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ORIGINAL ARTICLE

Study of the application of UAV and LiDAR to topographic survey of mountainous forest areas – Case study of Win 3 Wind Power Plant Project, Huong Hoa District, Quang Tri Province, Vietnam

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Abstract

Unmanned Aerial Vehicle (UAV) technology in conjunction with aerial photography and aerial Light Detection and Ranging (LiDAR) was used for topographic surveying of the Win 3 Wind Power Project area, a complex mountainous terrain situated in the Huong Hoa district of Quang Tri province, Vietnam with the primary objective to produce a map with a scale of 1:1,000 with a contour interval of 1.0 m, accompanied by 3D point clouds, a Digital Elevation Model (DEM), and an orthomosaic. Employing the UAV LiDAR system of DJI Matrice 300 RTK, we conduct ed survey flights, achieving a high point density laser scanning of 229 points/ m^2 and capturing ultra-high-resolution imagery at 4.22 cm/pixel. The integration of aerial LiDAR and photographic data results in a rich and detailed information repository regarding the surveyed terrain demonstrating that UAV LiDAR technology is a robust tool for geographic data collection, particularly in challenging terrain conditions in Vietnam. We also evaluated the accuracy of the created topographic map, achieving results that surpass the technical requirements and quality standards of the project. This underscores the potential and effectiveness of UAV LiDAR technology in the field of large-scale geographic data collection and mapping in Vietnam.

Key words: unmanned aerial vehicle, aerial photography, aerial LiDAR, topographic survey, DJI Matric 300 RTK, UAV LiDAR

1 Introduction

Unmanned Aerial Vehicles (UAVs), originally developed for military purposes, have become indispensable tools in topographic data collection. The evolution of UAV technology has opened new avenues for civilian applications, particularly in geomatics and cartography (Hlotov et al., 2017; Dung et al., 2021). The outstanding advantages of UAV technology in topographic surveying include its flexibility and accessibility in challenging conditions, the high detail and accuracy of collected data, affordability, and its compatibility with such modern technologies as Light Detection and Ranging (LiDAR) and Global Navigation Satellite System (GNSS).

LiDAR technology allows for the detailed collection of 3D spatial data with high precision by employing laser beams to measure distances to target objects automatically and continuously. The UAV LiDAR has enhanced the effectiveness of topographic surveying, especially by:

i. Increasing the altitude of aerial surveys with flexible flight angles and trajectories; thus, enabling the collection of geographical data over expansive and challenging-to-access areas.
ii. Achieving large measurement distances and high accuracy of laser measurements to create diverse types of maps and digital models with high levels of detail and precision.
iii. Swift and straightforward processing of aerial imagery and LiDAR data using powerful software and algorithms.

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Worldwide, research has demonstrated the effectiveness of UAV and LiDAR in topographic surveying (Chudley et al., 2019; Guisado-Pintado et al., 2019; Guo et al., 2017; Lin et al., 2019; Salach et al., 2018). For instance, a study by Lin et al. (2019) illustrated the applicability of UAV LiDAR for mapping coastal environments. The results indicated that both UAV LiDAR and photography techniques provide high-resolution and high-quality terrain data, with point clouds generated by both methods compatible within a range of 5–10 cm. This ensures accuracy in identifying changes in shoreline dynamics along the southern shore of Lake Michigan, specifically in Dune Acres and Beverly Shores.

Guo et al. (2017) employed a low-cost UAV LiDAR system to collect and process LiDAR data for biodiversity studies in China. The research area encompassed a diverse array of land cover types, including mixed coniferous-broadleaved forests, deciduous broad-leaved forests, and mangrove forests. The research findings demonstrated that the UAV LiDAR system could generate highly detailed 3D terrain and vegetation model with remarkably high resolution.

Salach et al. (2018) conducted a comparison between two Digital Terrain Models (DTMs) generated using airborne LiDAR and aerial imagery at the same location with different areas featuring varying vegetation covers. The results indicated that the DTM generated from LiDAR data was more accurate than the DTM created from aerial photography. Specifically, in areas with low and sparse vegetation cover, the accuracies of these two DTMs were 0.11 m and 0.14 m, respectively. In areas with an average vegetation cover of 60 cm, the corresponding accuracies of these two DTMs were 0.11 m and 0.36 m.

In Vietnam, although the application of UAV technology in topographic surveying has only become popular in recent years, its effectiveness has been remarkably high, particularly in mapping and creating 3D models in challenging areas, such as: urban areas (Le et al., 2022), military areas, open-pit mines (Nghia, 2020; Nguyen et al., 2020; Tien Bui et al., 2017). In a study by Thang and Long (2021), the combined use of the UAV Phantom 4 RTK and LiDAR Matrice 300 RTK was applied for surveying and establishing 3D maps in weak-dumping areas in Quang Ninh province. This study successfully produced a topographic map with a scale of 1:1,000 and DEM with achieved errors ranging from 0.026 m to 0.033 m in the horizontal plane and 0.029 m to 0.037 m in elevation, demonstrating the high effectiveness of the method and fully meeting the accuracy requirements for creating topographic maps.

