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Use of unmanned aerial vehicle (UAV) for mapping, and accuracy assessment of the orthophoto with and without using GCPs: A case study in Nepal

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Abstract

The conventional methods of aerial photogrammetry using helicopters or airplanes are costly and challenging for small areas. For a developing country like Nepal, where Geospatial data is in high demand, a new competitive approach is essential for rapid spatial data acquisition at a low cost and time. This article demonstrates how this can be achieved using one of the evolving remote sensing technology, Unmanned Aerial Vehicles (UAVs). The application of UAVs is rapidly increasing in Nepal due to its capability of acquiring images remotely and the potential to provide data with a very high spatial and temporal resolution even in inaccessible terrain at a relatively low cost. Here, the performance of UAVs for topographical surveying and mapping has been investigated, along with the comparison between orthophoto obtained using GCPs, and without using GCPs. For this study, a DJI Phantom 3 Advanced quadcopter collected about 700 images at a flying height of 50 m above the settlement area. An orthophoto of 3.78 cm GSD covering 40.83 hectares of area was produced. With appropriate ground control points, an absolute positional accuracy of 0.035 m RMSE was achieved, whereas the output obtained without using GCPs was satisfactory. This study also highlights the use of a High-Performance Computing (HPC) system and open-source platform for rapid image processing.

1. Introduction

Geospatial data and spatially aware technologies play a crucial role in infrastructure planning and development in every country [1]. Almost all the sectors of a nation have a spatial component, from cadastral records, land use, land cover, and smart cities to utility lines, transportation networks, and critical infrastructure [2]. There is an urgent need to change Nepal's development model because its current development path is not aiding it to escape from the low-growth trap it is in [3]. So, the country's development model should be reformed. Geospatial technologies can revolutionize a country's economy by assisting effective planning of infrastructure and sustainable development [4-5].

Unmanned Aerial Vehicle in the surveying industry is a new competitive and affordable approach for countries like Nepal for rapid spatial data collection at less cost and time [6-7]. The application of UAVs is rapidly increasing in Nepal due to its capability of acquiring images remotely and the potential to provide data with a very high spatial and temporal resolution even in inaccessible terrain at a relatively low cost [7-9].

UAV, also known as a drone, is an aircraft that can fly without a pilot [10-11]. It can fly autonomously and can be either human-operated or self-programmed in a wide range of missions that can be controlled from a ground base station [12]. It is a controllable platform for the data collection process that can go through risky areas to collect information rapidly and update the data without delay like satellite images or terrestrial surveying [13-15]. Aerial photogrammetry with aircraft is expensive and hard to operate with sophisticated planning. So, UAVs have become adequate and preferable among surveyors [16-17].

UAV use in research has increased over the past decades, which has greatly increased their significance [18-19]. This is further supported by the volume of academic articles on UAVs that have been published in various research communities during the past 20 years.

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According to [18], since then, more than 80,000 articles featuring the terms "UAV" or "drone" in the title or the keywords have been published, with the bulk of these works falling under the engineering and computer science fields and the majority of contributions coming from remote sensing domain [18, 20]. This technology has been effectively used for ecological applications [21-24], glacier monitoring [25], natural disasters [11, 17, 26], agriculture surveillance [27-29], and other environments that are continually changing [7, 30-33] .

The accuracy of UAVs for land surveying and mapping has been demonstrated all around the world. In Taiwan, for instance, [34] examined high-accuracy topographic mapping using UAV-based images and determined the integration capability of topographic maps via the image of UAV and GCPs. According to [34], UAV-based surveying may eventually be an effective replacement for GPS and total stations. Working on the application of UAV in Ghana for topographical mapping of inaccessible land, [35] concluded that, for mapping inaccessible locations, the combination of RTK technology with UAV and GIS is a viable and adequately accurate option and also recommends it for the creation of precise geometry and cross-sectional drawings for the design of Tailings Storage Facility (TSF).

Likewise, this study also investigates the performance of UAV for topographical mapping and compares the accuracy with and without using GCPs. This study involves image acquisition using UAV, Ground Control Points (GCPs), and check Points (CPs) establishment using DGPS, image processing using HPC, accuracy assessment, and finally extraction of 2D features and analysis using open-source GIS software.

