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Estimation of Earthwork for New Route Alignment Planning using UAV Data

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Abstract:
This paper presents a comprehensive exploration of utilizing Unmanned Aerial Vehicle (UAV) data for accurate earthwork estimation in the context of new route alignment projects. Traditional methods of earthwork estimation often rely on ground surveys, which can be time-consuming, labour-intensive, and prone to errors. With the advancements in UAV technology, the integration of aerial imagery and photogrammetric techniques offers a promising solution to streamline and enhance the earthwork estimation process. This paper discusses the workflow, challenges, benefits, and prospects of employing UAV data for earthwork estimation, thereby contributing to more efficient and informed decision-making in route alignment projects.
Keywords: Earthwork estimation, UAV, Route alignment, Photogrammetry, Remote sensing.

Introduction

Earthwork estimation is a fundamental aspect of civil engineering projects, particularly in the construction of new routes such as roads, railways, and pipelines. Earthwork refers to the movement and shaping of soil, rock, and other materials to create the desired topography for infrastructure development. Accurate estimation of earthwork volumes is essential for various stages of project planning, including budgeting, resource allocation, and scheduling.

Traditionally, earthwork estimation has relied on ground surveys conducted by skilled surveyors using total stations, GPS receivers, and other surveying equipment. These surveys involve manual measurements, site inspections, and the establishment of control points for reference. The collected data are then processed to generate contour maps and digital terrain models (DTMs), which serve as the basis for earthwork volume calculation.

However, traditional survey methods have several limitations, including their time-consuming nature, labor-intensive requirements, and susceptibility to errors. Additionally, ground surveys may be impractical or hazardous in certain terrain conditions, such as steep slopes or dense vegetation cover.

The emergence of Unmanned Aerial Vehicle (UAV) technology has revolutionized earthwork estimation by offering a new approach to data collection and analysis. UAVs, commonly known as drones, are equipped with high-resolution cameras and other sensors capable of capturing detailed aerial imagery over large areas. By deploying UAVs for earthwork estimation, project stakeholders can overcome the limitations of traditional methods and achieve more efficient, accurate, and cost-effective results.

The exploration of UAV data for earthwork estimation in new route alignment projects is motivated by several compelling factors. Firstly, the rapid advancements in UAV technology have significantly enhanced its capabilities, making it increasingly accessible, affordable, and capable of capturing high-resolution aerial imagery over large areas. This technological progress has opened up new possibilities for improving the efficiency and accuracy of earthwork estimation processes. Secondly, traditional methods of earthwork estimation, relying on ground surveys, are often time-consuming and labor-intensive. In contrast, UAV-based surveys can cover larger areas in a fraction of the time, accelerating project timelines and reducing overall costs. Moreover, UAVs offer a cost-effective alternative to traditional survey methods by minimizing the need for manual labor and equipment-intensive field surveys. Additionally, the high-resolution aerial imagery captured by UAVs provides detailed information about terrain features, surface conditions, and vegetation cover, enabling more accurate and comprehensive analysis for earthwork estimation, leading to better-informed decision-making. Furthermore, UAV-based surveys eliminate the need for surveyors to traverse hazardous or inaccessible terrain, enhancing safety outcomes for project personnel. Minimizing the ecological footprint of construction activities is also a growing concern, and UAV-based surveys have minimal environmental impact compared to traditional methods. Finally, the transparent and accessible nature of UAV-derived data improves stakeholder engagement by providing visualizations and insights into project progress for project owners, regulators, and local communities.

