Utilizing Unmanned Aerial Vehicles (UAVs) for Earthwork Fill Height Determination in Road Construction

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Abstract
Unmanned aerial vehicle (UAV) was utilized to determine fill height of earthwork construction project along a local road kilometer 16+675 to kilometer 17+275 in Nongthalay subdistrict, Muang district, Krabi province. The data processing was conducted on PIX4D and the heights were measured from point cloud generated from the UAV using QGIS software. The study compared elevation profiles obtained from UAV point cloud data with conventional leveling methods in the road construction project. The results revealed that elevation differences between the two methods ranged from 0.068 to 0.651 meter, with an average difference of 0.327 meter and a percentage difference of 1.06%. These differences exceeded the allowable error threshold of 0.010 meter recommended for leveling class III in road construction specifications. Consequently, the use of UAV technology for leveling in this scenario is questioned due to the significant disparities observed compared to conventional survey methods. Nevertheless, the accuracy of this method can be improved through strategies such as the integration of additional GCPs to enhance georeferencing precision, meticulous camera calibration, and careful consideration of UAV imagery resolution and flight altitude. Diligent planning is essential to ensure precise and reliable height determination. Incorporating UAV technology for elevation acquisition in road construction projects requires a thorough understanding of local road construction standards, project specifications, and design guidelines. These standards can vary by region and road classification, underscoring the importance of staying updated with the latest regulations to ensure accurate and compliant implementation.

Keywords: Earthwork, Elevation, PIX4D, Point cloud, Road construction, UAV

1. Introduction

The integration of Unmanned Aerial Vehicles (UAVs) or drones into diverse fields has heralded a transformative era, redefining the way we collect data, monitor landscapes, and make informed decisions across various industries. Among the many applications that have witnessed substantial growth and innovation in recent years, the use of UAV technology for crop monitoring and mapping has emerged as a compelling and indispensable tool. By harnessing the capabilities of these autonomous aerial platforms, practitioners in agriculture, environmental science, and related sectors have gained access to a wealth of high-resolution spatial data, empowering them to revolutionize their approaches to land management, precision agriculture, and resource optimization. However, the utility of UAV technology extends beyond agriculture, finding applications in environmental conservation, forestry management, land-use planning, and disaster response. UAVs equipped with specialized sensors can create high-resolution digital maps, detect changes in land cover, monitor deforestation, and assess the impact of climate change on ecosystems. Furthermore, in the wake of natural disasters, such as wildfires or floods, UAVs can rapidly capture detailed aerial imagery, supporting emergency response teams and facilitating disaster management. The application of Unmanned Aerial Vehicles (UAVs) in the construction industry has ushered in a new era of efficiency and precision [1] and [2]. These remotely operated aircraft, commonly referred to as drones, have revolutionized the way road construction projects are planned, executed, and monitored.

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The versatility of UAV technology transcends the construction sector and extends into various other fields, including agriculture, where it has found utility in crop height monitoring and yield estimation [3][4][5]and [6].

In the realm of road construction, UAVs have emerged as indispensable tools, offering a gamut of benefits that range from enhanced surveying capabilities to project management. The ability to capture high-resolution aerial imagery, create detailed topographic maps, and collect volumetric data with precision has transformed the way engineers and construction professionals approach their work. The integration of UAV technology in the construction industry is poised to significantly streamline processes, improve safety, and deliver cost-effective solutions. Currently, unmanned aerial vehicles, commonly referred to as drones, are extensively integrated into various facets of the construction industry. Their applications span from survey planning and construction survey control to inspections and project deliveries. The use of drones for building inspections, however, is not without limitations. These include their inability to provide comprehensive wide-angle views, making it challenging to inspect certain areas. Moreover, there's a risk to inspectors' safety, particularly in tasks like roof inspections or assessing the exterior walls of buildings [7][8] and [9]. The construction industry is increasingly embracing modern technology, which enhances efficiency and reduces costs. Among these technologies, unmanned aerial vehicles, or drones, have gained immense popularity. They are applied throughout the construction project lifecycle, from pre-construction stages to post-construction activities. These UAVs provide data in both 2D and 3D formats, facilitating applications such as project surveying, contour line preparation, progress tracking, quality control, and risk management.

