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TOPOGRAPHIC SURVEY OF A SECTION OF THE UNIVERSITY OF ILORIN, NIGERIA USING UNMANNED AERIAL VEHICLE (UAV) TECHNOLOGY

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ABSTRACT

Purpose: *This study evaluates the effectiveness and accuracy of Unmanned Aerial Vehicle (UAV) photogrammetry for generating reliable topographic data within a section of the University of Ilorin, Nigeria. It examines whether RTK-enabled UAVs can serve as efficient alternatives to conventional surveying methods for infrastructure planning and spatial analysis.*

Design/methodology/approach: *A DJI Mavic 3E UAV with an integrated Real-Time Kinematic (RTK) module was used to capture high-resolution imagery without external Ground Control Points (GCPs). Flights were conducted at about 100 m altitude with 80% frontal and 70% side overlap, yielding a Ground Sampling Distance (GSD) of 2.4 cm/pixel. Data processing in Agisoft Metashape included image alignment, dense point cloud generation, DSM/DTM creation, orthomosaic production, and extraction of topographic features. Accuracy was evaluated using RMSE metrics.*

Findings: *The study achieved centimeter-level positional accuracy consistent with international geospatial standards. Elevation values ranged from 320–400 m, revealing terrain variability that aids interpretation of slope characteristics, drainage pathways, and infrastructure suitability. UAV-derived outputs proved reliable for land-use planning and geospatial analysis.*

Research limitations/Implications: *Limitations include reliance on a single UAV platform and study area, which may affect result generalization. Weather, vegetation, and regulatory conditions may also influence data quality. Future research should assess larger areas or integrate other sensors such as LiDAR.*

Practical implications: *The study supports integrating UAV photogrammetry into the University's spatial data acquisition framework to enhance efficiency and accuracy in infrastructure planning.*

Originality/value: *This work demonstrates the capability of an RTK-enabled UAV, specifically the DJI Mavic 3E, to produce precise topographic data without GCPs, highlighting UAV photogrammetry as a modern alternative to traditional surveying techniques.*

Keywords: Unmanned Aerial Vehicle (UAV), Real-Time Kinematic (RTK), Topographic Survey, Photogrammetry, Digital Surface Model (DSM)

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1.0 INTRODUCTION

Topographical surveying is critical for accurately representing Earth's surface features such as terrain elevations, landforms, and structures (Okwuenu et al., 2024). Detailed topographic maps are essential for land-use planning, infrastructure development, disaster management, and environmental monitoring, as they provide comprehensive data on elevation, slopes, and landscape features (Bhatla et al., 2024; Kumari et al., 2025). With increasing demand for spatial data, particularly in rapidly growing urban and educational areas, ensuring accuracy and efficiency in data collection has become a priority for modern geospatial science (Dritsas & Trigka, 2025; Selmy et al., 2024).

Traditional surveying methods like ground measurements and aerial photogrammetry are reliable but often laborious, slow, and limited by accessibility issues, especially over large areas (Li, 2023; Dlamini & Ouma, 2025). Satellite remote sensing expanded data coverage and efficiency, enabling mapping of remote regions with improved accuracy (Zhang et al., 2022; Kumari et al., 2025). However, satellites may lack the required spatial and temporal resolution for engineering or disaster response needs, and their operational costs limit frequent updates (Kumari et al., 2025; Dritsas & Trigka, 2025).

Recent advances in Unmanned Aerial Vehicles (UAVs, or drones) have transformed geospatial data acquisition for surveying and mapping (Telli et al., 2023; Mohsan et al., 2022, 2023). UAVs provide a cost-effective, flexible, and high-resolution alternative capable of collecting precise aerial imagery even in hazardous or inaccessible areas (Hussain et al., 2024; Ok, 2025b). Equipped with sensors like Inertial Measurement Units (IMUs) and GPS, UAVs enable accurate flight planning and real-time monitoring, enhancing data reliability and operational efficiency (Zhukov, 2024; Ahmed & Jenihhin, 2022).