Objectives

This paper aims to explore the feasibility and effectiveness of using UAV data for earthwork estimation in the context of new route alignment projects. Specifically, the objectives are as follows:

- To outline the methodology for UAV data acquisition and processing
- To demonstrate the application of UAV-derived data in earthwork volume calculation
- To discuss the challenges, benefits, and prospects of UAV-based earthwork estimation

Literature Review

Traditional methods of earthwork estimation

Traditionally, earthwork estimation has relied on a range of surveying techniques conducted directly on the ground. These methods involve skilled personnel using equipment such as total stations, GPS receivers, and levels to collect data across the project site. Field surveys typically entail traversing the terrain to establish control points, taking measurements of elevations, distances, and angles, and recording the topographical features of the area. The data gathered through these surveys are then processed to create contour maps, cross-sections, and digital terrain models (DTMs). Contour maps depict the shape and elevation of the land surface through contour lines, while cross-sections provide detailed profiles of the terrain along specific transects. DTMs represent the three-dimensional surface of the terrain and are crucial for earthwork volume calculations.

While traditional methods have been widely used and are generally reliable, they have several limitations. Firstly, ground surveys can be time-consuming and labor-intensive, especially for large-scale projects or sites with complex terrain. Surveyors must physically access every part of the site, which can be challenging in rugged or remote areas. Moreover, the accuracy of ground surveys may be affected by factors such as visibility, vegetation cover, and ground conditions, leading to potential errors in the data collected. Additionally, ground surveys are subject to limitations in terms of spatial resolution and coverage, particularly in areas where access is restricted or unsafe.

Despite these challenges, traditional methods of earthwork estimation have been the standard approach for many years due to their proven reliability and accuracy. Highway alignment is typically considered a 3D challenge. However, in practice, it is more manageable when approached as two separate 2D problems: horizontal and vertical alignment. Numerous countries implement alignment design policies that are based on these 2D alignments and the concept of design speed [1]. A key factor in developing highway alignment is the significant influence of high earthwork costs on the overall expenses of the highway project [2]. In mountainous terrain, uneven ground elevation and abrupt features are common. In such challenging conditions, it is crucial to minimize earthwork and balance cut and fill. Various methods are employed to achieve this, as they help in aligning the grade line closely with the natural ground line. At the same time, the existing ground level elevation along the centerline is considered to establish the vertical alignment and to minimize and balance earthwork, such as cutting and filling [3]. Due to the increased volume of highway design work, engineers now utilize various computer software programs. These design tools typically function by exchanging graphic files. Initially, the software creates a contour map using a digital terrain model, and then it defines the horizontal and vertical alignments. As with traditional methods, the horizontal alignment is identified first. Subsequently, evaluations are conducted based on the horizontal alignment, and the ground elevation along the centerline and the grade line is determined. The benefit of using this design software is the rapid calculation of earthwork for different alignment alternatives [4, 5].

Additionally, the emergence of UAV technology has introduced new possibilities for improving the efficiency and accuracy of earthwork estimation processes. By using UAVs to capture high-resolution aerial imagery, project stakeholders can complement traditional survey methods and overcome some of the limitations associated with ground-based surveys.

Advantages and limitations of UAV technology

Unmanned Aerial Vehicles (UAVs), also known as drones, offer a range of advantages and limitations when utilized for earthwork estimation. UAVs are essential for earthwork estimation in the construction sector due to their rapid speed and high efficiency [6]. One significant advantage is the rapid data collection capability of UAVs. These aerial platforms can cover large areas efficiently and in a relatively short period compared to ground-based surveys, enabling frequent updates and real-time monitoring of project sites. Additionally, UAVs are equipped with high-resolution cameras capable of capturing detailed aerial imagery. This imagery provides valuable information about terrain features, surface conditions, and vegetation cover, facilitating accurate analysis for earthwork estimation purposes. Furthermore, UAVs have accessibility advantages, as they can access areas that may be challenging or hazardous for ground-based surveyors, such as steep slopes or dense vegetation. This capability allows UAVs to capture data from vantage points that would be otherwise inaccessible, enhancing the overall coverage and quality of the survey. However, UAV operations are subject to certain limitations, including weather dependency. Adverse weather conditions such as high winds or rain can restrict or prevent UAV flights, affecting data collection schedules and project timelines. Moreover, UAV operations are regulated by aviation authorities, requiring compliance with airspace restrictions and safety protocols. Technical challenges such as battery life, signal interference, and equipment malfunctions can also impact the reliability and effectiveness of UAV-based surveys. Additionally, processing large volumes of aerial imagery requires computational resources and specialized software, posing challenges for data processing and analysis. Despite these limitations, the advantages of UAV technology for earthwork estimation, including rapid data collection, high-resolution imagery, and accessibility, make it a valuable tool for enhancing the efficiency and accuracy of surveying and mapping activities in construction projects.

