Earthwork Volume Measurement in Road Construction Using Unmanned Aerial Vehicle (UAV)

Chonpatathip, S.,[1] Suanpaga, W.[1] and Muttitanon, W.[2*]
[1]Faculty of Engineering, Kasetsart University, Thailand, E-mail: Wutjanun.mut@mahidol.ac.th*
[2]Faculty of Engineering, Mahidol University, Thailand
Corresponding Author

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Abstract

This study utilized an Unmanned Aerial Vehicle (UAV) to estimate earthwork volumes in a road construction project spanning from kilometer 6+675 to kilometer 17+275 within the Nongthalay subdistrict, Muang district, Krabi province. Data processing was conducted with PIX4D software, where earthwork volumes were determined from UAV photogrammetry-derived Digital Elevation Models (UAV-DEMs), utilizing the Raster Volume Comparison plugin in QGIS. Aerial imageries were acquired before and after earthwork completion on November 24, 2022, and January 31, 2022, respectively. The results indicated that the UAV-DEM-derived volume was 126.32 m³ less than the prismoidal formula, accounting for a 4.25% difference. It is important to note that the traditional technique's volume estimation represents compacted soil required for road construction. However, prismoidal formula use of cross-sectional areas derived from polygonal shapes may introduce inaccuracies. Therefore, conclusive comparisons favoring the traditional technique over UAV-DEMs should be approached with caution. Additionally, it should be emphasized that the volume results do not directly align with the total earthwork quantity required for the project. The determined volumes reflect compacted soil, whereas the project necessitates the transport of loose soil that will subsequently be compacted on-site. UAV-derived DEMs provide valuable tools for road construction earthwork estimation. With meticulous planning and execution of data collection, and a focus on data quality through rigorous ground control and processing, UAV-derived DEMs can offer reliable estimates. However, the specific project requirements, terrain characteristics, and quality control measures should be considered to ensure the data's reliability and accuracy for earthwork estimation. Moreover, this study also examines the effectiveness of UAV data acquisition in comparison to traditional surveying methods, revealing valuable insights despite limitations in the Area of Interest (AOI). Despite a longer processing time for UAV imagery, the UAV exhibited efficiency by acquiring road surface data in less than half the time required by traditional surveying approaches. The UAV's ability to expedite data collection over larger road sections became increasingly evident as length increased, enabling concurrent progress in construction activities. Additionally, the UAV approach demonstrated cost efficiency, representing less than 50% of the expenses associated with traditional survey methods. Moreover, the UAV method showcased manpower efficiency, requiring only one operator compared to the three individuals needed for traditional survey techniques. Overall, the integration of UAV technology in road construction holds promise for improving time, cost, and manpower efficiency in surveying processes

Keywords: Earthwork, PIX4D, Raster Volume Comparison, Road construction, UAV, Volume

1. Introduction

The adoption of Unmanned Aerial Vehicles (UAVs) or drones has initiated a transformative era across multiple industries, reshaping data acquisition, landscape observation, and informed decision-making. Among the numerous applications that have seen remarkable growth and innovation in recent years, the utilization of UAV technology for crop monitoring and mapping stands out as an indispensable and compelling tool. By leveraging the capabilities of these autonomous aerial platforms, professionals in agriculture, environmental science, and related domains have gained access to a wealth of high-resolution spatial data, empowering them to redefine their strategies for land management, precision agriculture, and resource optimization. Nevertheless, the utility of UAV technology extends beyond agriculture and finds application in environmental conservation, forestry management, land-use planning, and disaster response.

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UAVs equipped with specialized sensors can generate detailed digital maps, identify changes in land cover, oversee deforestation, and evaluate the impact of climate change on ecosystems. Furthermore, during natural disasters such as wildfires or floods, UAVs can swiftly capture comprehensive aerial imagery, offering support to emergency response teams and streamlining disaster management. In the realm of construction, the incorporation of Unmanned Aerial Vehicles (UAVs) marks a new era of enhanced efficiency and precision [1] and [2]. These remotely piloted aircraft, colloquially known as drones, have transformed the way road construction projects are designed, executed, and supervised. The versatility of UAV technology extends beyond the construction sector, reaching into diverse fields, including agriculture, where it has proven valuable for tasks like crop height monitoring and yield estimation [3][4][5]and [6]. In road construction, Unmanned Aerial Vehicles (UAVs) have become indispensable tools, offering a wide array of advantages, ranging from enhanced surveying capabilities to more efficient project management. Their capacity to capture high-resolution aerial imagery, generate detailed topographic maps, and collect precise volumetric data has revolutionized the approaches of engineers and construction professionals. The integration of UAV technology in the construction sector is poised to significantly streamline processes, enhance safety measures, and provide cost-effective solutions.