This versatility has led to widespread UAV adoption in topographic mapping, infrastructure inspection, urban planning, agriculture, forestry, and disaster management (Khan et al., 2022; Muhmad Kamarulzaman et al., 2023; Quamar et al., 2024). UAV photogrammetry facilitates rapid acquisition of centimeter-level resolution orthomosaics and 3D topographic models, supporting applications needing high spatial detail and frequent updates (Jiang et al., 2021; Sohl & Mahmood, 2024).

At the University of Ilorin, Nigeria, there is a pressing need for accurate, up-to-date topographic data to support campus expansion, infrastructure development, and environmental management (Ali et al., 2024; Rai et al., 2022). Existing maps are often outdated and insufficient, complicating effective planning, especially given the campus's extensive and varied terrain (Oladimeji et al., 2025). UAV surveying presents a promising solution to generate precise topographic maps, aiding decision-making in infrastructure and land-use optimization (Ok, 2025a; Muhmad Kamarulzaman et al., 2023).

This study evaluates the use of UAV technology to conduct a detailed topographic survey of a designated area within the University of Ilorin campus. Using a DJI Mavic 3 Enterprise drone with an embedded RTK module, high-resolution aerial imagery was captured and processed to produce orthomosaic maps, Digital Surface Models (DSMs), and 3D point clouds. The research assesses UAV surveying's accuracy, efficiency, and practicality in delivering reliable topographic data, contributing to the advancement of modern geospatial data acquisition for large institutional environments like the University of Ilorin (Dritsas & Trigka, 2025).

2.0 MATERIALS AND METHODS

2.1 Study Area

The study area encompasses a 100-hectare section situated along the ring road within the University of Ilorin campus, Kwara State, Nigeria, which itself spans approximately 15,000 hectares (Oladimeji et al., 2025). This site features a heterogeneous mix of infrastructure, road networks, and undeveloped land, set within gently undulating terrain with elevations ranging from 317 to 377 meters above sea level. The landscape presents a combination of built environments, natural vegetation, and moderate topographic variability, making it an ideal location for assessing UAV-based topographic surveying methods. These characteristics, along with ongoing campus development activities, provide a practical context to evaluate the accuracy and operational efficiency of UAV photogrammetry for generating high-resolution spatial data to support informed campus planning and land management (Ok, 2025a; Muhmad Kamarulzaman et al., 2023; Kumari et al., 2025). Figure 1 presents the study area.

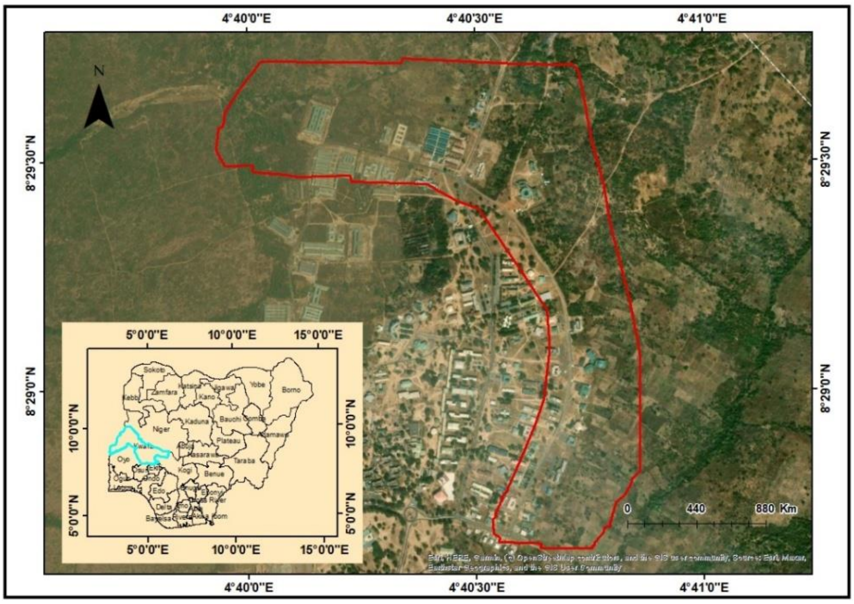


Figure 1: Overview of the study area – Location of the study area (a) Nigeria (b) Satellite imagery of University of Ilorin Campus

2.2 UAV Platform and Sensors

The DJI Mavic 3 Enterprise (Mavic 3E), a rotary-wing quadcopter, served as the UAV platform for data acquisition. It is equipped with a 4/3 CMOS sensor camera of 20-megapixel resolution, featuring a fixed focal length equivalent to 24 mm and an aperture range of f/2.8 to f/11, designed for high-quality photogrammetric imaging. The onboard Real-Time Kinematic (RTK) GNSS module provides centimeter-level positional accuracy, typically ±3 cm horizontal and ±5 cm vertical, facilitating precise georeferencing of aerial images in real time (Metehan, 2023; Hinzmann et al., 2018).