Previous studies on UAV-based earthwork estimation

Numerous studies have investigated the application of UAV technology for earthwork estimation in various contexts, providing valuable insights into its feasibility, accuracy, and effectiveness.

Akgul et al. [7] conducted a comparison of earthwork volume estimation for small-scale roads using DEMs generated by a fixed-wing UAV and a Network Real-Time Kinematic Global Navigation Satellite System (NRTK-GNSS). The findings showed that the UAV-based approach was more cost-effective and accurate than the NRTK-GNSS method. Lee et al. found that using UAV photogrammetry, contour lines can be generated with a plotter based on stereoscopic vision, similar to traditional photogrammetry methods [8]. Furthermore, UAV photogrammetry enables rapid disaster monitoring. Numerous studies have focused on generating topography in landslide-affected areas and assessing displacement [9, 10]. Research has also explored the application of UAV photogrammetry in construction sites, including the production of DEMs from point cloud data [11, 12] and methods for calculating earthwork volumes [13, 14]. Additionally, studies have investigated the detection of changes using periodically created 3D models or orthoimages of construction sites [15]. Road planning and construction require accurate earthwork estimation, influenced by the resolution of Digital Elevation Models (DEMs). Mustafa Akgul et. al, compared UAV and GNSS methods for DEM generation at Bursa Technical University Kestel campus. UAV-based surveying provided a significantly higher point density (234,385 points/ha) compared to GNSS (35 points/ha) [15]. The results showed that using UAV-based DEMs led to more precise excavation and embankment volume estimations, with similar volumes for both when averaged per unit road length [15]. Suk Bae Lee et al., performed a Comparison of Earthwork Volume Using Unmanned Aerial Vehicle Photogrammetry and Traditional Surveying Method [16]. Results showed that earthwork volume calculated using UAV photogrammetry was 2.36–2.51% larger than that obtained by traditional methods, indicating improved efficiency [16]. Hisashi Hasegawa et al., conclude that UAV-derived 3D model showed effective for accurately calculating earthwork volumes in steep forest terrains, with an average vertical error of - 0.146 m and a root mean square error of 0.098 m when compared to total station measurements [17].

In this paper, the researcher intends to investigate whether UAV data can be effectively used to estimate earthwork quantities in new route alignment projects. The goals include describing how UAV data is gathered and processed, showing how UAV-derived data can be used for calculating earthwork volumes and to analyse the difficulties, advantages, and potential future developments of using UAVs for earthwork estimation.

Methodology

The research site is situated along a planned route through undeveloped land in Ukhrul district, Manipur in Northeast India. It spans about 116.876 hectares in a mountainous region, with an average height of 278.53 meters. The area features barren land, traditional slash-and-burn cultivation plots, and dense vegetation composed of grasses and shrubs.

UAV data acquisition

UAV data acquisition is a critical initial step in the process of earthwork estimation for route alignment projects. This stage involves planning and executing UAV flights to capture high-resolution aerial imagery and establishing Ground Control Points (GCPs) using Differential GPS (DGPS) survey methods to ensure accurate georeferencing and calibration of the UAV data.