At present, unmanned aerial vehicles, commonly referred to as drones, are extensively incorporated into various aspects of the construction industry. Their applications encompass survey planning, construction survey control, inspections, and project deliveries. However, it's important to note that when it comes to building inspections, drones have their limitations. They may struggle to provide comprehensive wide-angle views, which can pose challenges when inspecting certain areas. Additionally, there are safety concerns for inspectors, particularly in tasks like roof inspections or assessing the exterior walls of buildings [7][8] and [9]. The construction industry is progressively embracing modern technology to enhance efficiency and reduce costs. Among these innovative technologies, unmanned aerial vehicles, or drones, have garnered significant popularity. They are applied across the entire 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.

A point cloud is a dataset comprising individual data points situated in a three-dimensional coordinate system, frequently employed to depict the form and attributes of objects or surfaces within the physical world. Each point in a point cloud typically possesses X, Y, and Z coordinates, which determine its spatial location in a three-dimensional context. Typically, point clouds are generated through terrestrial laser scanning (TLS) using Light Detection and Ranging (LiDAR) sensors. These sensors emit laser pulses and record the time taken for the pulses to return, enabling the calculation of distances to objects and thus forming a three-dimensional representation of the surrounding environment [10] and [11]. Nevertheless, it's essential to acknowledge that LiDAR sensors come at a considerable cost [12], which leads to the consideration of an alternative option for height measurement: photogrammetry.

UAV photogrammetry, a surveying technique, facilitates the generation of point clouds, 3D surface models, and orthophoto mosaics. UAV finds diverse applications on construction sites, offering a bird's-eye view for supervising personnel and providing real-time feedback on on-site activities. Lee et al., [13] demonstrated that UAV photogrammetry, employing stereoscopic vision similar to traditional photogrammetry, can create contour lines using a plotter. Moreover, its rapid disaster monitoring capabilities have been explored in studies assessing topography in landslide-prone areas and evaluating displacement. In the context of construction sites, research has focused on utilizing UAV photogrammetry for Digital Elevation Model (DEM) production based on point cloud data, earthwork volume calculations, and periodic creation of 3D models or orthoimages for change detection. These studies collectively contribute to the effective integration of UAV photogrammetry in construction site monitoring and management.

In photogrammetry, Unmanned Aerial Vehicles (UAVs) capture a series of overlapping images from various angles. Subsequently, these images undergo processing to create a 3D point cloud by identifying common features across the images. Specialized software is employed to process the images, match key points, and generate a dense point cloud, often involving techniques like bundle adjustment and multi-view stereo methods. Following data processing, a set of three-dimensional coordinates for each point within the point cloud is produced, signifying the positions of objects, terrain, and features in the surveyed area. The creation of point clouds from UAVs proves to be a valuable asset in fields such as surveying, agriculture, construction, and environmental monitoring.

The choice between using LiDAR or photogrammetry as a sensor depends on the precise project requirements, encompassing the desired level of detail and accuracy [14]. A 3D point cloud model of a road construction project proves to be a valuable asset with a multitude of applications, including project planning, progress monitoring, quality control, and asset management. It offers an intricately detailed portrayal of the road construction site in three dimensions, providing a precise, dynamic representation of the construction area. This level of detail empowers better decision-making, enhances quality control measures, and bolsters safety standards throughout the construction process. Furthermore, it functions as a valuable resource for documentation and long-term asset management, contributing to the sustained success and durability of road infrastructure [15][16] and [17]. One notable use of the 3D point cloud model is the ability to compare it with the original design to ensure the constructed road aligns with the specified plans. This verification process is crucial for maintaining quality and adhering to industry standards. Moreover, point clouds are instrumental in detecting defects or imperfections in the construction, such as surface irregularities, improper grading, or drainage issues, which can then be promptly addressed [18] and [19].

Currently, data acquisition for volume calculations involves employing a survey team to conduct on-site topographic measurements, providing essential quantities for pricing activities. The volume of excavated or filled material is then determined by subtracting these surfaces. Traditional surveying techniques, such as Total Station surveys and Global Positioning System (RTK), have been employed for volume measurements but are known for their labor-intensive and time-consuming nature [20].

Advancements in UAV systems and automated photogrammetric software have significantly improved the efficiency and cost-effectiveness of acquiring geospatial data. The evolution of UAVs as measuring instruments has garnered attention for surveying applications in civil engineering [21], particularly for volumetric computations in highway construction. However, the performance of UAVs in these applications remains not fully understood. Further research is essential to assess the UAV and photogrammetric software's ability to generate volumes for the various material layers involved in road structure construction, along with an analysis of accuracies and limitations.