2.3 Flight Planning and Data Collection

Flight missions were planned using DJI Pilot 2 software, enabling automation and optimization of photogrammetric parameters appropriate for the study area (Giordan et al., 2020). Data acquisition was conducted at a flight altitude of 100 meters above ground level, producing an estimated Ground Sampling Distance (GSD) of roughly 3.5 cm/pixel. The UAV followed a grid flight pattern with an 80% frontal overlap and 70% lateral overlap, sufficient for successful Structure-from-Motion (SfM) photogrammetry and detailed 3D reconstruction (Iheaturu et al., 2020). Flights were scheduled under clear weather conditions with wind speeds below 10 m/s to minimize motion blur and positional errors.

2.4 Ground Control and Accuracy Validation

Despite the precision of the RTK system, Ground Control Points (GCPs) and Check Points (CPs) were established using conventional survey methods for independent accuracy verification. GCP coordinates were precisely determined using GNSS base stations integrated with the RTK system, ensuring high positional reliability (Stott et al, 2020).

2.5 Data Processing Workflow

Captured imagery embedded with RTK metadata was imported into photogrammetric software for processing. The workflow entailed image alignment, followed by the generation of sparse and dense point clouds via multi-view stereo (MVS) algorithms, and then noise filtering and classification to separate terrain surfaces from above-ground features, such as vegetation and structures (Gherga et al., 2020; Hinzmann et al., 2018). The Orthomosaic production and Digital Surface Model (DSM) generation provided a detailed spatial representation of the survey area, incorporating both terrain and surface features (Stott et al, 2020).

2.6 Accuracy Assessment

The positional accuracy of UAV-derived products was quantitatively assessed by comparing coordinates obtained from UAV data with those of ground truth CPs. Root Mean Square Errors (RMSE) were computed for X (Easting), Y (Northing), and Z (Elevation) axes to evaluate the survey precision (El Meouche et al, 2016).

3.0 RESULTS AND DISCUSSION

3.1 UAV Data Acquisition and Processing Outcomes

The UAV survey conducted over the selected section of the University of Ilorin campus yielded high-quality aerial imagery and spatial data products. The DJI Mavic 3 Enterprise (Mavic 3E), equipped with integrated RTK technology, captured over 200 overlapping images at 100 meters altitude, providing an estimated Ground Sampling Distance (GSD) of approximately 3.5 cm/pixel. This spatial resolution was sufficient to capture fine details of both natural and man-made surface features.

Photogrammetric processing of the imagery generated dense point clouds via multi-view stereo (MVS) algorithms, subsequently producing orthomosaic images and Digital Surface Models (DSMs) representing the terrain and above-ground objects such as buildings and vegetation. The orthomosaic output demonstrated excellent geometric fidelity, with seamless stitching and minimal distortion, consistent with standards outlined by Gherga et al (2020) and Hinzmann et al (2018). The Orthomosaic Image and dense point cloud of the study area are presented in Figures 2a and 2b, respectively.