The measurement process begins with complete mission and flight planning using mission planner platform (figure 1). Key parameters set during this stage include an 80% forward overlap and a 70% side overlap, ensuring thorough coverage and high-quality data. A resolution of 5 cm per pixel is targeted, with the flying height calculated to achieve this GSD, typically around 100-120 meters above ground level, to ensure accurate photogrammetric processing for generating a detailed 3D model. The UAV (M-1000), equipped with an RGB camera (Sony DSC RX-1), was deployed to capture aerial images according to the flight plan. Multiple flights were performed to ensure full coverage.

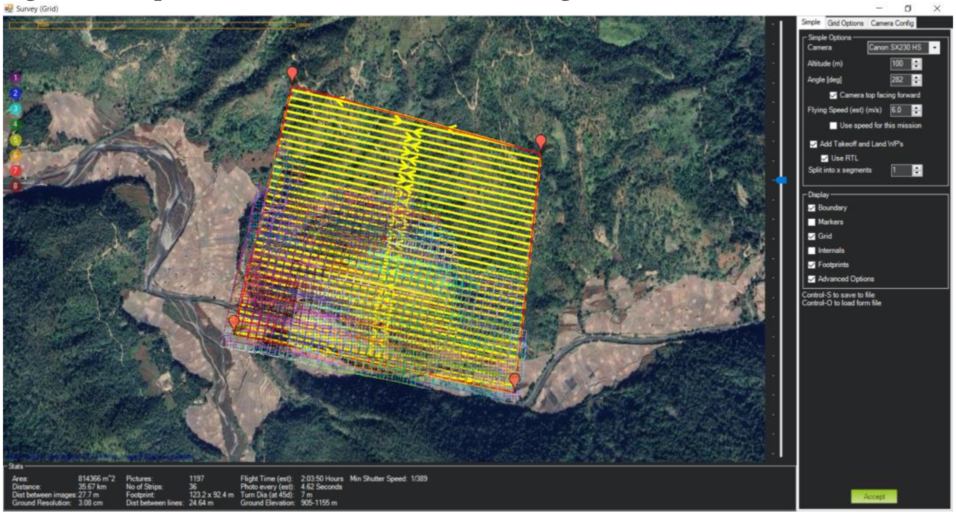


Fig.1: Flight planning of the study area using Mission Planner

Establishment of Ground Control Points (GCPs)

To ensure high accuracy in georeferencing the UAV data, four Ground Control Points (GCPs) are strategically placed to cover the study area. The locations for these GCPs are selected to provide optimal coverage. Markers are set up at these identified locations before aerial data acquisition as shown in figure 2. These markers should be large enough to be identifiable in the UAV imagery. Using Trimble R12 DGPS system, the coordinates of the GCPs are collected connected to the base station is set up at a known location with sub-centimeterlevel accuracy in WGS 84 geospatial reference system.

Fig.2: GCP marker & DGPS survey using R12

Aerial Data Collection and Processing

Securing necessary permits and permissions from aviation authorities and landowners is essential to ensure regulatory compliance and safety adherence. Subsequently, the UAV is launched to capture high-resolution images of the study area, adhering to the predefined overlaps and flight parameters. The photogrammetric processing transforms the raw aerial imagery captured by UAVs equipped with high-resolution RGB cameras into actionable geospatial data for earthwork estimation. The raw aerial imagery data are processed using AGISoft Metashape. The process encompasses several intricate steps aimed at enhancing image quality and extracting valuable information.

Initially, the raw aerial imagery captured by the high-resolution RGB camera undergoes meticulous pre-processing to correct distortions and enhance clarity. This includes correcting lens distortions, normalizing radiometric variations, and precisely georeferencing the images to ensure accurate spatial alignment. Subsequently, tie points & GCPs are identified and matched across overlapping images to establish precise correspondences, enabling accurate reconstruction of the three-dimensional scene. Equations (1), (2) & (3) are applied to correct lens distortions, normalize radiometric variations, and improve georeferencing accuracy:

$$I_{corrected} = LensDistortionCorrection(I_{raw}) \quad (1)$$

$$I_{enhanced} = RadiometricNormalization(I_{corrected}) \quad (2)$$

$$I_{georeferenced} = Georeferencing(I_{enhanced}) \quad (3)$$

where I_{raw} denote the raw aerial image, $I_{corrected}$ represent the corrected image, and $I_{enhanced}$ indicate the enhanced image.