The integration of UAV imagery and ground LiDAR data in point cloud generation demonstrates that this combined dataset allows for the creation of highly detailed and as accurate point clouds as to the millimeter scale. This has been observed in various applications, such as industrial mining areas (Cao et al., 2022), where the combined data facilitated the establishment of detailed and precise point clouds. Similarly, in urban areas, the integration has enabled the creation of LoD 3-level 3D models of high-rise buildings with an accuracy reaching a scale of 1:500 (Le et al., 2022).

Research on algorithms for processing UAV LiDAR data is also addressed. A study by (Tran et al., 2022) focuses on processing LiDAR point clouds using UAV in densely vegetated areas to establish DTM. The application of a simple morphological filter (SMRF) reduces the point cloud density for DTM establishing, ensuring smooth, accurate, and consistent contour interpolation for large-scale topographic maps. Specifically, this method was applied to establish the topographic map with a scale of 1:2,000 with a contour interval of 1.0 meter, in the Ba Be National Park, Bac Kan province, Vietnam.

Overall, research conducted both globally and in Vietnam illustrates the substantial benefits of integrating UAV and LiDAR technologies for data collection in various fields, particularly in topographic surveying. The versatility of UAVs in aerial photography, combined with the integration of advanced technologies like GNSS and LiDAR, alongside the high precision and processing efficiency of LiDAR, enables the development of comprehensive and effective solutions for geographic data collection and processing, especially in rugged terrain conditions. This facilitates the generation of large-scale topographic maps with exceptional accuracy and detail.

Figure 1. Location of Quang Tri Win 3 Wind Power Plant project

Especially in Vietnam, its diverse terrain featuring mountains, valleys, plains, and coastal areas pose numerous challenges in land resource management and urban planning. The technological and legal frameworks for geographic data collection are also garnering attention and steadily improving. Hence, the adoption of UAV LiDAR technology for topographic surveying in Vietnam is imperative. Data collection in complex terrains like mountains and forests is easier and more efficient with this technology.

2 Research area, equipment used, and study methodology

2.1 Study area and data requirements

The Quang Tri Win 3 Wind Power Plant project area is located in Huc commune, a mountainous region in the southern part of Huong Hoa district, Quang Tri province (Figure 1). The terrain of the project area is complex and hazardous, characterized by intertwining mountains and rivers, forming rugged landscapes. The land cover in the project area is diverse, with dense old-growth forests interspersed with cultivated and fallow lands. The climate exhibits typical features of a tropical climate, with monsoon winds and year-round hot and humid conditions, with an average annual temperature of 22 degrees Celsius and an average rainfall of 2,262 mm per year.

The Quang Tri Win 3 Wind Power Plant project is part of the Quang Tri Win 1–6 Wind Power Plant Project Cluster, developed by Win Energy Development Company Limited (Win Energy Development) scheduled to commence operations in 2025. The project is currently in its design phase. Its main components include the wind power plant, a 500 kV substation, and connecting transmission lines. The wind power plant has a capacity of 48 MW, utilizing wind turbines with an expected capacity of 4 MW each.

The Project covers an area of 2,577,792 m^2, characterized by varied, rugged mountainous terrain with elevation differences exceeding 300 meters, multiple layers of vegetation including old-growth forests, plantations, and cultivated fields. Travel is difficult, with only one winding and steep village road. Therefore, movement and direct surveying within the project area are difficult. The survey area itself is characterized by complex and hazardous terrain with its undulating hills, rich old-growth forests, and variable weather conditions, making conducting topographic surveys extremely important.

The wind power plant is a specialized construction project requiring geographic data for the purpose of design and operational management, including:

i. 3D models: Consisting of point cloud, DSM, and DEM accurately depicting the shape and characteristics of the mountainous terrain. The point cloud is in *.LAS format, while DSM and DEM are in geotiff format.
ii. A topographic map: 1:1,000 scale with a contour interval of 1.0m, providing accurate information on terrain features, slope, elevation, and other characteristics. The terrain map format is *.dxf.
iii. An orthophotomosaic: Orthophotomosaic with the same scale and coordinate system as the topographic map, providing comprehensive information on the raw surface of the project area and its surrounding environment. The format is geotiff.

The collected geographic data is in the VN2000 Vietnam national coordinate system, with a projection zone of 3°, a central meridian of 106.25° (central meridian for Quang Tri province), and the national elevation system. The data should be detailed and accurate, in standard formats to facilitate information exchange between different software and systems such as GIS (Geographic Information System) and CAD (Computer-Aided Design) to optimize the design process. These geographic data serve multiple purposes, including: (1) calculating the power output of turbines and selecting turbine installation locations, (2) designing infrastructure for construction and operation of the project, and (3) calculating and designing transformer substations and electrical transmission systems.

Given the requirement and purpose of such topographic surveying and the complex terrain and large area of the project, using traditional methods poses many difficulties and is costly. Therefore, the integration of UAV and LiDAR technology is an ideal choice, helping to save time and manpower while providing comprehensive data and delivering accurate measurement results as required.

2.2 Equipment used

The equipment used in the study consists of the Zenmuse L1 mounted on the DJI Matrice 300 RTK UAV.