The Department of Highways in Thailand is actively advocating for the integration of various technologies into their ongoing construction projects. This initiative seeks to modernize the department, recognizing the need for enhanced efficiency in the extensive road and bridge projects they undertake. Traditional methods of data collection in construction, particularly concerning quantity calculations and height measurements, have proven to be both time-consuming and costly. For instance, the theodolite-based approach is known for its high expenses and complexity. In response to these challenges, the introduction of unmanned aerial vehicles (UAVs) has been implemented in the Department of Highways' construction projects. This integration has brought about a significant transformation in data collection and project management, greatly improving convenience, speed, and overall work efficiency, surpassing the capabilities of the original system. The objective of this study was to assess the feasibility of accurately calculating earthwork volumes using UAV photogrammetry within a road construction site. This method holds the potential to significantly streamline the labor and cost associated with earthwork volume calculations traditionally conducted through the traditional surveying method (TSM). The overarching goal is to contribute valuable insights into the potential of UAVs in improving efficiency and accuracy in volume calculations for road construction projects.

2. Study Area and Data

The research is focused on a road expansion project that entails the conversion of a two-lane road into a four-lane configuration in the Nongthalay subdistrict, Muang district, Krabi province. The project encompasses the road segment from kilometer 6+675 to kilometer 17+275. To determine the earthwork volume, a combination of traditional survey methods employing a digital surveyor's telescope and Unmanned Aerial Vehicle (UAV) point cloud data was utilized. The assessment of the fill volume was carried out using both of these techniques, with observations conducted both before and after the earthwork was completed on November 24, 2021, and December 31, 2022, respectively. Aerial photographs of the study area were acquired by deploying a multirotor drone. Subsequently, data processing was conducted using PIX4D software, and a point cloud dataset was generated through photogrammetry techniques using the UAV.

3. Methodology

The methodology workflow of this study is depicted in Figure 1.

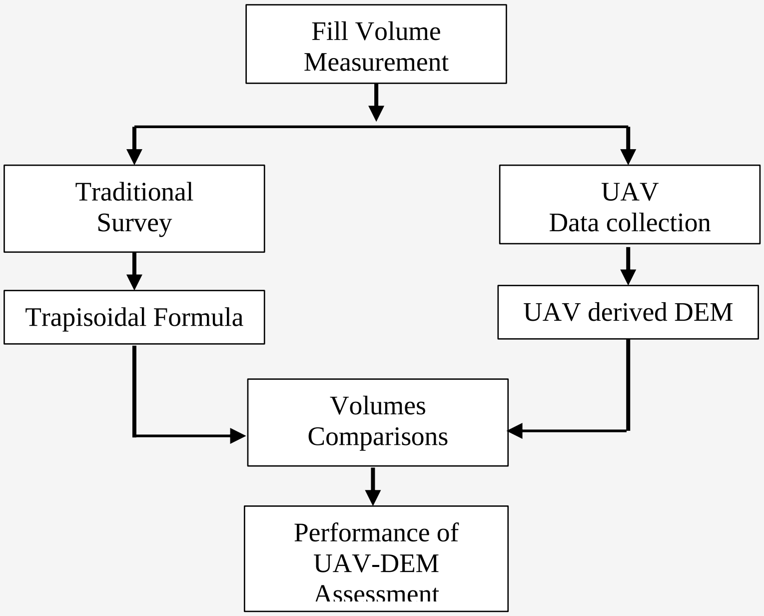

Figure 1: Study workflow

3.1 Preliminary survey

In the designated study area, encompassing the stretch from local road kilometer 6+675 to kilometer 17+275 in Nongthalay subdistrict, Muang district, Krabi province, Thailand, the positions for positioning 10 ground control points (GCP) and 24 check points (CP) were meticulously determined. These control points (GCPs and CPs) were strategically situated along the road itself and in adjacent off-road areas. The precise geographic coordinates for all 34 points were acquired using the CHCNAV i50 GNSS receiver, employing the Real-Time Kinematic (RTK) positioning technique for achieving highly accurate positioning measurements. The spatial locations of the GCPs and CPs are visually presented in Figure 2.

3.2 UAVs and flight plan

The Hexarotor, a type of multi-rotor drone with six rotors, as depicted in Figure 3a, is preferred for its ability to operate effectively within limited take-off and landing spaces. This feature renders it particularly well-suited for tasks in constrained environments. In contrast to other drone configurations, the Hexarotor is known for its user-friendly characteristics, making it an ideal choice for operations with spatial restrictions. Moreover, the 6-rotor multi-rotor drone offers enhanced safety in comparison to the Quadrotor, a variety with four rotors. In the event of an unexpected issue, such as a motor failure during a mission, the Hexarotor maintains the capability to continue its operation and execute a controlled landing with precision. Furthermore, Hexarotor drones demonstrate superior resilience in the face of adverse weather conditions, further underscoring their suitability for a wide range of applications [22].

The drone was equipped with a high-resolution camera, specifically the Sony A6000, as illustrated in Figure 3b. The camera possesses the capacity to capture images at its maximum resolution of 6000 x 4000 pixels (24.0 MP, 3:2 aspect ratio) and offers the added advantage of an adjustable focal length spanning from 16 to 50 millimeters [23]. This characteristic affords a heightened degree of flexibility, allowing for precise control over flight altitude and image resolution in centimeters per pixel, thus facilitating convenient adjustments as required. The survey team meticulously examined the points of interest, topographical configuration, and designated zones for the control and management of drone operations. It was imperative that the area be distant from potential obstructions such as tower structures, mobile networks, tall buildings, and imposing trees. For this purpose, the drone control and management area were designated at Ban Khaoklom school in Krabi Province. This selection was motivated by the school's extensive grounds and flat topography, rendering it an optimal location for facilitating drone operations. The relatively lower elevation of the area, coupled with the absence of significant impediments in its proximity, further solidifies its appropriateness for the effective supervision and regulation of drone activities.

