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UAV-based topographical mapping and accuracy assessment of orthophoto using GCP

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Abstract

For smaller locations, the traditional aerial photogrammetry techniques utilizing helicopters or airplanes are expensive and difficult. A new competitive strategy is necessary for quick spatial data collecting at a low cost and in a short amount of time for a developing nation like Nepal where geospatial data is in great demand. Currently, the Unmanned Aerial Vehicle (UAV) has become an alternative for different engineering applications, especially in surveying, one of these applications is for making a topographical map. This study demonstrates how this can be achieved using one of the evolving remote sensing technologies, Unmanned Aerial Vehicles (UAV). Besides, this study also involves image processing and topographic map production using Pix4D and GIS environments. For this study, the DJI Mavic Air-2 Advanced quadcopter collected about 207 images at a flying height of 80 m above the Kathmandu University area. An orthophoto of 2.4 cm GSD covering 127064 sq. Meter of the area was produced. The RMSE of 5.37 cm in X 4.94 cm in Y and 6.1 cm in Z was achieved with appropriate checkpoints. The measurements in the orthophoto replicated the field measurements to an error of less than 0.5% of the actual dimensions.

1. Introduction

Topographical maps are the types of maps that show detailed ground relief, including landforms and scenery, drainage (lakes and streams), forest cover, administrative zones, and population areas, as well as transportation routes, structures (including streets and railroads), and other man-made features. For roads, railroads, canals, pipelines, transmission lines, reservoirs, and other facilities, engineers utilize them to determine the most desirable and cost-effective locations. They are also utilized in soil conservation work by architects, geologists, and agriculturalists. Topographical maps are necessary because they contain basic map features such as earth surface terrain information with respect to their proper geometric accuracy. The use of geospatial data, using a topographic map as a base reference, is mandatory to ensure accurate rapid response to emergencies, often referred to as quick mapping. This critical aspect marked the beginning of worldwide cooperation under the International Charter on Space and Major Disasters, in which the use of satellite data, including data from very high resolution (VHRS) will indeed be provided immediately during major catastrophes around the world [1,2].

Topographical mapping is the first application of surveying, and it is a method that is constantly evolving. With the rapid advancement of computer vision science and the increasing use of small unmanned aerial vehicles (UAVs), photogrammetry has shown incredible potential in providing topographic information with comparable resolution and precision to lidar surveys, but at a much lower cost. By using photogrammetry techniques, UAV surveys produce orthophotos that are georeferenced and then further processed for geographic data with the aid of software [3].UAVs are aircraft that can either fly autonomously using pre-programmed flight plans or more advanced dynamic automation systems, or they can fly remotely controlled by a pilot at a ground station. The creation of high-resolution, high-quality digital elevation models (DEMs) demands a large investment in staff time, technology, and/or software despite the variety of accessible approaches However, image-based methods such as digital photogrammetry have been decreasing in costs [2].

In recent years, advances in technology have allowed for the creation of more accurate and detailed topographical maps of Nepal. The use of satellite imagery and GPS has made it possible to create high-resolution digital maps that are more accurate and up-to-date than ever before. These digital maps are used for a variety of purposes, including land use planning, resource management, and disaster preparedness. This study seeks to address the use of drone technology and the GIS environment how efficient and effective of this technology in mapping operations and what is the difficulties faced by this approach, if any.

For surveillance and reconnaissance reasons during World Wars I & II, the US military developed the unmanned aerial vehicle (UAV) in prototype form. From the 1960s to 1980s in the early 20th century, UAV was frequently deployed [4]. In the past few years, unmanned aerial vehicles (UAV) or drones have been a hot topic encompassing technology, security issues, rules, and regulations globally due to its remarkable advancements and uses in remote sensing and photogrammetry applications. The largest percentage of uses for unmanned aerial vehicles is in agriculture and infrastructure. Autonomous UAV use in agriculture is expanding quickly in areas including crop health monitoring, early warning systems, forestry, fisheries, and wildlife protection [5,6]. The two main types of UAVs are rotary-wing and fixed-wing. Fixed-wing UAVs function similarly to small unmanned aircraft in terms of structure, rotary-wing UAVs also known as multirotor, rotorcraft, or multi-copter UAVs are comparable to small unmanned helicopters Propellers, which are fans that provide thrust by rotating rotor blades on a rotor mast, provide lift for these craft. But unlike helicopters, which normally have a single rotor with two blades, most rotary-wing UAVs need more than one rotor to handle the forces placed on the rotor blades during flight [7,8]. According to the American Society for Photogrammetry and Remote Sensing, photogrammetry is the art, science, and technology of gathering accurate data about real-world objects and their surroundings through the recording, measuring, and interpretation of photographic images and patterns of electromagnetic radiation and other phenomena [9]. To accurately establish the geometric relationship between the image and the object as it appeared at the time of the imaging event is the crucial task of photogrammetry. Once this connection has been appropriately established, it is possible to infer details about an object just from its images [10]. In aerial triangulation, integrating GPS/inertial orientations offers flexibility and high accuracy [11]. The Direct Georeferencing method achieves 1:5000 scale accuracy, reducing reliance on Ground Control Points (GCPs) while maintaining precision [12,13].