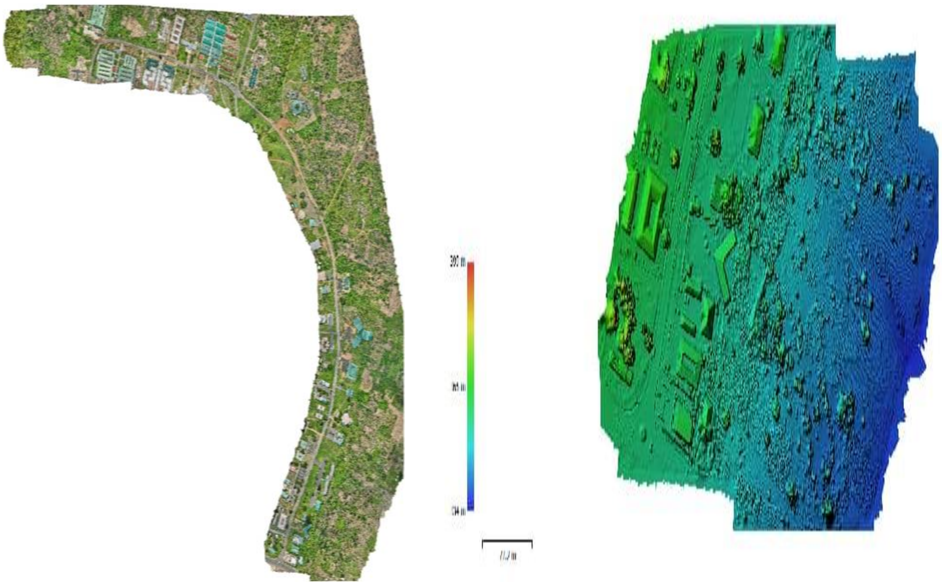


Figure 2a: Orthomosaic Image of the study area   Figure 2b: Image of the Dense Point Cloud

3.2 Topographic Outputs: Contour, Spot Height, and Aspect Maps

UAV-based photogrammetric surveying produces reliable topographic outputs such as contour maps, spot height charts, and aspect maps essential for detailed terrain analysis and planning. After image acquisition and processing in Agisoft Metashape, both Digital Surface Model (DSM) and Digital Terrain Model (DTM) are generated, serving as key datasets for accurate terrain representation. These elevation models form the basis for producing precise topographic products that characterize terrain features for surveying, engineering, and land development purposes.

Contour Map

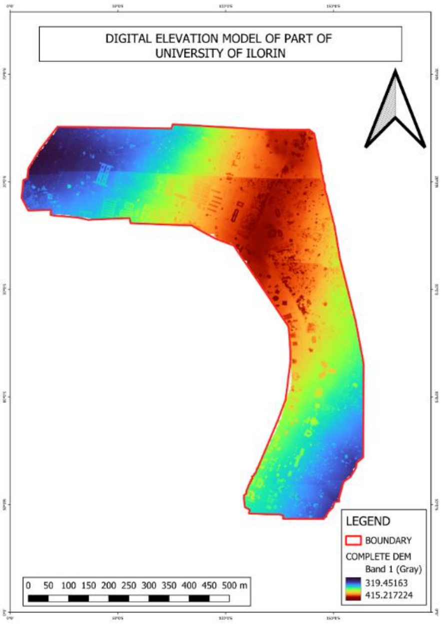
Contour lines, extracted from the filtered Digital Terrain Model using Agisoft Metashape at 5-meter intervals, represent terrain relief and slope gradients on the University of Ilorin campus. Elevations range from 320 to 380 meters, with dense contours indicating steep slopes and wide spacing showing gentle terrain. Low-relief areas (330–350m) are suitable for construction, while higher zones (370–380m) offer strategic advantages for installations. Low elevations near 320m risk of flooding, requiring mitigation. The contour map supports informed infrastructure planning, environmental management, and land-use decisions by linking topography with practical campus development needs. Figure 3b shows the contour map.

Spot Height Map

Spot heights are discrete elevation points extracted from the DTM in Agisoft, with spatial resolution matching the UAV’s 2.4 cm/pixel GSD at 100 m altitude. Elevations range from 320 to 400 meters, indicating gently rolling terrain typical of Ilorin’s transitional savannah (Olatunji, 2020). Variation in spot heights guides civil engineering decisions, prioritizing elevated areas for construction and lower zones for parks or stormwater management (Simperler et al. 2020). The spot height map provides valuable geomorphological and infrastructural insights to support sustainable land development and hazard mitigation on the University of Ilorin campus. UAV mapping with DJI Mavic 3E enables rapid, accurate elevation data generation for diverse planning and engineering uses. Figure 3c shows the spot height map.