Figure 2: Locations of GCPs and CPs in the study area

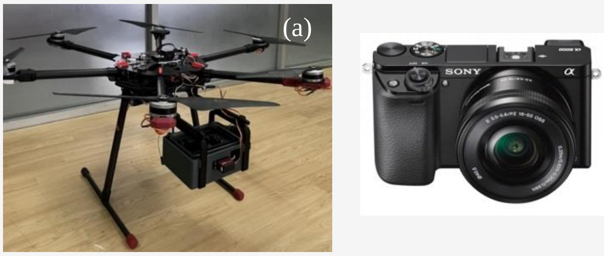

Figure 3: (a) Tarot Hexacoptor X6 drone (b) Sony A6000 camera

Table 1: UAV flight configuration

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

Following the calculation of the flight configuration, as detailed in Table 1, the flight plan was formulated using the Mission Planner program, a dedicated tool designed for drone planning and control. The program's interface is illustrated in Figure 4. In this research, a camera-equipped UAV was employed to capture images of different sections within the study area, which were later amalgamated to produce a single, high-resolution image. Flight planning and drone control were carried out using the Mission Planner software as shown in Figure 4, serving as a pivotal component in this endeavor.

The study encompassed the formulation of three distinct flight plans, as visually represented in Figure 5:

- Flightplan 1: Devised for comprehensive area coverage.
- Flightplan 2: Focused on meticulous data collection within the area of particular interest.
- Flightplan 3: Directed towards augmenting the overall level of detail and comprehensiveness within the area.

Data collection was conducted on November 24, 2021, and again on January 31, 2023, before and after the earthwork was finalized, respectively.

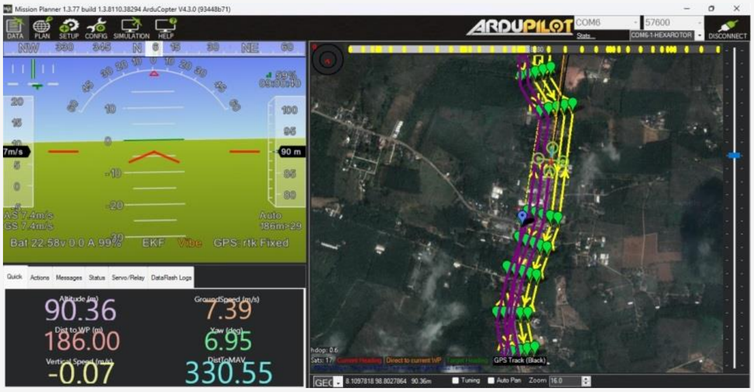

Figure 4: Mission Planner software interface

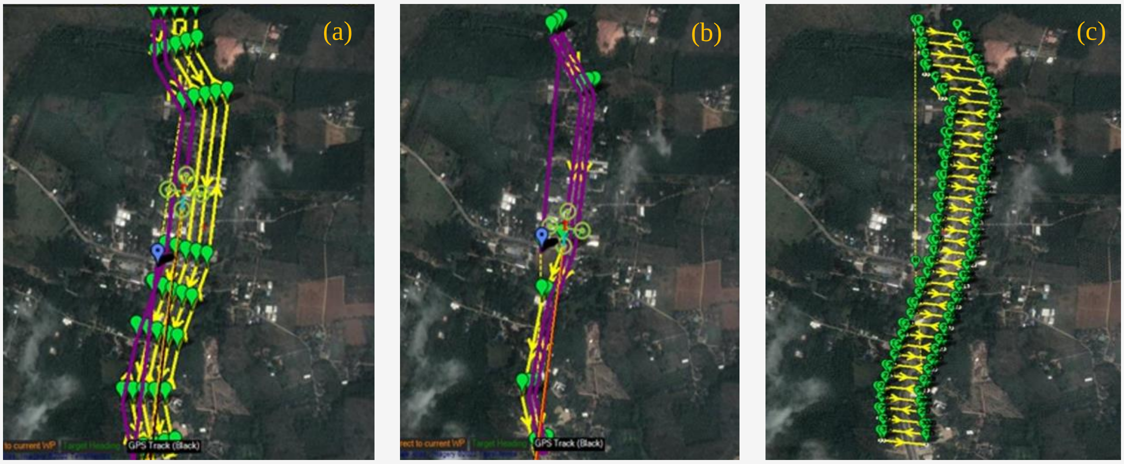

Figure 5: Flightplans on Mission Planner software: (a) Flightplan 1, (b) Flightplan 2, and (c) Flightplan 3