DJI Matrice 300 RTK UAV:
The DJI Matrice 300 RTK integrates stable flight capabilities, high performance, and accurate Real-Time Kinematic (RTK) positioning. The main components attached to the UAV body include: GNSS RTK positioning system, six-directional obstacle avoidance sensors (left, right, front, top, bottom), four motors and detachable propellers, and fixed landing gear below the fuselage (Figure 2a). The integrated GNSS RTK component enables real-time positioning of the scanner's center with an accuracy of up to 2 cm and provides guidance to the UAV during the scanning flight.

Zenmuse L1:
The Zenmuse L1 is mounted on the Matrice 300 RTK (Figure 2b), integrates a Mid70 LiDAR sensor, a high-accuracy Inertial Measurement Unit (IMU), and a Red Green Blue (RGB) camera with a 1-inch CMOS on a 3-axis stabilized gimbal. The technical parameters of Zenmuse L1 are detailed in Table 1.

The Mid70 LiDAR sensor is capable of collecting spatial data with high accuracy and detail. This sensor has a data collection range of up to 450 meters and a point rate of up to 480,000 points/s. Its accuracy is 3 cm over a measuring range of 100 meters.

The IMU aids in tracking the motion and position of the aircraft in space. With a refresh rate of 200 Hz and high accuracy, the IMU ensures that every movement and transformation of the aircraft is recorded and processed accurately.

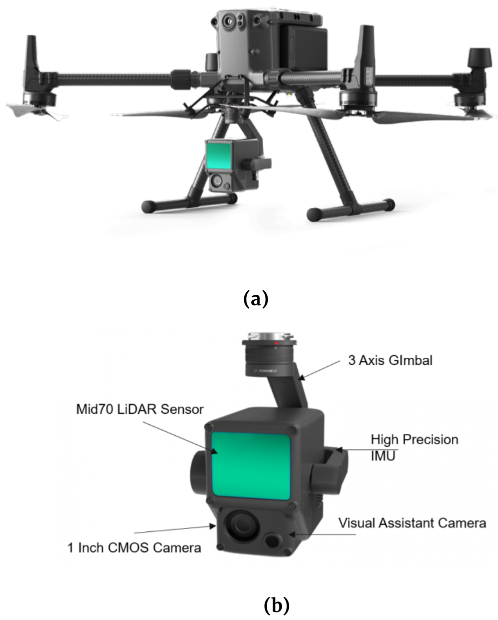

Figure 2. (a) DJI Matrice 300 RTK; (b) Zenmuse L1, (https://Images.App.Goo.Gl/V6CVgVWcb5g2PqUp8)

The RGB camera provides high-quality color images of the surrounding environment during LiDAR scanning. With a sensor size of 1 inch and a resolution of 20 MP, this camera is capable of capturing images in various lighting conditions.

The 3-axis gimbal keeps the Lidar sensor, IMU, and RGB camera stable during flight, ensuring that the collected data is clear and free from vibration. The gimbal has a wide range of rotation, from -120° to +30° in tilt and ±320° in pan, allowing the aircraft to scan the surrounding environment flexibly and effectively.

The Zenmuse L1 combined with the Matrice 300 RTK is a powerful system for topographic surveying and 3D modeling. This system provides the capability to collect data with high accuracy and a high acquisition speed, facilitating research and development of applications in data collection not only in topographic surveying but also in other fields.

2.3 Research methodology

The terrain surveying in the Project area was conducted following the procedure outlined in Figure 3.

Preparation: collecting existing geomatic data (topographic maps, cadastral maps, national geodetic benchmarks), preparing equipment, and obtaining the necessary permits for UAV flights.

In this step, we collected 2 national coordinate benchmarks and 1 national elevation benchmark. Obtaining UAV flight permits required over 1 week at the Operations Bureau, General Staff Headquarters at No. 1 Nguyen Tri Phuong, Ba Dinh District, Hanoi.

Establishment of control point network: A coordinate-elevation control point network was established to facilitate precise positioning during flight operations and to measure control points, and check points.

In this step, we identified and established the network of 4 control points and selected suitable positions for these points. The control points have accuracy equivalent to Class 1 traverse in term of horizontal and Class IV leveling in terms of elevation (Circular, 2015). Additionally, we identified 20 check points as fixed geograph-

Table 1. Main technical parameters of the Zenmuse L1

Lidar sensor	
Detection Range	450 m @ 80% reflectivity, 0 klx 190 m @ 10% reflectivity, 100 klx
Point Rate	Single return: max. 240,000 pts/s Multiple return: max. 480,000 pts/s
Ranging Accuracy (RMS 1σ)	3 cm @ 100 m
Inertial Navigation System	
IMU Update Frequency	200 Hz
Yaw Accuracy (RMS 1σ)	Real-time: 0.3°, Post-processing: 0.15°
Pitch / Roll Accuracy (RMS 1σ)	Real-time: 0.05°, Post-processing: 0.025°
RGB Mapping Camera	
Sensor Size	1 inch
Effective Pixels	20 MP
Shutter Speed	Mechanical Shutter Speed: 1/2000 – 8 s Electronic Shutter Speed: 1/8000 – 8 s
Gimbal	
Stabilized System	3-axis (tilt, roll, pan)
Angular Vibration Range	0.01°
Mechanical Range	Tilt: -120° to +30°; Pan: ±320°