Aspect Map

The aspect map, derived from DSM or DTM in Agisoft, shows slopes between 320–400 m elevation, mainly facing north-east and south-west. This directional pattern reflects natural terrain shaped by hydrological and geological processes (Lehmann & Totsche, 2020; Gnann et al., 2025). Understanding dominant aspects aids in assessing drainage, erosion, wind exposure, microclimate, and sustainable land-use (Bhatla et al, 2024). For the University of Ilorin, aspect analysis supports environmentally aware and structurally sound development planning. Figure 3d shows the aspect map.



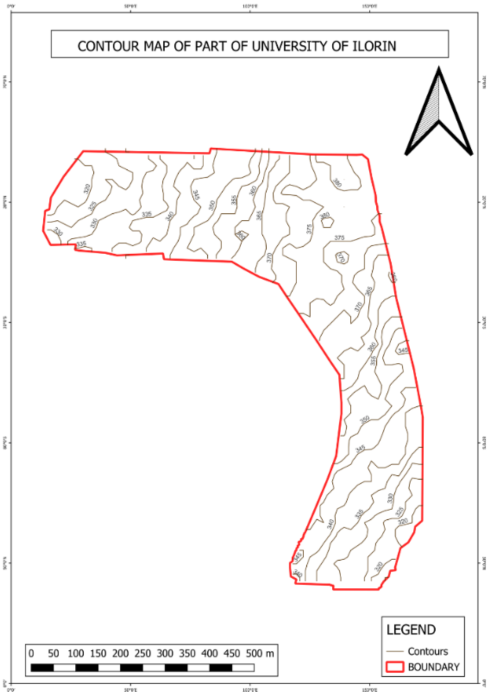
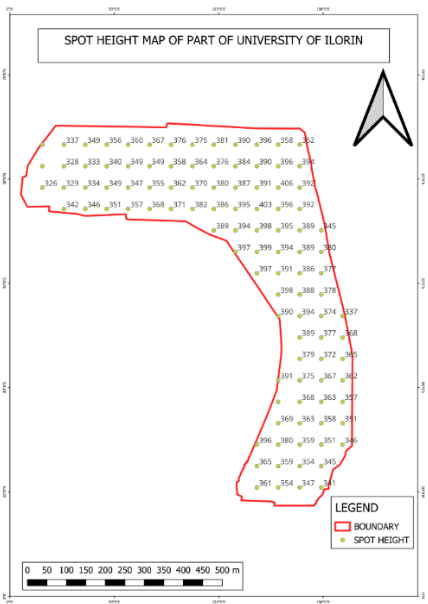


Figure 3a: Digital Elevation Model of the study area   Figure 3b: Contour Map of the study area



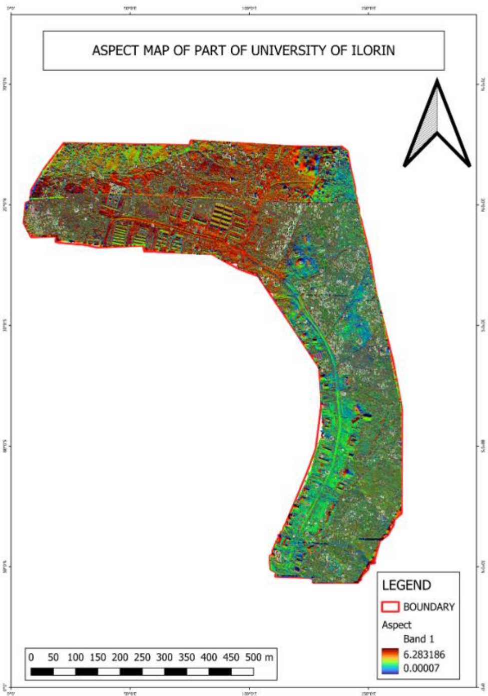


Figure 3c: Contour Map   Figure 3d: Aspect Map

3.3 Positional Accuracy and Validation

Accuracy assessments employed ground-validated check points (CPs) established using GNSS base station data integrated with the RTK system. Comparison of UAV-derived coordinates against these CPs revealed root mean square errors (RMSE) of 0.018 m, 0.017 m, and 0.014 m along the X (Easting), Y (Northing), and Z (Elevation) axes, respectively (see Table 1). The total RMSE of 0.049 m confirms the capability of the UAV-RTK system to achieve centimeter-level accuracy.