3.3 Image processing

After configuring the flight plan within the Mission Planner program, the drone proceeded to execute the pre-defined mission. Upon successful mission completion, the captured images were subsequently imported into PIX4D, a dedicated image stitching software, as depicted in Figure 6. A point cloud is created through the process of photogrammetry, which employs multiple 2D images to reconstruct the 3D geometry of objects and scenes [24]. This technique involves capturing a sequence of overlapping images of the object or scene of interest, ensuring they are obtained from various angles and viewpoints. The accuracy of the resulting point cloud is directly proportional to the number of images used in the acquisition process. Upon completing the image processing, the outcomes, which encompass aerial photographs and a 3D point cloud, are generated. The point cloud will be instrumental in ascertaining the elevation of specific points or areas of interest, with the support of the QGIS software.

3.4 Leveling

Within the realm of road construction, the utilization of a surveyor's telescope for leveling is an indispensable technique with far-reaching implications for road safety, functionality, and alignment with engineering standards. It assumes a pivotal role in the meticulous planning, execution, and quality control of road infrastructure projects. Surveyors leverage this telescope to set elevation benchmarks and control points, thereby ensuring that different segments of the road align correctly in terms of height, validating cross-sectional profiles at multiple locations along the road's span, and establishing the road's desired grades and slopes. This meticulous process is instrumental in ensuring that the road adheres to safety and engineering standards, allowing for effective drainage. Elevations for the road's central axis at 25-meter intervals, or the elevations of each station along the road profile, were precisely determined using a digital surveyor's telescope [25].

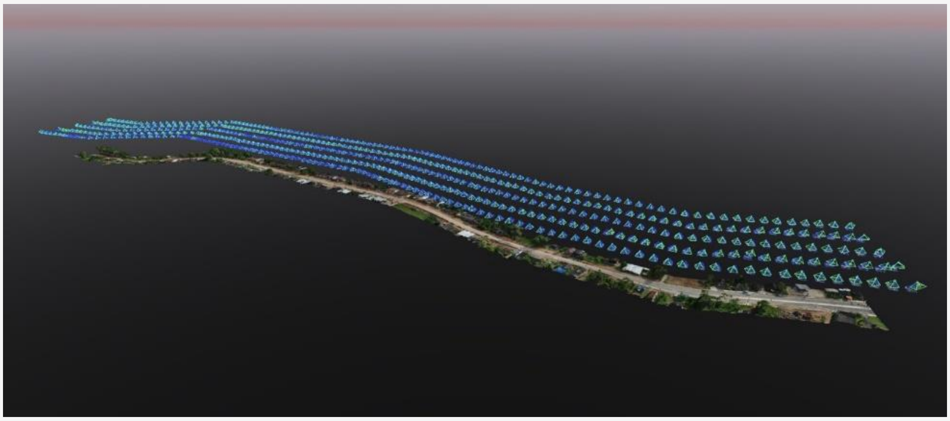

Figure 6: Image stitching in PIX4D

Subsequently, these UAV-derived elevations underwent a comprehensive cross-verification against the elevations acquired through the telescope, serving as a robust quality control measure.

3.5 Volume of Earthwork Determination

The determination of earthwork volumes holds a pivotal role in the planning, design, and execution of road construction projects. Accurate calculation of earthwork volumes is not merely a technical necessity but a fundamental aspect that underpins the success of any road infrastructure endeavor. It involves the meticulous assessment of cut and fill requirements, the balance between excavation and embankment, and the ultimate shaping of the road's topography. The volume of earthwork, ascertained through comprehensive surveying and mathematical analysis, offers critical insights into project feasibility, cost estimation, and adherence to engineering standards. In this exploration of earthwork volume calculation in road construction, we delve into the principles, methodologies, and significance of this essential process that ensures the safe and efficient development of transportation networks. The volume was determined using "Raster Volume Comparison" plugin in QGIS. The algorithm for calculating volume using raster data is straightforward. It involves multiplying the area of a pixel (p) by the corresponding value (h) of the pixel containing height information. For a raster with multiple pixels, the total volume is the sum of each pixel's area multiplied by its respective pixel value, as illustrated in equation 1 [26].

$$V = \sum_{i=1}^{n} p_i h_i$$

Equation 1

where:

- V is volume to be determined from DEMs
- i is the pixels number
- n is the totla number of pixel
- p is the pixel size
- h is the difference of elevation of corresponding pixel

The area of a pixel is contingent on its pixel dimension, referred to as pixel resolution. A raster possessing high resolution, such as a UAV-DEM from a drone survey with a 0.1 m resolution, will yield markedly distinct results compared to a SRTM-DEM with a 30 m resolution. This distinction arises from the fact that a pixel in the UAV-DEM represents an area of 0.1 m x 0.1 m, while a pixel in the SRTM-DEM corresponds to an area of 30 m x 30 m. When considering accuracy, the DEM from the drone survey is more reliable than the SRTM, making it the preferred choice in projects requiring volume calculation.