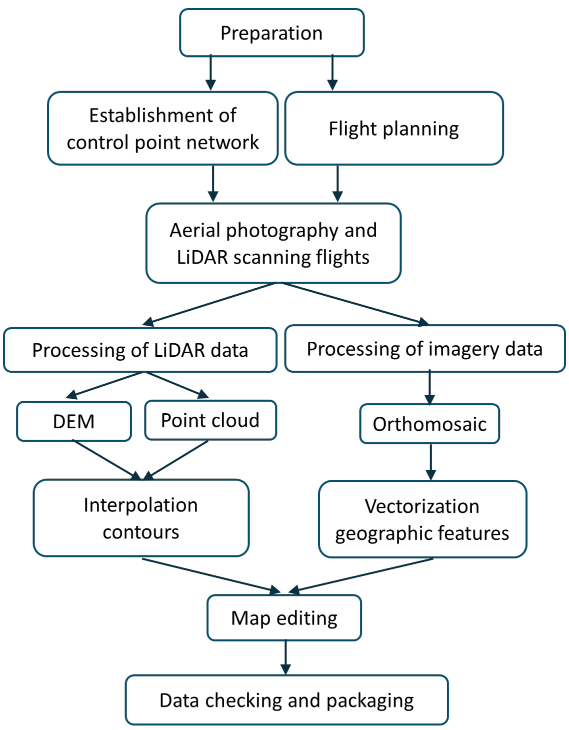

Figure 3. Topographic surveying process in the Win 3 Wind Power Plant project area using UAV LiDAR

ical features, easily recognizable both in imagery and on-site. The control network was measured by GNSS statistic using 03 Trimble R8s GNSS receivers for horizontal coordinates and by a Leica NA720 automatic level for elevation.

Flight planning: includes determining the coverage area, flying altitude, number of flight lines, overlap between images, etc.

In this step, the flights were planned directly within the DJI Pilot software. Considering the area and terrain characteristics of the survey area in the project, we determined the flying altitude for image acquisition to 121 meters above the control station, with a vertical overlap of 81% and a horizontal overlap of 74% (see Figure 4), and the ground sampling distance (GSD) at 6.5 cm/pixel.

Aerial photography and LiDAR scanning flights: Conducting aerial photography and LiDAR scanning flights according to the designed plan to collect data of the surveyed area. This step requires selecting a GNSS base station in an open area to facilitate GNSS signal reception and UAV control.

In this step, we selected a high and open area to facilitate flight control and the GNSS signal reception, and broadcast correction data from the GNSS base station to the GNSS RTK positioning device on the UAV Matrice 300 RTK. Subsequently, LiDAR scanning and aerial photography flights were conducted simultaneously. Data acquisition flights for both imagery and LiDAR were carried out for approximately 2 hours in clear, sunny-weather conditions.

Processing of imagery and LiDAR data: The data collected during the flight operations underwent processing using specialized software to create a point cloud, DEM, and orthomosaic at predefined scales, accuracies, and within the coordinate reference system specified by the set requirements.

In the processing of imagery data, the aerial imagery data collected for the project was primarily processed to create an orthomosaic with a scale of 1:1,000. Agisoft Metashape Professional software was used with general input parameters for aerial imagery processing. The coordinate system was set to VN-2000/TM-3 106-15 (EPSG:9212), and the rotation angles were set to Yaw, Pitch, and Roll. The processing of aerial imagery data involved the following main steps: (1) aligning the individual images to correct any discrepancies and ensure proper spatial registration, and (2) generating the orthomosaic by compiling the aligned images and correcting any distortions to produce a seamless orthomosaic representing the surveyed area. The orthomosaic was saved in GeoTIFF-24bit format.

In the processing of LiDAR data, the LiDAR data collected for the Project was used to generate a DEM and a point cloud. Using DJI

Terra software was used with the input parameters for generating the DEM set to "By GSD" at 0.25 m/pixel. The output coordinate system was set to "VN-2000/TM-3 106-15" for horizontal datum and "Hon Dau 1992 height" for geoid. The DEM was saved as raster files in the GeoTiff-32bit format (*.tif) and the point cloud data was saved in *.las format.

The orthomosaic ensures resolution and the DEM ensures grid size according to (Circular, 2021). These datasets are processed within the VN2000 national coordinate system, with the projection zone of 3°, the central meridian of 106,25° and using the Vietnam national elevation system.

Map editing: This step involves vectorization of geographic features on the orthomosaic, interpolating contour lines from the DEM, and presenting the map according to the relevant technical standards.

In this step, we interpolated contour lines at regular intervals of 1.0m based on the DEM generated using DJI Terra software. The interpolated contour lines were saved in *.dxf format. Then, vectorization of geographic features on the orthomosaic with a scale of 1:1,000 into vector format was performed using AutoCAD software according to (Circular, 2015). The geographic features were vectored and organized into layers including: Human Settlements, Socio-Economic, Transportation, Hydrology, and Vegetation. Subsequently, the topographic map was edited and presented according to (Circular, 2018) using AutoCAD software. The editing process involved standardizing features in terms of color, line style, font size, and terminology; symbolization for features; and annotation for clarification of features.