These findings align with accuracy expectations of RTK-enabled UAV surveys reported by Metehan (2023) and Hinzmann *et al*. (2018), reinforcing the efficiency of RTK integration in reducing reliance on extensive ground control deployment without compromising spatial precision. Accuracy assessment of UAV-derived spatial data compared to ground truth data is depicted in Table 1.

Table 1. Accuracy assessment of UAV-derived spatial data compared to ground truth

Axis	RMSE (meters)
X (Easting)	0.018
Y (Northing)	0.017
Z (Elevation)	0.014
Total RMSE	**0.049**

3. 4 Discussion

The study validates the applicability of UAV technology equipped with RTK positioning for topographic and detailed surveying in mixed land cover environments. The ultrahigh-resolution data and positional precision achieved highlight several advantages over conventional ground-based surveys. Some of the advantages include efficiency and cost-effectiveness, high spatial resolution and accuracy, reduced ground control requirements, and data integration potential.

UAV deployment drastically reduced fieldwork time and labor, enabling comprehensive coverage of the study area within a short period. The automated flight planning with DJI Pilot 2 software and real-time georeferencing with RTK minimized manual post-survey corrections, consistent with procedures recommended by Giordan et al. (2020). The fine GSD and centimeter-level accuracy affirm UAV capability in capturing detailed terrain and surface features, validating assertions by Balázsik et al. (2021). This precision is critical for urban planning, environmental assessment, and infrastructure monitoring on campus and in similar environments. The embedded RTK GNSS system effectively mitigated the need for extensive deployment of GCPs, aligning with findings from Olivart et al (2020) and reinforcing operational flexibility, especially in areas where ground access is restricted or challenging.

Generated orthomosaics and DSMs provide a robust spatial framework for further geospatial analyses and integration with multispectral or LiDAR data, as suggested by Hieu (2022) and Ngure (2022), enhancing the versatility of UAV-based surveying in diverse applications.

Despite these benefits, operational challenges require consideration, including environmental factors (e.g., wind conditions, lighting), UAV battery life constraints, and regulatory compliance. Adherence to recommended flight parameters and mission planning safeguards data quality, as reflected in this study's successful outcomes.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The DJI Mavic 3 Enterprise UAV equipped with integrated Real-Time Kinematic (RTK) GNSS achieved centimeter-level positional accuracy (RMSE ~ 0.049 m total), enabling highly accurate topographic mapping with reduced need for extensive ground control points. Automated flight planning and optimized photogrammetric parameters (100 m altitude, 80% frontal and 70% lateral image overlap) facilitated rapid collection of high-resolution aerial imagery (GSD ~3.5 cm/pixel), supporting the generation of detailed orthomosaics, Digital Surface Models (DSMs), and dense 3D point clouds. The UAV-RTK system proved cost-effective, time-efficient, and adaptable for surveying mixed land cover environments such as university campuses, with potential for integration with multisensor data to enhance future mapping precision and versatility.

The results underscore the transformative impact of UAV-RTK systems in geospatial data acquisition, empowering rapid, accurate, and cost-efficient surveying workflows. This investigation confirms that the DJI Mavic 3 Enterprise UAV, combined with optimized flight planning and rigorous accuracy validation, is a viable tool for detailed topographic surveying in complex land cover areas such as university campuses. Future work will focus on integrating additional sensor modalities and advancing automated classification algorithms to enhance data richness and mapping capabilities.

4.2 Recommendations

The following are hereby recommended based on the research:

- Academic institutions and survey agencies should integrate UAV-RTK systems like the DJI Mavic 3 Enterprise into routine surveys and extend their use to complex terrains to enhance survey efficiency and adaptability.
- Incorporation of complementary sensors (multispectral, thermal, LiDAR) with RTK imaging and development of standardized flight, data acquisition, and processing protocols alongside comprehensive operator training to ensure consistent, high-quality results.
- Conduct accuracy and reliability studies to refine practices, and utilize cloud computing platforms for efficient processing, data management, and stakeholder collaboration

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