A bundle adjustment process is then performed to refine the camera parameters and optimize the alignment of the images, ensuring geometric consistency and accuracy. With the camera parameters optimized, digital surface models (DSMs) of 20 cm posting and orthomosaic image (5cm/pix GSD) are generated from the processed imagery. DSMs depict the terrain's three-dimensional surface, including elevation data and surface features, while orthomosaics are geometrically corrected aerial images projected onto a planar surface. These geospatial products provide invaluable insights into terrain characteristics essential for earthwork estimation, such as elevation variations, slope gradients, and surface roughness.

Throughout the photogrammetric processing workflow, quality control measures are implemented to validate the accuracy and reliability of the generated geospatial products. This involves comprehensive error analysis, validation against ground truth data, and assessment of positional accuracy and resolution to ensure the fidelity of the final outputs for deriving precise and actionable geospatial information crucial for informed decision-making in earthwork estimation for route alignment projects. The accuracy of the processed data is assessed by comparing the coordinates of the GCPs with respect to their positions on the orthomosaic and DSM. Statistical analysis, specifically the calculation of Root Mean Square Error (RMSE), quantifies the accuracy of the data as shown below (Table 1):

Table 1: Root Mean Square Error (RMSE)

GCP-NAME	**Residual X (ΔX)**	**Residual Y (ΔY)**	**Residual Z (ΔZ)**	**ΔX^2**	**ΔY^2**	**ΔZ^2**
GCP-1	-0.91	-0.29	0.60	0.84	0.09	0.36
GCP-2	-0.70	0.97	-1.40	0.49	0.95	1.95
GCP-3	1.39	-0.47	0.24	1.93	0.22	0.06
GCP-4	0.83	0.62	1.10	0.69	0.39	1.20

$RMSE_X$	0.50
$RMSE_Y$	0.64
Overall $RMSE_{X\&Y}$	0.57
$RMSE_Z$	0.94

Digital Terrain Models (DTMs) serve as key components in earthwork estimation, providing detailed representations of terrain surfaces in three dimensions. Ground filtering techniques are employed to distinguish ground points from non-ground features like vegetation and buildings, facilitating the extraction of the final DTM of 20 cm posting. This DTM represents the bare earth surface, devoid of non-ground elements, and offers a complete depiction of terrain topography suitable for earthwork estimation.

Volumetric Analysis and Earthwork Estimation

Earthwork volume calculation in route alignment projects, involving the assessment of material excavation or filling required to achieve desired terrain profiles. Using QGIS, crossections are generated at 20-meter intervals along the proposed greenfield alignment route, extending 10 meters on either side as shown in the figure 3 below.