Data checking and packaging: The topographic surveying products, including topographic maps, orthomosaic, DEM, and DSM generated from the aerial photography and LiDAR scanning processes, undergo validation and packaging according to (Circular, 2018). This includes compiling and organizing the delivered data, which consists of control point network measurement data, UAV GNSS data, original image data, point cloud data, DSM, DEM, topographic, and orthomosaic.

2.4 Evaluation of Accuracy

Evaluating accuracy is a crucial task to demonstrate that the results of establishing the topographic map of the project area from aerial photography and LiDAR data achieve the required level of accuracy and are suitable for the project's engineering design purposes.

The accuracy of the established topographic map is evaluated based on the easting and northing coordinates and elevations determined on the map ($E_i^{map}, N_i^{map}, H_i^{map}$) and those determined in the field using direct measurement technologies ($E_i^{RTK}, N_i^{RTK}, H_i^{RTK}$) of the checkpoints, using the following formulas:

$$RMS_E = \sqrt{\frac{\sum_{i=1}^{n}(E_i^{map} - E_i^{RTK})^2}{n}} \tag{1}$$

$$RMS_N = \sqrt{\frac{\sum_{i=1}^{n}(N_i^{map} - N_i^{RTK})^2}{n}} \tag{2}$$

$$RMS_H = \sqrt{\frac{\sum_{i=1}^{n}(H_i^{map} - H_i^{RTK})^2}{n}} \tag{3}$$

$$RMS_{2D} = \sqrt{RMS_E^2 + RMS_N^2} \tag{4}$$

where RMS_E, RMS_N represent the root mean square errors in the easting and northing coordinate components, respectively; RMS_H denotes the root mean square error in the elevation component; and RMS_{2D} signifies the root mean square error in the horizontal position of the checkpoints.

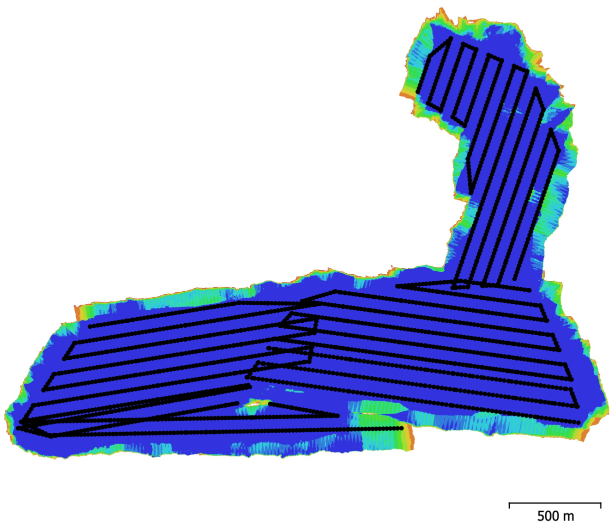

Figure 4. Camera locations and image overlap

3 Results and discussion

3.1 Aerial photography and LiDAR scanning results

As mentioned in section 2.1, the objective of this study is to create a topographic map with a scale of 1:1000, with an interval of contours of 1.0 m, covering a survey area of approximately 2,577,792 square meters for the WIN3 Wind Power Project. The terrain in this area is characterized by mountainous forests with elevation differences of over 300 m, and it encompasses a diverse range of vegetation types, including old-growth forests, planted forests, and agricultural fields.

The aerial photography was conducted at a height of 151 m, with a total of 2,547 images covering an area of approximately 3.65 km^2. The photography flight lasted approximately 2 hours. The Zenmuse L1 system has camera specifications adjusted to a focal length of 8.8 mm, pixel size of 2.41x2.41 μm, and resolution of 5472x3648, equivalent to a ground resolution of 4.22 cm/pixel. According to (Circular, 2021), with this resolution, the aerial photography results fully meet the accuracy requirements for a topographic map to be produced with a scale of 1:500 with a contour interval of 0.5 m. The LiDAR scanning process was carried out simultaneously with the photography using the Zenmuse L1 system, with a scan rate of 720 kHz, laser pulse rate of 240 kHz, and point cloud density of 229 points/m^2.

3.2 Data processing results

The results obtained after processing aerial imagery and LiDAR data from the Zenmuse L1 include point clouds, DEM, orthomosaic, and topographic map. These terrain survey products are processed in the Vietnam national coordinate system VN2000, with a central meridian of 106.25° and a projection zone of 3°, and the Vietnam national elevation system.

Point cloud:
Figure 5 illustrates the point cloud representation of the project area, derived from UAV LiDAR data processing. The point cloud, comprises a total of 255,399,039 points, corresponding to a density of 229 points/m^2. This high-density point cloud ensures accurate and reliable processing of detailed terrain information.