2. Study area

The study area for the study is the Kathmandu University premises which is located in Dhulikhel Municipality (Figure 1). The university has an area of 35518 square meters. The area of study consists of an undulating terrain, vegetation, a settlement area, roads, departmental and administrative buildings, and water bodies.

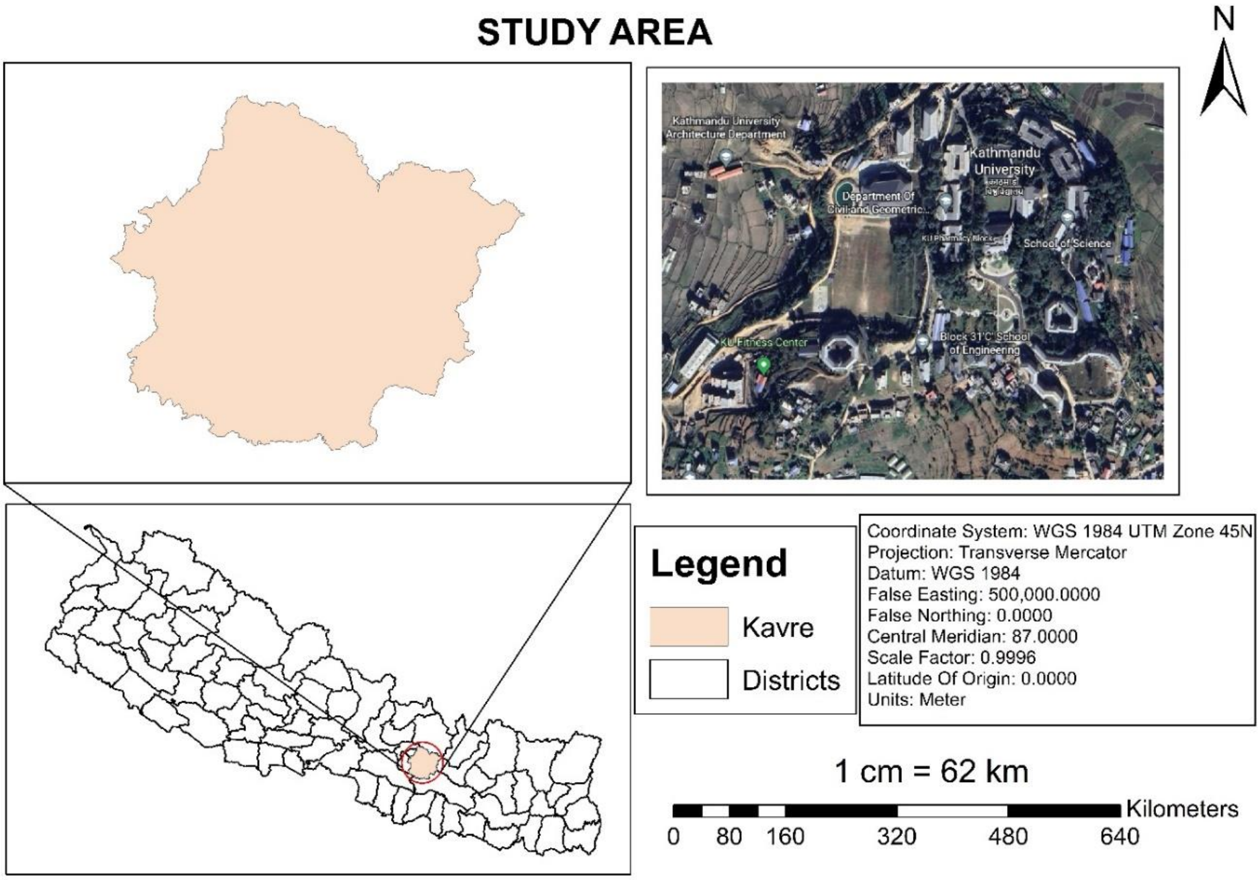

Figure 1. Location map of the study area.