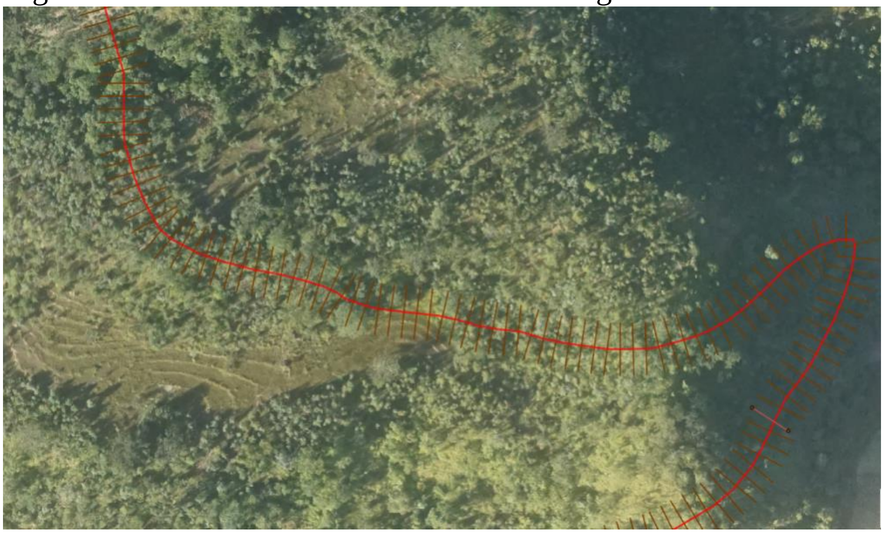
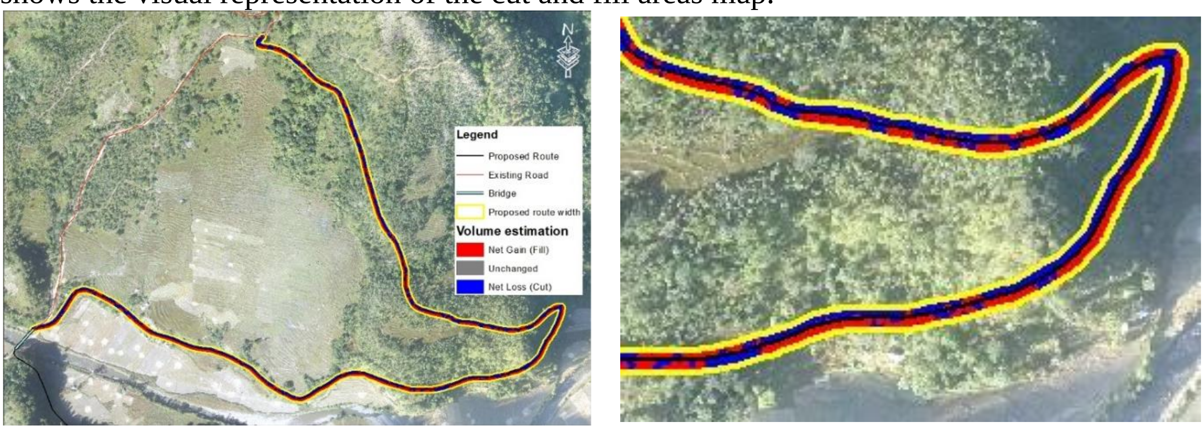


Fig.3: Crossections along the greenfield proposed aligned route at 20 m intervals

For every location where these crossections intersect with the proposed aligned route, points are generated. Using the DTM, the elevation information is assigned to the points and assumed as the reference heights for the designed surface along the proposed aligned route. Spatially, the elevation information is transferred to the crossections and convert to isolines. Using raster to topo tool in ArcMap, the designed surface is generated. According to IRC guidelines, the width of the proposed route is considered as 11.2672 m for double lanes with ROW (4.2672m). To calculate the volume of earthwork, the “Cut Fill” tool in ArcMap has been used. This tool analyzes the difference surface and quantifies the volume of material that needs to be moved—whether it is to be added (fill) or taken away (cut). The figure4 below shows the visual representation of the cut and fill areas map.



(a) (b)

Fig.4: Cross sections and cut and fill areas along proposed greenfield aligned route

The earthwork volumes are calculated based on the Grid Method which involves dividing the area into a grid of cells and calculating the volume of the prisms formed by the grid cells between the two surfaces using equation (4).

$$V=A\times (h1+h2)/2 \quad (4)$$

where A is the area of the grid cell; h1 is the height of the existing surface; h2 is the height of the design surface and V is the grid cell volume calculation.

In this study, the route length of 2.02 km has been identified for the earthwork estimation. The estimated volume for cutting is 17505.609 m^3 and the estimated fill volume is 19173.234 m^3, as depicted in Table 2. These methods and tools allow for precise earthwork volume calculations, ensuring accuracy in construction planning and cost estimation.