2. Study Area

A study area is located around the Kathmandu University Central Campus, Kavre District, Bagmati Province, Nepal. It is shown in Figure 1. The total area of this site is about 40 hectares. The elevation of the site ranges from about 1400m to 1480m above the mean sea level. This area includes built-up areas, open spaces, water bodies, road networks, and agricultural land - so it was chosen.

3. Material And Methods

For this study, DJI Phantom 3 Advanced quadcopter with the following specification was used. Table 1 depicts the specification of the UAV used in this study.

A schematic overview of the methodology workflow is shown in Figure 2.

Table 1. Specification of UAV (DJI Phantom 3 Advanced)

Model	DJI Phantom3 Advanced
Camera	FC300S
Resolution	12.4 MP
Sensor width and height	6.317 [mm] x 4.738 [mm]
Image Size (max.)	4000 X 3000
Pixel Size	1.56*1.56 µm
Focal length	3.6 mm
Geolocation	On-board GPS
Control System	Remote/phone/table

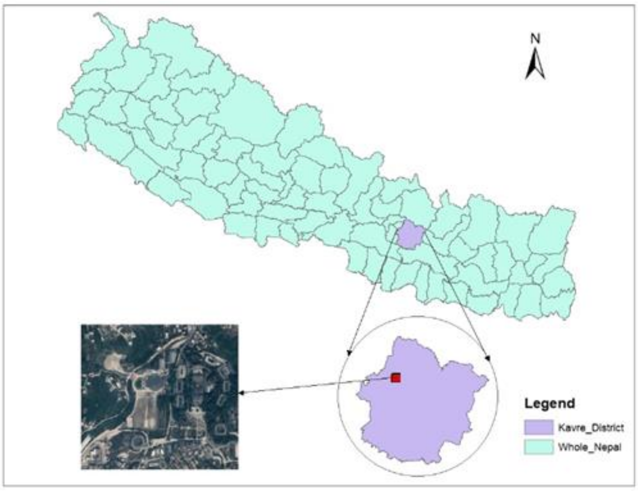

Figure 1. Study Area Map

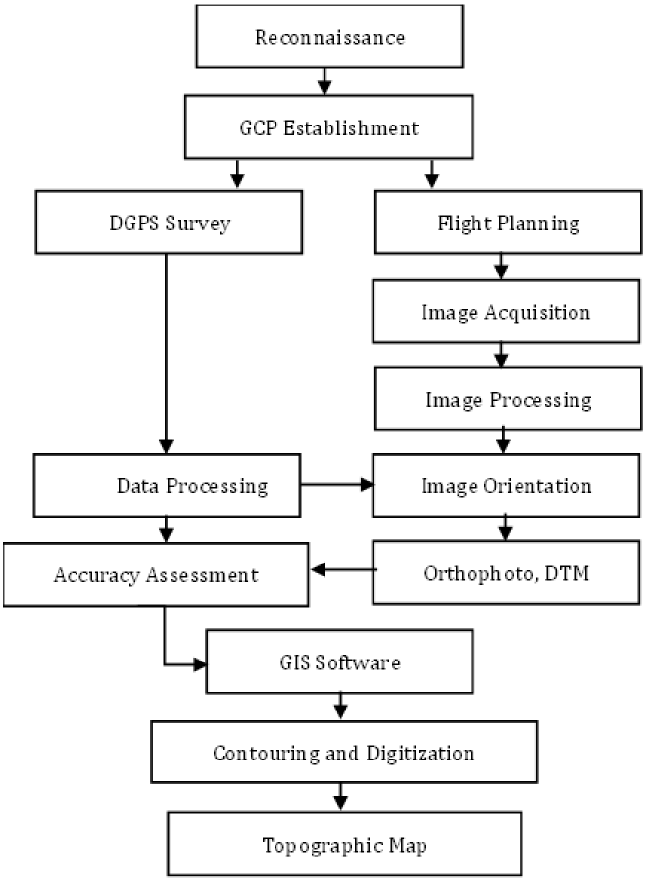

Figure 2. The workflow of methodology

3.1. Reconnaissance

At first, a desk study was done by looking at Google maps and existing Topographical maps of the study area, and necessary planning and preparation were done.