Point cloud is a collection of data points in a three-dimensional coordinate system, often used to represent the shape and characteristics of objects or surfaces in the physical world. Each point in a point cloud typically has X, Y, and Z coordinates, which define its position in 3D space. Point clouds are generally generated from terrestrial laser scanning (TSL) using Light Detection and Ranging (LiDAR) sensor. The sensor emits laser pulses and measures the time it takes for the pulse to return. This data is used to calculate the distance to objects, creating a 3D representation of the environment [10] and [11]. However, the LiDAR sensor comes with a high cost [12], so opting for photogrammetry is another viable choice for height measurement. In photogrammetry, the UAV captures a series of overlapping images from different angles. These images are then processed to create a 3D point cloud by matching common features in the images. Specialized software is used to process the images, match keypoints, and create a dense point cloud. This process often involves bundle adjustment and multi-view stereo techniques. After data processing, a set of 3D coordinates for each point in point cloud will be generated. These coordinates represent the location of objects, terrain, and features in the surveyed area. Generating point clouds from UAVs is a valuable tool in fields like surveying, agriculture, construction, and environmental monitoring. The choice of sensor (LiDAR or photogrammetry) will depend on the specific requirements of projects, including the level of detail and accuracy needed [13].

3D model point cloud of road construction is a valuable asset for various purposes, such as project planning, progress monitoring, quality control, and asset management. It offers a highly detailed representation of the road construction site in three dimensions. It also provides a detailed, accurate, and dynamic representation of the construction site, enabling better decision-making, improved quality control, and enhanced safety throughout the construction process. Additionally, it serves as a valuable resource for documentation and future asset management, contributing to the long-term success and sustainability of road infrastructure [14][15] and [16]. The 3D model point cloud can be compared with the original design to verify that the constructed road aligns with the specifications. This is crucial for ensuring quality and compliance with standards. Additionally, point clouds can reveal defects or imperfections in the construction, such as surface irregularities, improper grading, or drainage issues, which can then be addressed promptly [17] and [18].

The Department of Highways, Thailand actively promotes the adoption of diverse technologies in ongoing construction projects. This drive aims to modernize the agency, ensuring optimal efficiency, given the nature of its involvement in road and bridge works, often spanning long distances. Traditional methods of data collection in construction projects have proven time-consuming and costly, especially during quantity calculations and height measurements. The theodolite-based approach, for instance, is known for its high costs and complexity. To address these challenges, the unmanned aerial vehicles was introduced to the Department of Highways' construction projects. This integration has revolutionized data collection and project management, significantly enhancing convenience, speed, and overall work efficiency beyond the capabilities of the original system.

The objective of this study is to Evaluate the accuracy and precision of UAV-based elevation data collection methods in comparison to traditional surveying techniques, and develop practices and recommendations for the adoption of UAV technology in elevation data collection along the profile for road construction, considering regulatory compliance, data accuracy, and road construction standards.

2. Study area and data

The research area pertains to a road expansion project, spanning from a two-lane to a four-lane configuration, within the geographical bounds of Nongthalay subdistrict, Muang district, Krabi province. The project encompasses the stretch from kilometer 16+675 to kilometer 17+275. To establish the elevations along the road profile, both conventional survey methods employing a digital surveyor's telescope and Unmanned Aerial Vehicle (UAV) point cloud data were employed. The assessment of fill heights was executed using both of these techniques, with observations conducted both prior to and after the completion of earthwork on November 24, 2021, and December 31, 2022, respectively. The acquisition of aerial photographs over the study area was accomplished through the deployment of a multirotor drone. Data processing was carried out using PIX4D software, and a point cloud dataset was generated through photogrammetry techniques utilizing the UAV.

3. Methodology

The methodology workflow of this study illustrates in Figure 1.