The point cloud describes detailed spatial information about the mountainous forest terrain, highlighting various land cover types including dense forest, clearings, agricultural fields, and such

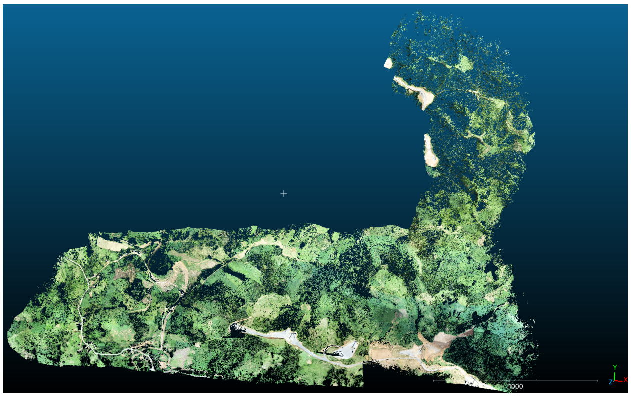

Figure 5. Point cloud of project area

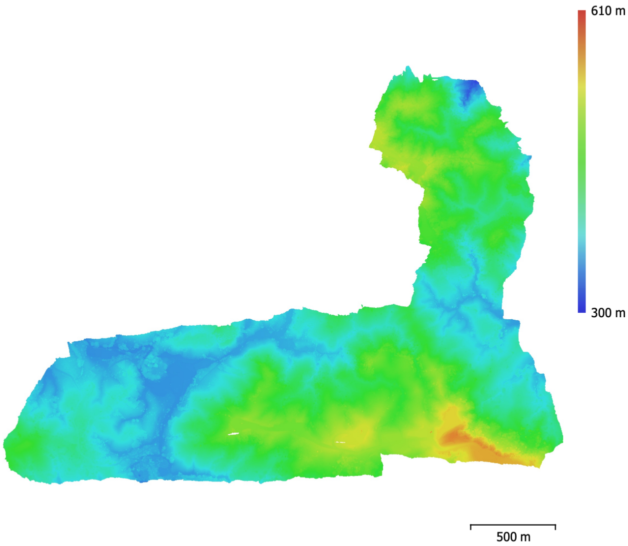

Figure 6. DEM of project area

infrastructure such pathways and roads. This visualization demonstrates the capability of UAV LiDAR technology to map complex and inaccessible terrains accurately. Each point in the cloud represents a precise geolocation, providing a three-dimensional model that reveals the topographic nuances and vegetative structure of the area.

DEM:
The DEM obtained is in GeoTiFF 24-bit format (Circular, 2021), with a resolution of 25 cm/pixel and a point density of 229 points/m^2 after filtering (Figure 6). Point density in DEM is an important metric assessing the quantity of data points used for terrain modeling. Higher point density can offer better surface terrain detail but also generates a larger dataset. For this project's DEM, the point density is 229 points/m^2, ensuring an optimal balance between detail and computational efficiency. With such DEM accuracy, it guarantees precision for tasks requiring high accuracy, such as contour interpolation with an interval of 0.5 m (Circular, 2021).

The accuracy of the DEM was verified through a comparison with independent ground truth data, terrain flatness checks, and other methods to ensure the correctness and reliability of the DEM data.

The DEM of project area illustrates the terrain elevation variations, with elevation values ranging from 300 meters to 610 meters in national elevation system, as indicated by the color gradient scale. Lower elevations are represented by blue hues, while higher elevations are shown in red. This high-resolution DEM provides a comprehensive visualization of the topography, capturing the complex terrain features including ridges, valleys, and slopes. The detailed elevation data is crucial for an accurate topographic mapping and analysis, particularly in inaccessible and densely vegetated areas covered by the project.

Figure 7. Orthomosaic of project area

Orthomosaic:
The obtained orthomosaic features high resolution and accuracy, providing a comprehensive view of the terrain and environment within the study area. The orthomosaic is stored in GeoTIFF 24-bit format (Circular, 2021), with data processed in the VN2000 coordinate system, in a projection zone of 106.25 degrees. It has dimensions of 78,324 x 58,516 pixels, with color represented in 3 uint8 format bands.

Figure 7 illustrates the orthomosaic of processed result of aerial imagery of WIN3 Wind Power Project area. The high-resolution orthomosaic image reveals detailed topographic and vegetation features across the surveyed area, exhibiting the spatial distribution of land cover types, including dense forest patches, agricultural areas, constructions, houses, and pathways.

Topographic map:
The topographic map of the project area is generated after editing from the geographic features vectorization and contour interpolation results, saved in *.dxf format. The contour interpolation process and vectorization of geographic features are executed swiftly and accurately, facilitated by the comprehensive LiDAR data acquisition and the clear and sparse nature of the terrain features within the project area, primarily consisting of newly constructed wind energy projects. The topographic map of the project area has a scale of 1:1,000 with an interval elevation of 1.0m (Figure 8), as required by the project, ensuring strict adherence to technical specifications (Circular, 2018).

This topographic map provides an accurate and detailed representation of the project area, essential for planning, analysis, and decision-making in various engineering, environmental, and construction of project.