3.2. GCP Establishment

The GCPs and CPs were established for georeferencing and accuracy assessment, respectively. A total of 14 points were installed on the ground. The GCPs and CPs were selected considering the proper distribution in all the parts of the study area and clear aerial visibility. GCP and CP were established by static DGPS method using a GNSS receiver [36].

3.3. Flight Planning and Image Acquisition

Flight planning was done using the Pix4D capture application above the study area. The UAV flew autonomously in a pre-defined flight plan at an approximate altitude of 50m above ground. Several UAS criteria as mentioned by [37] were considered while choosing flight parameters. A total of 700 geotagged images were taken from a nadir perspective, with 80% forward and 70 % side overlap. Although percentages of forward and side overlaps vary depending on the kind of terrain [38], the research on UAV imagery acquisition suggests above 70% forward and 60–70% side overlap for the majority of situations [39-40].

3.4. Image Processing

Images captured from UAV were processed in Pix4D mapper and Web Open Drone Map (ODM) - in the HPC system, also known as Supercomputer. WebODM is an open-source platform written in the Python programming language designed to perform photogrammetric analysis and processing of UAV imagery [41]. Image processing involves several steps which are discussed in the later part.

3.5. Image Orientation

Image orientation was done using 14 high-accuracy ground control points (GCPs). Figure 3 shows the 14 points statically surveyed on the ground using DGPS/GNSS receiver with approximately 1.8 cm standard deviation. These points were marked using a notable flag during image acquisition. Out of the 14 points, seven were selected as GCP for the exterior orientation process, and seven were considered CP for accuracy assessment. It was ensured that each point got marked in at least six images to avoid distortion [36].

Similarly, images were also oriented without using the ground control points to test the accuracy with UAV onboard GPS. It can help to quantify the geolocation differences when it is not possible to collect GCPs. All GCPs were assigned to be checkpoints for checking the accuracy of this output.

3.6. Dense point cloud generation

After a proper internal and external orientation, a dense matching technique was applied to represent the object space through dense point clouds. These point clouds are, later on, structured, interpolated, simplified, and textured for photo-realistic representation and visualization [42]. To generate a mesh and create a surface with all the terrain features, it is used directly [33].

3.7. Orthophoto Generation

After interpolating the 3D points generated in previous steps, a triangulated irregular network was formed, which resulted in a Digital Surface Model (DSM). Now, to develop an orthophoto, the orthorectification process was performed from DSM. This task produced an orthogonal projection from the initially taken images by re-projecting the original image pixels [23]. Moreover, to retrieve a more appealing orthophoto, texture and color balancing were applied.

3.8. Accuracy Assessment

Quantitative accuracy assessment was done using CPs. Root Mean Square Error (RMSE) result is used to display the accuracy value of the dataset by calculating the difference between reference and observed coordinates [36, 40]. On the other hand, the features' appearance in the orthophoto, deformations, and hazes were checked through visual inspection for qualitative evaluation. Also, the positional accuracy of orthophoto obtained using GCPs and without GCPs was compared. It helped to know the accuracy and their corresponding application in each condition.

3.9. Map Preparation

After getting a true orthophoto, all the spatial data are extracted by digitizing it in GIS software. Similarly, the contour is also generated using Digital Terrain Model (DTM). Due to the high-resolution orthophoto, even small features and changes were detected. Finally, they are combined to prepare a topographical map.

4. Results and Discussion

4.1. Coordinates Collected

The processed coordinates that were obtained from raw data after the GNNS survey are shown below. Table 2 shows the coordinates of GCPs, which were used to georeference the images, whereas Table 3 represents the coordinates of CPs used for the accuracy assessment of the orthophoto.