3.1 Preliminary Survey

Designate the positions for positioning 10 ground control points (GCP) and 24 check points (CP) within the specified study area, spanning from local road kilometer 6+675 to kilometer 17+275 in Nongthalay subdistrict, Muang district, Krabi province, Thailand. These GCPs and CPs were strategically placed both along the road and in adjacent off-road areas. The precise coordinates for all 34 points were obtained using the CHCNAV i50 GNSS receiver, utilizing the RTK positioning technique for precise positioning measurements. The locations of the GCPs and CPs illustrates in Figure 2. In the context of UAV photogrammetry, GCP and CP are two important terms that refer to specific points on the ground used to assess and improve the accuracy of photogrammetric mapping or surveying.

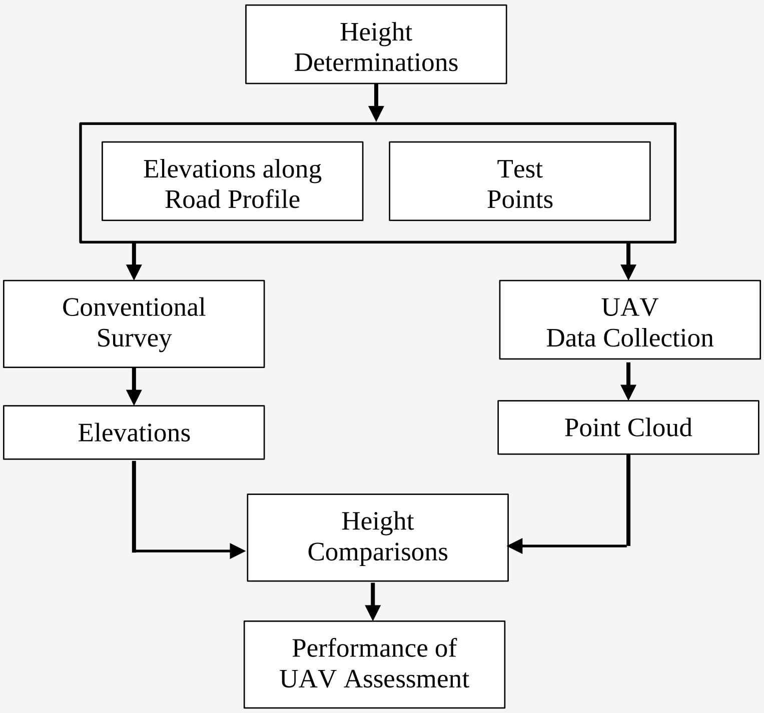

Figure 1: Study workflow

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Figure 2: Distribution of GCPs and CPs

GCPs are precisely located and known points on the Earth's surface with accurately surveyed coordinates. These points serve as reference markers that are visible in the images captured by the UAV. GCPs are typically marked on the ground with highly visible features like painted crosses or targets as depicts in Figure 3. The primary purpose of GCPs is to georeference the photogrammetric model, aligning the 3D model with the real-world coordinates. This allows for precise mapping, measurements, and integration with existing geospatial data.

CPs are additional points on the ground that are not used during the initial georeferencing process but are reserved for accuracy assessment. CPs have accurately surveyed coordinates that are not used during the initial processing of the photogrammetry project. After the initial photogrammetric model is created using the GCPs, the Check Points are used to assess the model's accuracy. By comparing the coordinates of the CPs in the model to their known surveyed coordinates, the level of precision and error in the photogrammetric mapping process can be determined. CPs are essential for quality control and validation. If the model's coordinates closely match the known coordinates of the CPs, it indicates that the photogrammetry process is accurate and reliable. If discrepancies are observed, adjustments or corrections may be needed.

In conclusion, GCPs are used in UAV photogrammetry to accurately georeference the photogrammetric model, aligning it with real-world coordinates. Check Points, on the other hand, are reserved for assessing the accuracy of the model after it has been created, serving as a quality control measure to validate the accuracy of the photogrammetric mapping process. Both GCPs and CPs play critical roles in ensuring the precision and reliability of UAV photogrammetry results.