3.3 Accuracy Assessment Results

The research findings (Mai et al., 2017; Nguyen, 2021; Doi et al., 2022) consistently indicate that, utilizing UAV imaging technology alone is sufficient to ensure the accuracy of large-scale mapping, up to a scale of 1:500. However, in this study, assess the accuracy of the established topographic map, aiming to verify and affirm the

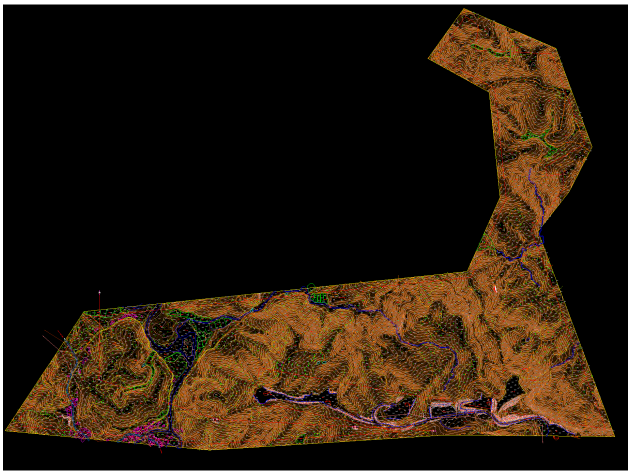

Figure 8. Topographic map of project area

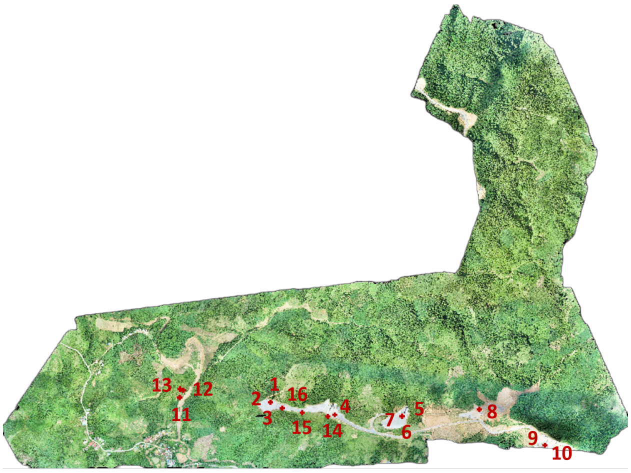

Figure 9. Location of checkpoints on photomosaic of project area

accuracy of the image and LiDAR data processing in creating the topographic map with a scale of 1:1,000 with an interval contour of 1.0 m for the Project area. We identified 16 checkpoints, numbered from 1 to 16 and illustrated in red in Figure 9, which are distinct terrain points clearly identifiable on the topographic map and easily measurable in the field, specifically including transformer station corners (check-points 4 and 8), turbine base points (check-points 1, 2, 3, 5, 6, 7, 9, and 10), power pole points (check-points 14, 15, and 16), and residential house corner points (check-point s 11, 12, and 13). In the field, these points were directly measured using GNSS RTK technology, namely, the Trimble R8s device. The coordinates and elevations determined on the created topographic map (map-defined) and directly measured (field-measured) for these checkpoints are presented in Table 2, with the discrepancies between them shown in Table 3.

Using formulas (1–4) we calculated the RMS errors for the horizontal coordinates as follows: RMS_E = 0.020 m, RMS_N = 0.020 m, The RMS error for the elevation component is RMS_H = 0.035 m, and the RMS error for the 2D position is RMS_{2D} = 0.028 m.

The computation results reveal that the errors in both the N and E coordinates are 2.0 cm, the positional error reaches 2.8 cm, and the elevation error is 3.5 cm. Therefore, after comparing and assessing these errors, it can be observed that the results obtained from the aerial imagery and LiDAR scanning by UAV significantly meet the accuracy requirements for establishing a topographic map with a 1:1000 scale with a uniform elevation interval of 1.0 m (Circular, 2018).

3.4 Discussion

The UAV LiDAR technology enables laser scanning with dense point clouds, coupled with high-resolution imagery and GNSS RTK positioning technology, facilitating convenient geographical data collection. In the case of the Win 3 Wind Power Project, situated in an area with complex terrain and diverse ground cover, this technology has demonstrated its suitability and ensured accuracy for establishing large-scale topographic maps with a 1:1,000 scale as per the project requirements. The high accuracy of the data collected from UAV LiDAR also meets the demands for maps with scales larger than 1:500.

With a survey area extending up to 3.65 km^2, the flight time for image capture and scanning of about 2 hours is sufficient and is which is significantly less than using traditional surveying methods. DJI Terra and Agisoft Metashape software have significantly facilitated the processing of image and LiDAR data, generating high-precision 3D models and topographic maps.

In the challenging mountainous forest area of the Project, direct surveying for mapping is not feasible. Therefore, we did not compare the topographic map of our study with a topographic map established by direct surveying technology. Instead, we based our comparison on 16 checkpoints that are easily accessible for direct measurement using GNSS RTK. The evaluation results of these checkpoints show that both horizontal and vertical accuracies are reliable. This not only meets the project's requirement for topographic map with a 1:1,000 scale but also satisfies the needs for a larger-scale maps of 1:500. Similar to studies conducted by Lee and Park (2019); He and Li (2020); Wang et al. (2023) in other regions, maps produced using UAV LiDAR technology consistently achieve high accuracy with larger-scales.