Table 2. Ground Control Point Coordinates

GCP Name	Easting (m)	Northing (m)	Elevation (m)
1000	355785.301	3055784.53	1459.631
1001	355737.436	3056024.12	1443.244
1003	355435.732	3055657.31	1418.243
1013	355883.056	3055904.63	1451.323
1008	355556.938	3055921.53	1418.751
1012	355800.501	3055885.7	1466.698
1015	355893.612	3055677.96	1448.762

Table 3. Check Point Coordinates

CP Name	Easting (m)	Northing(m)	Elevation(m)
1004	355588.556	3055682.47	1442.044
1006	355688.922	3055794.37	1430.637
1007	355760.222	3055735.94	1445.875
1009	355737.705	3055913.09	1451.685
1010	355771.695	3055947.9	1457.136
1011	355812.974	3055966.78	1451.311
1014	355905.762	3055756.41	1438.522

4.2. Image Orientation

For image orientation, two experiments were carried out. One was Georeferencing using ground control points, and the other was orientation using geotags images only, without relying on ground control points.

Geolocation results (errors in x, y, and z) using GCPs and Check Points are shown in Table 4 and Table 5, respectively. While using GCPs, the model is geolocated accurately with an accuracy of 4 cm in x, 2 cm in y, and 3 cm in z. It is a significantly high accuracy, which can be used for any project.

Table 4. Geolocation result with GCPs

GCP Name	Error X [m]	Error Y [m]	Error Z [m]
1000	-0.095	0.033	0.047
1012	-0.0106	0.0053	0.0405
1003	0.001	0.002	-0.005
1008	0.004	-0.002	-0.006
1001	-0.032	-0.049	0.057
1015	0.028	0.009	-0.009
1013	0.072	-0.03	-0.014
Mean[m]	-0.00466	-0.00453	0.01579
Sigma[m]	0.04780	0.02497	0.02851
RMSE(m)	0.04493	0.02374	0.03049

Table 5. Check Point Errors

CP Name	Error X [m]	Error Y [m]	Error Z [m]
1004	-0.06385	0.0804	-0.0224
1006	-0.03139	0.039	-0.1065
1010	-0.0361	-0.0467	0.0871
1011	0.0253	-0.0565	0.0883
1007	-0.0544	0.0512	-0.0446
1014	0.0204	-0.0443	-0.0423
1009	-0.0579	-0.0402	-0.0591
Mean [m]	-0.02828	-0.002443	-0.01421
Sigma[m]	0.034093	0.052802	0.068748
RMSE[m]	0.044293	0.052859	0.070202

In another case, the images were processed in WebODM without using GCPs. Images were oriented with geotags only using the HPC system, which resulted, in a speedy orthophoto generation. The geolocation check result is shown in Table 6. The result is relatively less accurate, especially in the case of height. It is due to only the use of inbuilt GPS that is present in UAV. However, this result is promising for projects that require an accuracy of less than a meter. The limited accuracy is because of not using ground control points, GPS quality, and lack of precise time synchronization between the image acquisition and GPS receiver.

Table 6. Geolocation results without GCP

CP Name	Error X [m]	Error Y [m]	ErrorZ [m]
1004	-0.4155	0.3985	-0.5242
1006	-0.1148	0.1039	-0.4556
1010	-0.3067	-0.41457	0.6081
1011	0.1983	-0.2085	0.7738
1007	-0.2595	0.31921	-0.9954
1014	0.46027	-0.20344	-0.8423
1009	-0.20779	-0.18012	-0.6591
Mean [m]	-0.09225	-0.02643	-0.29924
Sigma[m]	0.288347	0.281773	0.650142
RMSE[m]	0.302743	0.283010	0.715703

4.3. Orthophoto

Finally, the orthophoto with 3.78 cm/pixel resolution was produced as shown in Figure 3. The quality of the orthophoto is outstanding as all the objects have been orthorectified, and the features can be detected very clearly.

This orthophoto can be a reliable source for digitization, feature extraction, various map preparation, and other spatial planning activities. Digital Surface Model (DSM) can also be seen in Figure 4, which has been extracted from orthophoto. The elevation of DSM ranges from 1402.45 m to 1481.75m.