Figure 3: GCP in the study area

3.2 UAVs and Flight Plan

The multi-rotor drone, specifically the 6-rotor type known as a Hexarotor as illustrates in Figure 4(a), is favored for its minimal take-off and landing space requirements, making it particularly well-suited for tasks in confined environments. Unlike other formats, this type of drone is user-friendly and thus ideal for operations with limited space constraints. The 6-rotor multi-rotor drone also boasts enhanced safety compared to the 4-rotor variety, commonly referred to as a Quadrotor. In the event of an unforeseen circumstance, such as a motor failure during a mission, the Hexarotor remains equipped to continue its operation, skillfully executing a controlled landing. Additionally, Hexarotor drones exhibit superior resilience in the face of strong wind conditions, further solidifying their suitability for various applications.

The drone was outfitted with a high-resolution camera, specifically the Sony A6000 as depicted in Figure 4b. This camera is capable of capturing images at the maximum resolution of 6000 x 4000 pixels (24.0 MP, 3:2 aspect ratio) and offers the convenience of an adjustable focal length ranging from 16 to 50 millimeters [19]. This feature provides a heightened level of flexibility, enabling precise control over flight altitude and image resolution in centimeters per pixel, facilitating easier adjustments as needed. The survey team conducted a comprehensive inspection of the points of interest, the topographical layout, and designated zones for drone operation control and management, the area should be away from tower structures, mobile networks, tall buildings, and towering trees, for example. The drone control and management area was established at Ban Khaoklom school situated in Krabi Province. This location was chosen due to its expansive grounds and level terrain, which make it ideal for drone operation. The area's lower elevation and minimal obstructions in the vicinity further enhance its suitability for managing and controlling the drones. After the flight data, as presented in Table 1, was calculated, the flight plan was created using the Mission Planner program, a tool designed for drone planning and control. The program's interface is depicted in Figure 5. In this study, a camera-equipped UAV was deployed to capture images of various sections of the area and subsequently stitch them together to create a single, high-resolution image. The Mission Planner program played a pivotal role in flight planning and drone control. The study involved the creation of three distinct flight plans, as depicted in Figure 6:

- Flightplan 1: Designed for comprehensive area coverage.
- Flightplan 2: Focused on detailed data collection within the area of interest.
- Flightplan 3: Aimed at enhancing the overall area's level of detail and completeness.

The data collections were made on 24 November 2021, and on 31 January 2023 before and after the earthwork was completed, respectively.

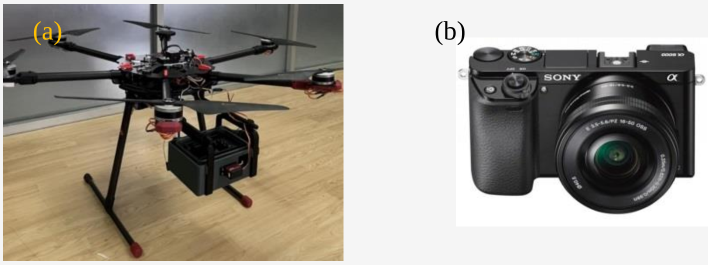

Figure 4: (a) Tarot Hexacoptor X6 drone (b) Sony A6000 camera

Table 1: Drone flight data

Description	
Overlap	85%
Sidelap	75%
Altitude	90 m
Ground Speed	7 m/s
Ground sample distance (GSD)	2.2 cm
Focal length	16 mm