Figure 7 illustrates a 2D profile of an object in relation to different raster resolutions. The figure highlights that a raster with higher resolution as in Figure 7(a) closely approximates the actual topographic surface, in contrast to another raster with a lower resolution as in Figure 7(b). The volume calculations is based on two raster DEMs. If the two DEMs differ in size, the larger DEM will be adjusted to match the dimensions of the smaller one. In the traditional technique, earthwork volume is computed by establishing elevation points on cross-sections positioned along the road's central axis. The cross-sectional area at each station is then ascertained through the use of coordinates, which denote heights and distances relative to the road's central line, and this is achieved by applying the principles of coordinate geometry and relevant area formulas.

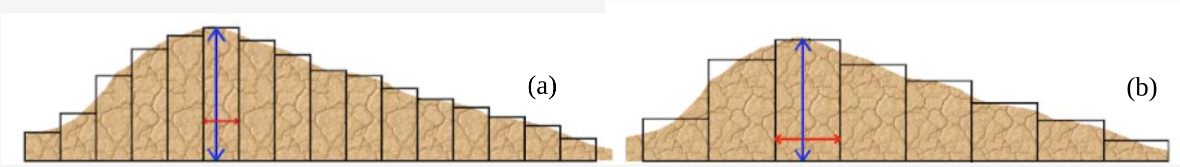

Figure 7: DEM resolution and volume accuracy
(a) High resolution DEM (UAV) (b) Low Resolution DEM (SRTM-DEM)

Subsequently, end area formula, represented by equation 2 or the prismoidal formula as in equation 3 is employed in the calculation of earthwork volume [25].

$$V = D\left[\frac{A_1 + A_n}{2} + \sum_{i=2}^{n-1} A_i\right]$$

Equation 2

$$V = \frac{D}{3}\left[A_1 + 4\sum A_{even} + 2\sum A_{odd} + A_n\right]$$

Equation 3

Where:

- V is total volume of earthwork (m^3)
- D is station interval in road profile (normally D=25 m)
- A_1 is area at the first station in road profile (m^2)
- A_n is area at the last station in road profile (m^2)
- n is total number of stations
- A_{even} is area of even numbered station in road profile (m^2)
- A_{odd} is area of odd numbered station in road profile (m^2)

This study employed the prismoidal formula for the computation of the total earthwork volume.

In this study, the elevations of the study area were represented by Digital Elevation Model (DEM) created through the UAV photogrammetry technique. Ten Ground Control Points (GCPs) were strategically placed along the road project. The coordinates of these GCPs were meticulously recorded using the precise Real-Time Kinematic (RTK) measurement technique. A careful georeferencing process was then applied to the UAV photos, aligning them with the GCPs. Subsequently, a dense point cloud was generated following spatial correction procedures, and, lastly, the DEMs were derived from this point cloud through the utilization of PIX4D software. The Raster Volume Comparison is employed for volume calculations based on two raster DEMs. If the two DEMs differ in size, the larger DEM will be adjusted to match the dimensions of the smaller one. The unit of measurement for the DEM volume is consistent with that of the original DEM. The plugins can be downloaded from *https://plugins.qgis.org/plugins/raster_volume_compare/*. The results are presented as both negative and positive numbers, signifying cut and fill, respectively [27].

4. Results and Discussions

4.1 Point Cloud

The 3D point cloud was generated from an assemblage of 583 images using PIX4D software as presented in Figure 8. This rendering unveils the study area in a stunningly realistic 3D model, replete with intricate surface details. What's more, the exceptional spatial resolution of 2.2 cm significantly bolsters the precision of measurements conducted within this 3D model, affirming its unwavering accuracy. The volume of earthwork was determined from the UAV derived point cloud using QGIS software. QGIS demonstrates its proficiency in visualizing landscape point cloud data and offers support for an array of data formats, including Entwine Point Tile (EPT) and LAS/LAZ. An essential point to note is that QGIS automatically preserves point cloud data in the EPT format, which comprises multiple files conveniently housed within a shared folder [28].

4.2 Point clouds pre- and post-earthwork completion

Drone imagery was standardized in accordance with the principles outlined in the 2014 guidelines of the American Society for Photogrammetry and Remote Sensing (ASPRS), both for the initial survey conducted on November 24, 2022, and the subsequent survey on January 31, 2022. Using the QGIS program, alterations in the road construction can be analyzed by establishing a boundary with an area of approximately 10,298.14 m^2 and a length of approximately 1,050 m, as illustrated in Figure 9. Earthwork elevations were methodically assessed by analyzing point clouds from two distinct occasions: the initial evaluation carried out on November 24, 2021, and a subsequent assessment on January 31, 2022, both preceding and following the completion of the earthwork project. Figure 10 visually presents the 3D point clouds obtained from these surveys.

