6.

(a)

(b)

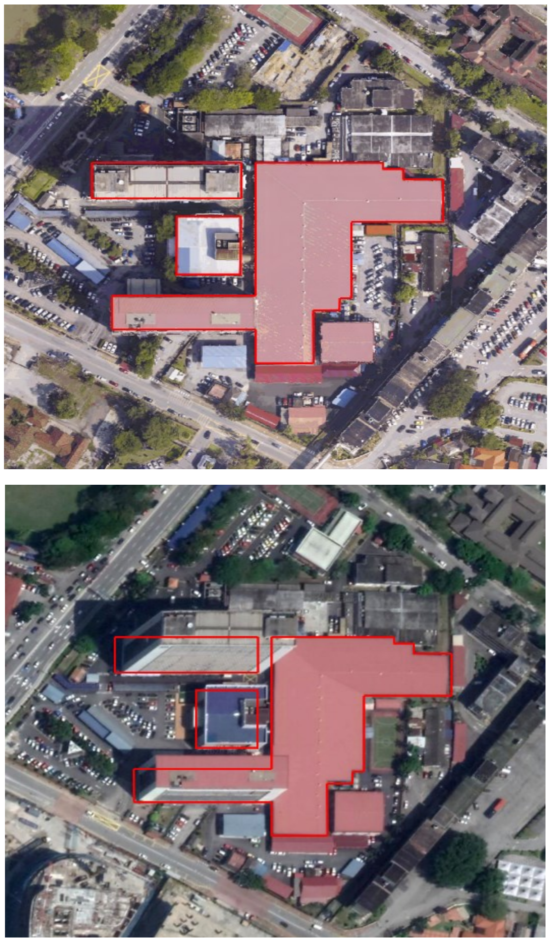

Fig. 6. Different between (a) true-orthophoto and (b) orthophoto imagery.

VI. CONCLUSION

LiDAR's technological capabilities in identifying landform structures have been tested and proven through various applications around the world. The application of this method for topographic mapping is accurate and very suitable to describe the information of height, slope through high accuracy DSM and DTM. The data obtained is utilised in various uses both in disaster management and national development not only for other agencies but also for JUPEM itself. Therefore, the development of LiDAR technology should be constantly scrutinised from time to time and the capabilities offered should be fully utilised to improve work processes, especially for surveying and mapping purposes.

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