Figure 5: Flight plan in mission planner software

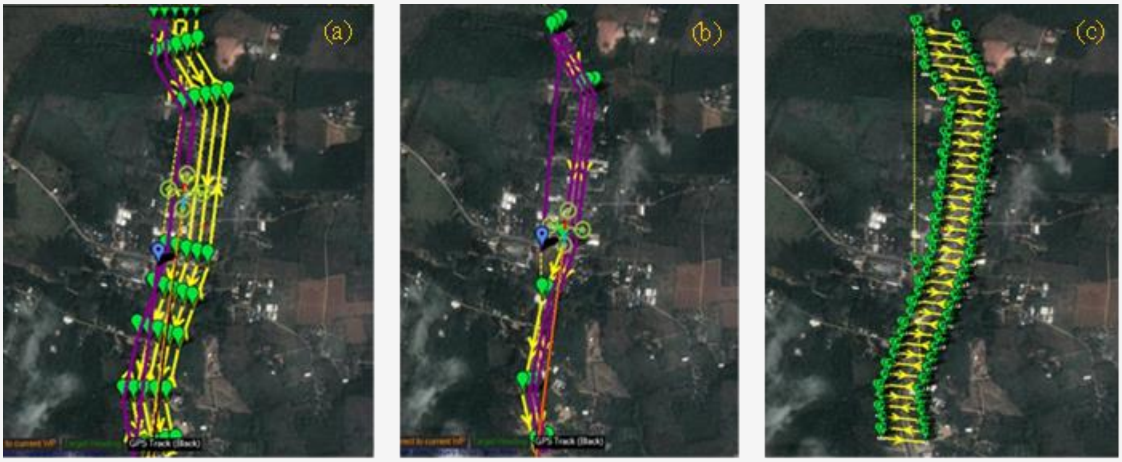

Figure 6: Flightplans in data collection: (a) Flightplan 1, (b) Flightplan 2, and (c) Flightplan 3

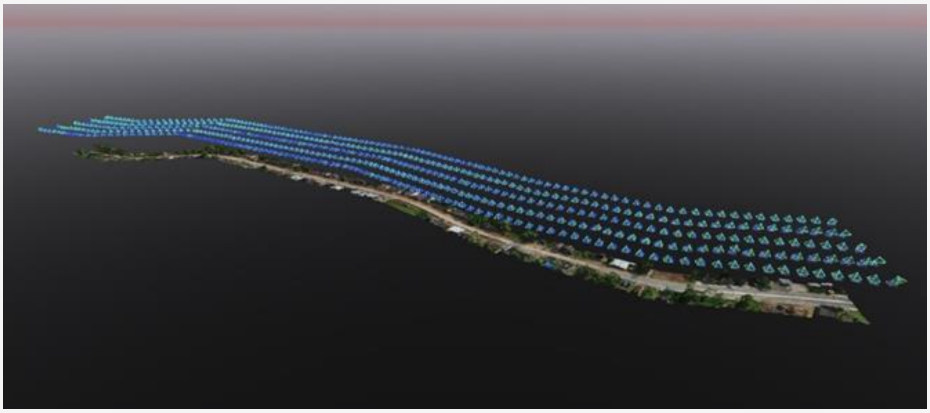

Figure 7: Image stitching in PIX4D

3.3 Image Processing

Once the flight plan had been configured within the Mission Planner program, the drone executed the prearranged plan. Following the successful completion of the mission, the captured images were subsequently imported into PIX4D, a specialized image stitching software, as illustrated in the Figure 7. A point cloud is generated from images through a process known as photogrammetry.

Photogrammetry is a technique that uses multiple 2D images to reconstruct the 3D geometry of objects and scenes. The image acquisition involved capturing a sequence of overlapping images of the scene or the object of interest, ensuring that these images were obtained from various angles and viewpoints. The greater the number of images, the higher the resulting point cloud's accuracy. Upon the completion of image processing, the results, including aerial photographs and a 3D point cloud, were generated. The point cloud will be utilized to determine the elevation of specific points or areas of interest, with the assistance of the QGIS program.

3.4 Leveling

In road construction, leveling with a surveyor's telescope is a conventional technique that helps ensure the road's safety, functionality, and alignment with engineering standards. It plays a vital role in the successful planning, construction, and quality control of road infrastructure projects. Surveyors use the telescope to establish elevation benchmarks and control points, ensuring that road segments are at the correct height relative to one another, verify the cross-sectional profiles of the road at different points along its length, and determine the road's desired grades and slopes. The surveyor's telescope as illustrates in Figure 8, often referred to as a dumpy level or level instrument, is an essential tool used in road construction to establish and maintain a level reference plane along the profile of a road. This instrument relies on basic principles of surveying and geometry to ensure that the road is built with the correct slope and elevation.