Figure 3. Orthophoto of Study Area

4.4. Accuracy Assessment

Checkpoints were used to analyze the quantitative accuracy of the model. As shown in Table 5, while using GCPs, the Root Mean Square Error (RMSE) in X, Y, and Z were 4 cm, 5 cm, and 7 cm, respectively. Similarly, while GCPs were not considered, as shown in Table 6, RMSE in X, Y, and Z were 30cm, 28cm, and 71cm, respectively. The result obtained using GPC is excellent and can be used for high-precision works. Previous studies, for example, done by [36, 43, 44] have given average RMSE of ± 0.05 m, ± 0.338 m, and ± 0.283m respectively for planimetry and ± 0.300 m, ± 0.704 m, and ± 0.178 m respectively for height. The accuracy result shown by this study is more promising.

On the other hand, the vertical error without ground control points is comparatively high because of the consumer-grade inbuilt GPS of UAV. This error is a bit high but can be helpful in mapping works that don't require absolute accuracy. UAVs may often be used for emergency mapping applications in areas where human accessibility is hard, and it's not easy to take GCPs; in such cases, this result shows the accuracy will be promising. However, a highly accurate model using GCP was used to get the final output for this study.

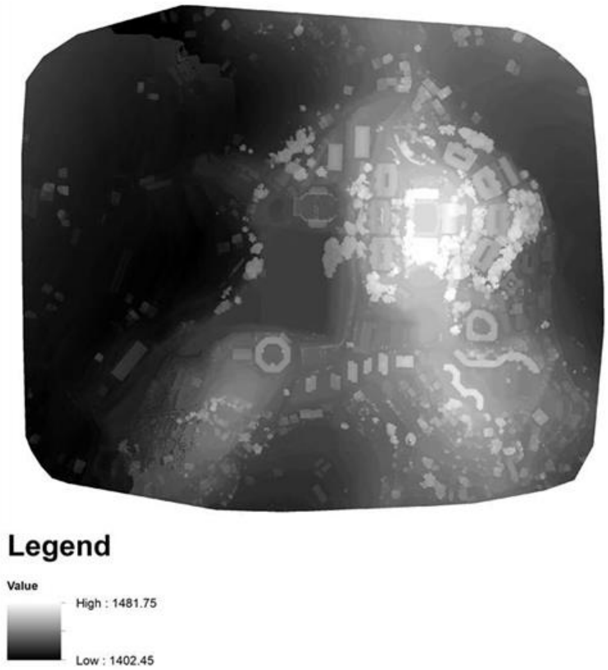

Figure 4. Digital Surface Model

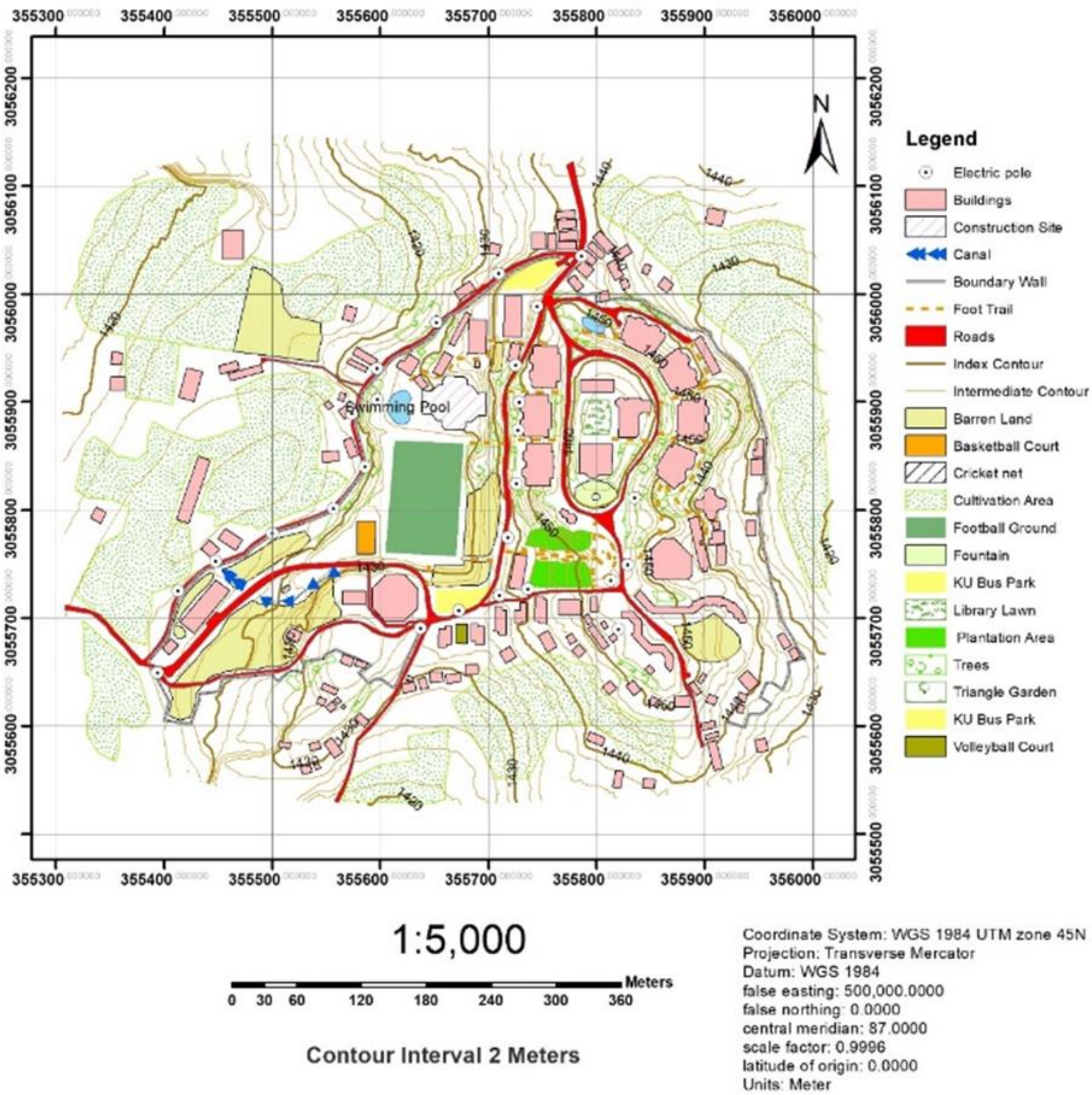

Figure 5. Topographic map of the study area

4.5. Topographic Map

Finally, the topographic map of the study area was prepared in GIS software (Figure 5). Land cover classification and utility mapping were also done. Similarly, contour lines were used in a 2m interval to show the shape of the Earth's surface. This map can be handy in carrying out any planning, designing, and construction activities on the given premises.

5. Conclusion and Recommendations