Table 2: Cut and fill volume report of roads planned by using UAV-based DTM and the designed surface

Route Length = 2.02 Km		
Earthwork Type	**Volume (m^3)**	**Area (m^2)**
Cut	-17505.609	11404.000
Fill	19173.234	11429.000
Unchanged	0.000	0.000

The UAV-based approach significantly reduces the time required for data collection and processing compared to traditional survey methods. The integration of high-resolution imagery and precise DGPS data enhances the accuracy of earthwork estimation. This methodology reduces costs associated with extensive field surveys, making the DPR preparation more economical. The estimated earthwork volumes and detailed terrain models aid road construction organizations in planning and executing projects more effectively. This methodology supports informed decision-making and resource allocation, ultimately leading to successful project outcomes.

Challenges and Solutions

Data acquisition challenges

One of the main challenges in UAV-based earthwork estimation is the acquisition of high-quality aerial imagery under varying environmental conditions. Factors such as weather, lighting, and terrain complexity can affect the quality and reliability of the data. To address these challenges, careful mission planning and sensor calibration are essential, along with the implementation of quality control measures during data collection.

Photogrammetric processing issues

Another challenge lies in the processing of UAV-derived imagery to generate accurate terrain models and orthomosaics. Photogrammetric processing requires computational resources and expertise in geospatial analysis techniques. To overcome this challenge, automated software tools and cloud-based processing platforms can be utilized to streamline the workflow and improve efficiency.

Accuracy and validation concerns

While UAV-based earthwork estimation offers numerous benefits, ensuring the accuracy and reliability of the results remains a critical concern. Factors such as ground control point selection, image georeferencing, and interpolation methods can impact the accuracy of volume calculations. To address these concerns, rigorous validation procedures and sensitivity analyses should be conducted to assess the robustness of the estimation approach.

Benefits and Future Directions

UAV-based earthwork estimation offers cost savings by reducing the need for extensive field surveys and manual data collection. The use of UAVs can lower operational costs and accelerate project timelines, leading to overall cost savings for route alignment projects.The rapid data collection and processing capabilities of UAVs enable real-time monitoring of construction progress and earthwork activities. This enhances project management efficiency and allows for timely adjustments to be made based on the evolving site conditions.By utilising high-resolution imagery and advanced photogrammetric techniques, UAV-based earthwork estimation can achieve greater accuracy and reliability compared to traditional methods. This enables more informed decision-making and improves the overall quality of route alignment planning. Furthermore, UAV-based earthwork estimation can be further enhanced through integration with other technologies such as Light Detection and Ranging (LiDAR). LiDAR data can complement UAV-derived imagery by providing detailed elevation information and enhancing the precision of terrain modelling and volume calculation.The future of UAV-based earthwork estimation lies in automation and machine learning algorithms. By developing intelligent systems capable of analyzing large volumes of aerial data, it will be possible to automate the earthwork estimation process and extract valuable insights for route alignment projects.

Conclusion

This paper has demonstrated the feasibility and effectiveness of using UAV data for earthwork estimation in new route alignment projects. By employing photogrammetric techniques and advanced data processing methods, UAV-based surveys can provide accurate and timely information for construction planning and management.The adoption of UAV technology offers numerous benefits for route alignment projects, including cost savings, time efficiency, and improved accuracy. By integrating UAV-based earthwork estimation into the project workflow, stakeholders can make more informed decisions and optimize resource allocation throughout the construction process.Future research in UAV-based earthwork estimation should focus on addressing remaining challenges such as accuracy validation, data processing automation, and integration with complementary technologies. By continuing to innovate and refine UAV-based survey techniques, the construction industry can unlock new opportunities for efficiency and sustainability in infrastructure development.