The road profile indicates the road's elevation at different points on the road centerline, allowing engineers to ensure the road is constructed with the desired grade or slope. Elevations for the road centerlines at 25-meter intervals or the elevations of each station along the road profile, were established through the use of a digital surveyor's telescope, and subsequently, the UAV-derived elevations were cross-checked against those acquired through the telescope. The accuracy of leveling using the conventional leveling is based on the total surveying distance as recommended in Table 2.

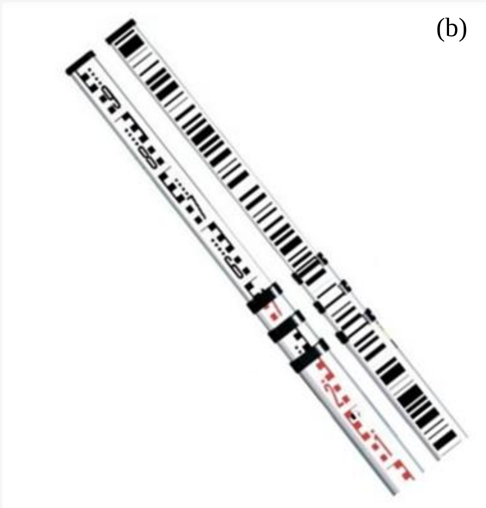

Figure 8: Conventional surveying in raod construction (a) telescope (b) Leveling staff or rod

Table 2: Allowable error in leveling [20]

Class	Allowable error [mm]
Special	$1\sqrt{K}$
I	$4\sqrt{K}$
II	$8\sqrt{K}$
III	$12\sqrt{K}$
IV	$25\sqrt{K}$

Where: *K* is the total distance in the unit of km

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4. Results and Discussions

4.1 Point Cloud

The 3D point cloud, generated from a set of 583 images using PIX4D software, is depicted in Figure 9. This illustration clearly presents the study area, rendered in a highly realistic 3D model with remarkable surface detail. The impressive spatial resolution of 2.2 cm further enhances the reliability of measurements made on this 3D model, owing to its exceptional accuracy. In the next step, the elevations of each station along the road center line were extracted from the point cloud using QGIS software. QGIS is adept at visualizing landscape point cloud data and supports various data formats, including Entwine Point Tile (EPT) and LAS/LAZ. Notably, QGIS automatically saves point cloud data in the EPT format, which consists of multiple files conveniently stored within a common folder [21].

4.2 Elevations Differences between Conventional Leveling and UAV Point Cloud

The elevations obtained from the point cloud were cross-referenced with elevations acquired through conventional leveling techniques, employing a surveyor's telescope and rods. The data collected via the traditional leveling method was documented within the road construction plan, commonly referred to as the "ground level," with elevation measurements taken at 25-meter intervals. The outcomes of these elevation measurements are presented in Table 3. For visualization and comparison purpose, Table 2 is presented as line chart as shown in Figure 10. The findings presented in Table 2 and Figure 8 reveal a close alignment between the profile characteristics of elevations derived from the UAV point cloud and conventional leveling. Notably, the lowest and highest elevations were observed at Sta.16+800 and Sta.17+375, respectively. The range of elevation differences between the conventional leveling and UAV point cloud varies from 0.068 to 0.651 m, with an average of 0.327 m, a standard deviation of 0.182 m, and average percentage difference of 1.06%. According to road construction leveling specifications, it is recommended to adopt leveling class III, which allows for allowable tolerances. In this specific case, where the total distance covers 700 meters, the allowable error, as determined from Table 1, stands at 10.03 mm. However, a careful examination of Table 2 reveals that all the elevation differences exceed the allowable error threshold of 0.010 m. Consequently, it is apparent that the use of UAV with photogrammetry techniques for leveling purposes in this scenario may not be deemed appropriate.