The primary aim of this project was to use UAVs for spatial data collection, create a high-resolution orthophoto, and later extract the features for mapping applications. Contour and topographic maps were made through photogrammetric and GIS processing, which have significant importance in various infrastructure and development planning. Similarly, the vector layer obtained after digitizing features, land use, and land covers can be helpful in land use planning, base, and cadastral map preparation, etc.

This study has ensured that UAV is a reliable and portable technology to acquire data remotely and provide a result with a very high spatial and temporal resolution even in inaccessible terrain at a relatively low cost. Furthermore, this study also unfolds the use of the HPC system for image processing which can be a game-changer in the future. For a developing country like Nepal, where Geospatial data is highly demanded, UAVs can be revolutionary for effective and rapid spatial data acquisition at low cost and time.

Furthermore, the HPC system and WebODM can be beneficial for decreasing the processing time. The HPC can be 10 to 20x faster than the PC at dense point cloud processing, depending on the number of HPC nodes and the total number of images [45]. It needs further research for improvement and a better conclusion. Similarly, the image orientation without GCPs is still less accurate for high-precision work. At the same time, the use of GCPs will consequently consume extra time for field and office work and give more accuracy.

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Author contributions

Abinash Silwal: Conceptualization, Methodology, Software, Data curation, Writing-Original, Editing. **Sunil Tamang:** Draft preparation, Software, Validation. **Rajendra Adhikari:** Visualization, Investigation, Reviewing, and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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