Although it was not necessary to integrate direct surveying methods for dense vegetation areas within the project site, in practice, for other such areas where topographic maps need to be generated with larger scales, such as 1:200, it is important to consider integrating direct surveying technology. Additionally, it is crucial to evaluate the economic efficiency of applying this technology as compared to other technologies for similar mountainous areas in the specific conditions in Vietnam. Further studies are needed to explore the capabilities and limitations of the technology in other areas, particularly those with complex, hazardous terrain and dense vegetation.

At present, the legal regulations in Vietnam regarding the use of UAVs for aerial surveying, and the technical standards for UAV image usage in topographic mapping, are comprehensive and stringent. Adhering to legal regulations and technical standards is particularly important to ensure the accuracy and reliability of the collected data.

The study result is innovative in the context of applying UAV LiDAR technology in Vietnam where UAV LiDAR technology is becoming an inevitable trend in the field of geographical data collection, especially in large-scale topographic mapping.

4 Conclusion

In this study, we employed aerial LiDAR and photography UAV to create topographic maps with a scale of 1:1,000 with interval contour at 1.0 m, as well as a point cloud, DEM and orthomosaic for the Win3 Wind Power Project area, located in Huong Hoa district, Quang Tri province, Vietnam, an area characterized by complex mountainous terrain. The results demonstrate that this technology is a robust and efficient tool for geographic data collection, particularly in complex terrain conditions.

The geographic data collected from UAV LiDAR provides detailed and reliable information regarding coordinates, elevation, and ground structure, with a point density reaching 229 points/m^2 and the accuracy of LiDAR measurements within the surveyed area

Table 2. Coordinates map-defined and field-measured of checkpoints

No	Code	Coordinates on topographic map			Coordinates on site		
		E_i^{map} [m]	N_i^{map} [m]	H_i^{map} [m]	E_i^{RTK} [m]	N_i^{RTK} [m]	H_i^{RTK} [m]
1	checkpoint1	553772.597	1836449.331	488.010	553772.607	1836449.301	487.970
2	checkpoint2	553770.137	1836451.792	488.050	553770.117	1836451.762	488.100
3	checkpoint3	553767.676	1836449.331	488.032	553767.656	1836449.361	488.042
4	checkpoint4	554096.393	1836391.611	481.400	554096.413	1836391.621	481.440
5	checkpoint5	554478.055	1836394.693	524.120	554478.045	1836394.693	524.110
6	checkpoint6	554475.594	1836392.233	524.280	554475.614	1836392.233	524.270
7	checkpoint7	554473.134	1836394.700	527.700	554473.134	1836394.670	527.660
8	checkpoint8	554887.308	1836416.447	517.200	554887.278	1836416.417	517.160
9	checkpoint9	555222.795	1836225.631	557.050	555222.765	1836225.621	557.010
10	checkpoint10	555225.255	1836228.092	557.053	555225.275	1836228.082	557.093
11	checkpoint11	553309.962	1836508.590	348.300	553309.972	1836508.560	348.300
12	checkpoint12	553317.451	1836521.490	348.720	553317.481	1836521.490	348.680
13	checkpoint13	553311.970	1836524.440	349.500	553312.000	1836524.460	349.460
14	checkpoint14	554076.097	1836383.794	483.501	554076.087	1836383.794	483.501
15	checkpoint15	553955.214	1836396.853	492.703	553955.194	1836396.863	492.753
16	checkpoint16	553830.234	1836419.538	488.052	553830.244	1836419.528	488.012

Table 3. Discrepancies in coordinates between map-defined and field-measured of checkpoints

No	Code	Difference of coordinates [m]		
		$E_i^{map} - E_i^{RTK}$	$N_i^{map} - N_i^{RTK}$	$H_i^{map} - H_i^{RTK}$
1	checkpoint1	-0.010	0.030	0.040
2	checkpoint2	0.020	0.030	-0.050
3	checkpoint3	0.020	-0.030	-0.010
4	checkpoint4	-0.020	-0.010	-0.040
5	checkpoint5	0.010	0.000	0.010
6	checkpoint6	-0.020	0.000	0.010
7	checkpoint7	0.000	0.030	0.040
8	checkpoint8	0.030	0.030	0.040
9	checkpoint9	0.030	0.010	0.040
10	checkpoint10	-0.020	0.010	-0.040
11	checkpoint11	-0.010	0.030	0.000
12	checkpoint12	-0.030	0.000	0.040
13	checkpoint13	-0.030	-0.020	0.040
14	checkpoint14	0.010	0.000	0.000
15	checkpoint15	0.020	-0.010	-0.050
16	checkpoint16	-0.010	0.010	0.040

at approximately 0.57 cm. Simultaneously, UAV photography provides an overall image of the surveyed area with a high-resolution of 4.22 cm/pixel. The combination of these two technologies has resulted in high-quality topographic maps, digital models, and orthomosaic.

The assessment of the accuracy of the 1:1,000 scale topographic map reveals a horizontal RMS of only 0.028 m and an elevation RMS of 0.035 m. This not only meets the technical requirements of the project but also surpasses expectations, opening opportunities for utilizing maps with scales larger than 1:500.

This study has elucidated the potential and effectiveness of UAV LiDAR technology in geographic data collection and large-scale mapping in Vietnam. The development of this technology not only meets the needs of specific projects but also opens opportunities for diverse future applications.

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