4.3 Elevations before and after the Earthwork using Point Cloud

The earthwork elevations were systematically examined through the analysis of point clouds derived from two distinct instances: the initial assessment conducted on November 24, 2021, followed by a subsequent evaluation on January 31, 2022, both occurring before and after the finalization of the earthwork project. Figure 9 illustrates the 3D point clouds acquired from the aforementioned surveys, while Table 3 provide a comprehensive presentation of the elevation data outcomes. Table 4 is presented as a bar chart, which serves to evaluate the performance of the UAV-derived point cloud data in height determination in road construction earthwork. This comparison entails an analysis of UAV-derived heights compared to traditional survey data, as visually demonstrated in Figure 11.

Figure 9: 3D point cloud generated from PIX4D

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Table 3: Elevation comparison between UAV and leveling conventional technique

Station	Northing	Easting	UAV point cloud (m)	Leveling Telescope (m)	Difference (m)	Percentage difference (%)
16+675	478123.10	895793.27	29.272	29.357	0.085	0.290
16+700	478128.99	895817.57	28.746	28.900	0.154	0.533
16+725	478134.94	895841.87	28.296	28.382	0.086	0.303
16+750	478141.10	895866.18	27.675	27.935	0.260	0.931
16+775	478147.30	895890.38	27.277	27.422	0.145	0.529
16+800	478153.64	895914.59	26.875	27.034	0.159	0.588
16+825	478160.46	895938.74	26.758	26.941	0.183	0.679
16+850	478168.15	895962.48	26.896	27.096	0.200	0.738
16+875	478176.77	895985.93	27.264	27.491	0.227	0.826
16+900	478186.30	896009.20	27.683	28.039	0.356	1.270
16+925	478196.64	896031.87	28.233	28.574	0.341	1.193
16+950	478207.63	896054.29	28.682	29.060	0.378	1.301
16+975	478218.45	896076.93	29.217	29.494	0.277	0.939
17+000	478227.42	896100.31	29.552	29.911	0.359	1.200
17+025	478235.62	896124.12	30.173	30.329	0.156	0.514
17+050	478241.64	896148.42	30.613	30.693	0.080	0.261
17+075	478245.66	896173.14	31.11	31.042	-0.068	-0.219
17+100	478249.13	896197.95	31.56	31.331	-0.229	-0.731
17+125	478252.05	896222.81	31.936	31.557	-0.379	-1.201
17+150	478255.28	896247.65	32.146	31.773	-0.373	-1.174
17+175	478258.56	896272.45	32.427	31.934	-0.493	-1.544
17+200	478262.05	896297.20	32.568	32.065	-0.503	-1.569
17+225	478265.18	896322.04	32.82	32.252	-0.568	-1.761
17+250	478268.41	896346.83	33.066	32.495	-0.571	-1.757
17+275	478271.89	896371.61	33.298	32.758	-0.540	-1.648
17+300	478275.20	896396.43	33.456	32.943	-0.513	-1.557
17+325	478278.61	896421.27	33.585	33.026	-0.559	-1.693
17+350	478282.12	896446.16	33.676	33.076	-0.600	-1.814
17+375	478285.71	896470.88	33.759	33.108	-0.651	-1.966
				Average	**0.327**	**1.060**