Figure 8: 3D point cloud of the study area

Figure 9: Drone imagery (a) November 24, 2022 and (b) January 31, 2022

Figure 10: Point cloud results (a) Before earthwork filling, and (b) After earthwork filling

4.3 UAV-DEMs

The point cloud acquired by the UAV, as discussed in the preceding section, was employed to generate Digital Elevation Models (DEMs), subsequently utilized for the computation of earthwork volumes in the road construction project. The initial step involves UAV data acquisition through photogrammetric PIX4D softwarer, resulting in a dense point cloud representation. Subsequent processing includes filtering to eliminate outliers and noise, contributing to the improvement of overall data quality. Ground control points (GCPs) are incorporated to achieve georeferencing accuracy, enhancing the spatial alignment of the point cloud with real-world coordinates. Following this, the point cloud undergoes a classification process to distinguish ground and non-ground points. Triangulation-based or grid-based interpolation methods, including Delaunay triangulation, Inverse Distance Weighting (IDW), or kriging, are employed to generate the DEM, providing elevation values across the surveyed area.

The UAV images were processed using Pix4D to create a dense point cloud. The point cloud comprises a large numeber of 3D coordinates, each representing a specific point on the Earth's surface. The software aligns these points in three-dimensional space, creating an accurate representation of elevation variations. From the dense point cloud, a DEM is generated, representing the elevation values across the study area. DEMs are typically represented as a grid, with each cell containing an elevation value. These values can be used to create contour lines, visualize slopes, analyze terrain characteristics, and calculate volumes, among other applications [29] and [30]. The UAV derived DEMs before and after the completion of earthwork illustrate in Figure 11.

4.4 Earthwork Volume Results

The earthwork volumes for the road construction project were calculated using traditional survey methods, employing a surveyor's telescope and applying the prismoidal formula described in Equation 2. Additionally, differences in volume were assessed by comparing UAV-derived Digital Elevation Models (UAV-DEMs) using QGIS software [27]. The outcomes of these volume calculations are summarized in Table 2.

Table 2 indicates that the volume derived from UAV-DEMs is 126.32 m^3 less than the prismoidal formula, constituting a difference of 4.25%. Nevertheless, it's important to note that the volume estimated by the classical technique represents the anticipated compacted soil required for road construction. The formula in Equation 2 is susceptible to inaccuracies because it derives cross-sectional areas from polygonal shapes, which may not faithfully represent the actual field conditions [20]. Therefore, it would be premature to conclude that the traditional technique offers more precise results in comparison to UAV-DEMs. Furthermore, it is important to note that the volume results cannot be directly validated against the total earthwork quantity required for the road construction project. This is because the determined volumes represent compacted soil, whereas the actual soil to be transported for the construction project is loose soil that will subsequently be compacted on-site [31] and [32].

4.5 Data acquisition cost and manpower

In theory, the UAV data acquisition process should be notably quicker than acquiring the same data through traditional surveying methods. However, due to the limited Area of Interest (AOI), the anticipated substantial reduction in data acquisition time may not be realized. On the other hand, the processing of UAV imagery took significantly longer than the post-processing of Total Station data. The UAV processing spanned from a few hours to up to 24 hours, depending on computer performance, whereas Total Station processing took just 15 minutes.

Nevertheless, the time required for the UAV to acquire data for the road surface was less than half of that needed by Traditional Total Station surveying. As the length of the road section increases, this time gap between the two methods tends to widen further. This underscores that the UAV facilitates quicker data collection over larger areas, enabling construction work to proceed concurrently with data capture. Moreover, the expenses for data acquisition differ between the UAV and traditional survey methods using a survey telescope, with costs amounting to 12,775 USD and 26,760 USD, respectively. As a result, the UAV approach is priced at less than 50% of the cost associated with the traditional approach. Another consideration in the use of UAVs for road construction is the manpower required for data acquisition. In this study, operating the UAV only necessitated one person, whereas the traditional survey technique involved a minimum of three individuals: one surveyor and two chainmen. Consequently, in terms of manpower, UAV usage requires fewer individuals for data acquisition, although it's essential for the drone operator to be well-trained in drone operation.

Table 2: Comparison of earthwork volume between traditional technique and UAV-DEM