Conflict of Interests

This paper is an attempt to highlight the efficacy of geospatial technology and drone technology in earthwork estimations for route alignment planning with predefined criteria. The authors declared that there is no conflict of interests regarding the work and the publication of this paper.

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References

[1]. Krammes, R.A., and Garnham, M.A. Worldwide review of alignment design policies. International Symposium on Highway Geometric Design Practices, Boston. 1995.

[2]. Sthapit, N and Mori, H. Model to Estimate Highway Earthwork Cost in Nepal.https://ascelibrary.org/doi/10.1061/%28ASCE%290733-947X%281994%29120%3A3%28498%29. 1994.

[3]. AASHTO. A policy on geometric design of highways and streets. AASHTO Publication, Washington, D.C. 1994.

[4]. Banks, J. H. *Introduction to Transportation Engineering*, WCB/ McGraw-Hill Company, Singapore. 1998.
[5]. NETCAD-NETPRO. *Software manual*. Ak Engineering Publication, Ankara, Turkey. 1999.
[6]. Park, H.C.; Rachmawati, T.S.N.; Kim, S. UAV-Based High-Rise Buildings Earthwork Monitoring—A Case Study. Sustainability 2022, 14, 10179.
[7]. Akgul, M.; Yurtseven, H.; Gulci, S.; Akay, A.E. Evaluation of UAV- and GNSS-Based DEMs for Earthwork Volume. Arab. J. Sci. Eng. 2018, 43, 1893–1909.
[8]. S. B. Lee, T. Kim, Y. J. Ahn, and J. O. Lee: Sens. Mate. 31 (2019) 3797. https://doi.org/10.18494/SAM.2019.2553
[9]. J. Travelletti, C. Delacourt, P. Allemand, J. P. Malet, J. Schmittbuhl, R. Toussaint, and M. Bastard: ISPRS J. Photogramm. Remote Sens. 70 (2012) 39. https://doi.org/10.1016/j.isprsjprs.2012.03.007
[10]. D. Turner, A. Lucieer, and S. de Jong: Remote Sens. 27 (2015) 1736. https://doi.org/10.1177/0309133313515293
[11]. M. M. Quédraogo, A. Degré, C. Debouche, and J. Lisein: Geomorphology 214 (2014) 339. https://doi. org/10.1016/j.geomorph.2014.02.016.
[12]. S. B. Lee, J. H. Won, K. Y. Jung, M. Song, and Y. J. Ahn: Sens. Mater. 32 (2020) 4347. https://doi.org/10.18494/ SAM.2020.2973
[13]. H. H. Chris, M. W. Jordan, B. Owen, and M. A. Steve: J. Surv. Eng. 141 (2015). https://doi.org/10.1061/(ASCE) SU.1943-5428.0000138
[14]. S. Siebert and J. Teizer: Autom. Constr. 41 (2014) 1. https://doi.org/10.1016/j.autcon.2014.01.00
[15]. Mustafa Akgul, Huseyin Yurtseven, Sercan Gulci, Abdullah E. Akay. Evaluation of UAV- and GNSS-Based DEMs for Earthwork Volume. Arab J Sci Eng (2018) 43:1893–1909. https://doi.org/10.1007/s13369-017-2811-9
[16]. Suk Bae Lee, Dongyeob Han, and Mihwa Song. Calculation and Comparison of Earthwork Volume Using Unmanned Aerial Vehicle Photogrammetry and Traditional Surveying Method. Sensors and Materials, Vol. 34, No. 12 (2022) 4737–4753
[17]. Hasegawa, H.; Sujaswara, A.A.; Kanemoto, T.; Tsubota, K. Possibilities of Using UAV for Estimating Earthwork Volumes during Process of Repairing a Small-Scale Forest Road, Case Study from Kyoto Prefecture, Japan. Forests 2023, 14, 677. https://doi.org/10.3390/f14040677
[18]. https://docs.qgis.org
[19]. https://www.esri.com
[20]. https://www.agisoft.com