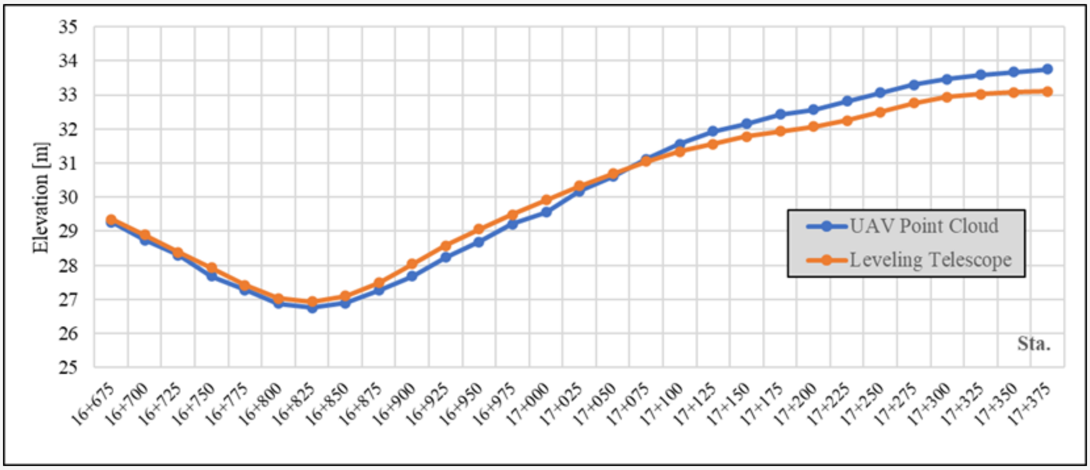

Figure 10: Elevation comparison between UAV and leveling conventional technique

Figure 10 illustrates the feasibility of determining earthwork fill heights in road construction through UAV point cloud data. The comparison between the heights obtained via UAV point cloud and those acquired using a conventional surveyor's telescope reveals a discrepancy range spanning from 0.043 m to 0.395 m.

It is essential to consider leveling specifications that depend on the total surveyed distance. In this specific study, encompassing a total length of 700 meters, the allowable error for leveling class III is 10.04. However, the lower range of the observed differences, which measures 43 millimeters, surpasses the acceptable error threshold. Thus, in this study, the adoption of UAV technology for earthwork height determination is called into question due to the significant disparities observed when compared to conventional survey methods.

The accuracy of height determination from UAV photogrammetry point clouds can vary depending on several factors such as numbers of GCPs which is critical for accurate georeferencing and height determination [22]. The more GCPs, the better their distribution across the survey area, and the higher the accuracy can be achieved. Moreover, it's important to understand that errors in the horizontal (XY) dimensions can propagate to the vertical (Z) dimension. Therefore, minimizing errors in all dimensions is essential for accurate height determination [23]. The accuracy of the camera's intrinsic and extrinsic parameters (calibration) also affects the accuracy of photogrammetric measurements. Properly calibrated cameras are essential for precise height determination [24][25] and [26]. Additionally, the nature of the terrain in the survey area can impact accuracy. Dense vegetation, steep slopes, or complex topography can make height determination more challenging [27][28] and [29].

The achievable accuracy of height determination from UAV photogrammetry point clouds can range from centimeters to decimeters, depending on the several influencing factors and the specific project requirements. In some cases, it may be suitable for applications like topographic mapping and construction site monitoring, while in other cases, such as precise engineering or surveying tasks, ground-based survey methods may still be required for the highest accuracy.

5. Conclusion

In conclusion, when comparing the heights derived from UAV point clouds to those obtained through traditional surveyors' telescopes, a noticeable discrepancy range of 0.043 meters to 0.395 meters becomes evident. Consequently, this study raises concerns about the suitability of UAV technology for accurately determining earthwork heights, given the considerable disparities observed in comparison to conventional surveying methods. The earthwork height determination achieved through UAV technology in this road construction study surpasses the tolerances prescribed by leveling specification class III, as commonly recommended for road construction projects. Nevertheless, enhancements in measurement accuracy can be realized through several key strategies. These include the incorporation of additional GCPs to enhance georeferencing precision, meticulous camera calibration procedures, and mindful consideration of UAV imagery resolution and flight altitude, as these factors exert a notable influence on height accuracy. Ultimately, diligent planning and the deliberate assessment of these aspects can yield more precise and reliable outcomes.

When adopting UAV in acquiring elevation in road construction. It's crucial to consult local road construction standards, project specifications, and design guidelines to determine the precise acceptable range for leveling in a given context. Road construction standards can vary by country, region, and road classification, and they may be subject to change or updates over time. Therefore, always refer to the most current and relevant standards and specifications for accurate information.

The UAV photogrammetry technique should be more extensively employed in the calculation of earthwork volumes for road construction projects. While, in general, volume calculations can be derived from point clouds generated by terrestrial laser scanners (TLS), this approach is costly to implement. However, point clouds can also be produced through UAV photogrammetry, thus, applying UAV in volume calculation should be an interesting topic to be conducted.

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