Measurement Technique	Volume [m^3]
Traditional	2,970.23
UAV-DEMs	2,843.91

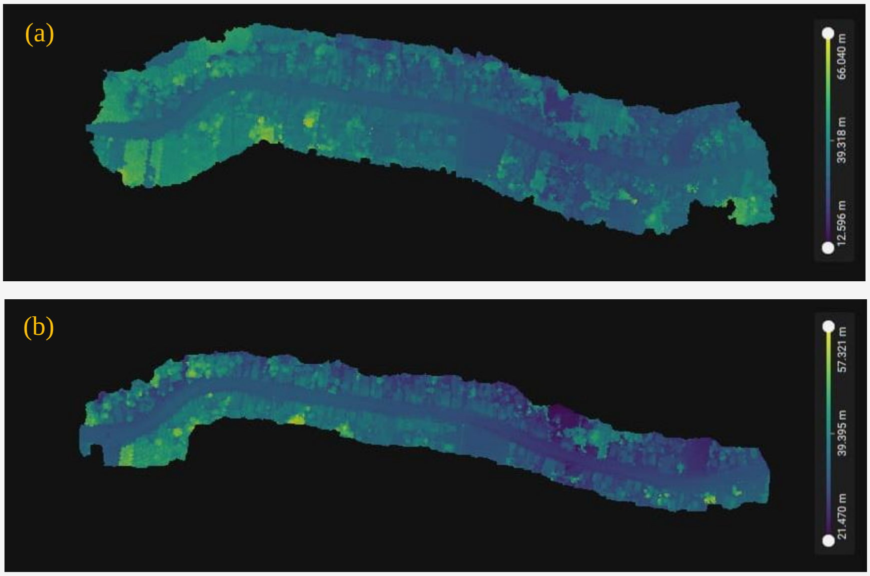

Figure 11: UAV derived DEMs (a) Before earthwork filling on November 24, 2022 and (b) After earthwork filling on January 31, 2022

5. Conclusion

This study explored the efficacy of UAVs in volumetric calculation, comparing the performance to the traditional Total Station surface measurements. Measurements were conducted using both Total Station and UAV techniques on the road construction project *spanning from kilometer 6+675 to kilometer 17+275 within the Nongthalay subdistrict, Muang district, Krabi province*. Utilizing data from both techniques, two volume values were computed for the compacted soil. The UAV method exhibited a 4.25% difference in volume compared to the Total Station measurement. It is clearly seen that the UAV method demonstrated superior cost and time efficiency when contrasted with Total Station surveying for measuring earthwork volume road construction. The precision achieved through accurate Ground Control Point (GCP) measurements makes UAV surveying a viable choice for application in highway construction.

Using UAV-derived Digital Elevation Models (DEMs) in the estimation of earthwork for road construction can offer several benefits and provide reliable results, but it also comes with certain considerations related to accuracy and data quality. The reliability of using photogrammetry UAV-derived DEMs in estimating earthwork for road construction depends on several factors as (1) UAV photogrammetry can provide highly accurate elevation data, which is crucial for earthwork estimation. The DEMs generated from UAV imagery can capture detailed terrain information, helping to accurately calculate cut and fill volumes. However, the accuracy of UAV-derived DEMs depends on factors such as the quality of ground control points, the accuracy of GPS and GNSS systems, and the quality of the photogrammetric processing software. (2) The reliability of UAV-derived DEMs also depends on the data processing workflow. Proper georeferencing, tie point selection, and photogrammetric processing are essential for generating accurate DEMs. (3) The use of accurate GCPs is crucial to georeference the UAV-derived data. Reliable GCPs help align the imagery with real-world coordinates and improve the accuracy of the DEMs. Errors in GCP selection and measurement can impact reliability.

The advantages of the UAV data acquisition process over traditional surveying methods may not fully materialize due to the constraints of the limited AOI, our investigation revealed valuable insights. Despite the prolonged processing time for UAV imagery compared to traditional surveying approach, the UAV demonstrated its efficiency by acquiring road surface data in less than half the time required by traditional surveying.

As road sections increase in length, the UAV's capability to expedite data collection over larger areas becomes increasingly evident, allowing for simultaneous progress in construction activities. Beyond cost considerations, the UAV approach also demonstrated a manpower efficiency, requiring only one operator compared to the three individuals involved in traditional survey techniques. In conclusion, the integration of UAV technology in road construction not only offers time and cost efficiencies in data acquisition but also streamlines manpower requirements. This underscores the potential of UAVs to significantly enhance the overall efficiency and effectiveness of surveying processes in construction projects.

DEMs generated from UAV photogrammetry are a powerful tool for accurately capturing and analyzing the topography of a region. The combination of aerial imagery, precise ground control, and advanced software processing results in highly accurate, high-resolution elevation data that has diverse applications across various industries. These DEMs offer a comprehensive understanding of the Earth's surface, aiding in decision-making and planning processes in fields ranging from civil engineering to environmental science. In conclusion, UAV-derived DEMs are a valuable tool for estimating earthwork in road construction. When the data collection process is carefully planned and executed, and data quality is assured through proper ground control and processing, UAV-derived DEMs can provide reliable estimates. However, it's important to consider the specific project requirements, terrain characteristics, and quality control measures to ensure the data's reliability and accuracy for earthwork estimation.

6. Suggestions

To ensure the reliability of the DEMs, it's advisable to conduct quality control and validation processes. This may involve cross-checking UAV-derived data with ground surveys to assess the accuracy and identify potential discrepancies. The suitability of using UAV-derived DEMs can vary depending on the specific terrain characteristics of the road construction site. Steep slopes, dense vegetation, or complex terrain may present challenges that affect data quality.

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