3. Material and methods

This study mainly focuses on the primary data sources to achieve the motive of this study. The study is based upon primary data collected from field surveys using both ground survey using DGPS and UAV-based survey (Mavic air-2). UAV-based topographical mapping refers to the use of unmanned aerial vehicles (UAV) to capture aerial images of the topography. This data can be used to create maps and 3D models of the terrain, which can be useful for a variety of purposes, such as land management, planning, and engineering. The workflow is shown in Figure 2.

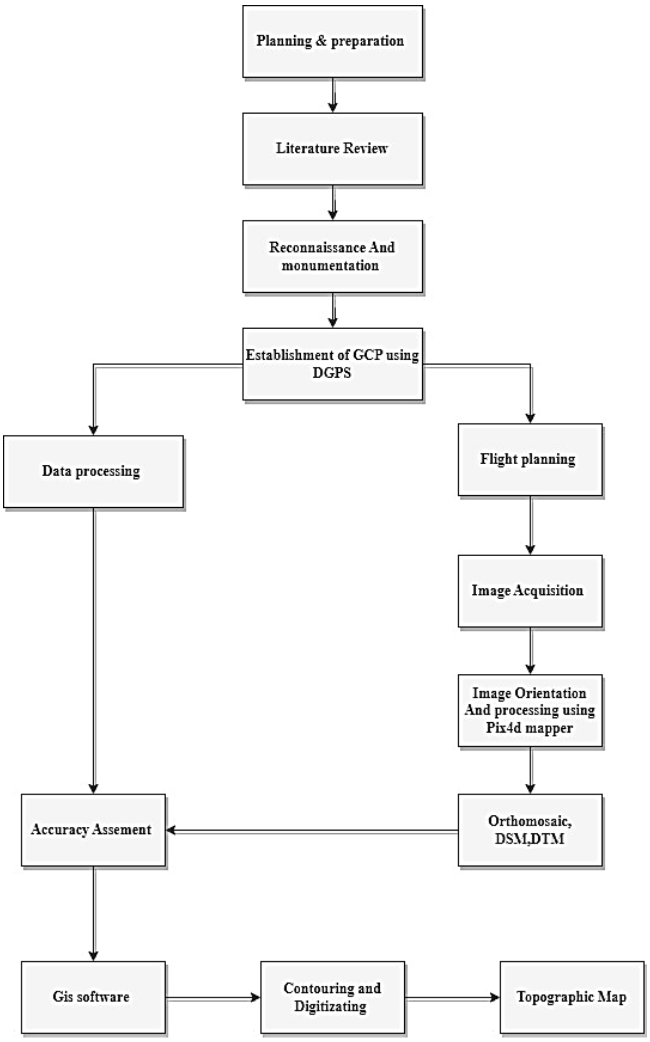

Figure 2. Study workflow.

An unmanned aerial vehicle was used to acquire aerial images of the study area. The Specification of the UAV is shown in Table 1.

3.1. Reconnaissance

Preparation of topographic mapping using UAV in this study includes preliminary surveys and preparation of instruments. The study area, software, and instrument selection, including the choice of digital camera and UAV platform types, are all part of this phase. This is the stage where the reconnaissance survey of the site was done by visiting the site. With the help of Google Earth images, the points for placing the control points were visualized. In the case of an Area with Undulating Terrain the most suitable arrangement of GCPs is one with GCP placed in a die shape (i.e. GCP at the central region and other GCPs well distributed along the boundary Furthermore, the GCPs should be arranged such that they cover all elevations [14]. A minimum number of 3 GCPs is required but 5 to 10 GCPs are usually enough, even for large projects More GCPs do not contribute significantly to increasing the accuracy [15]. The distribution of control points should be even and well-distributed to get better output with better accuracy throughout the project area. The Recommended Number of [16] Checkpoints Based on Area is shown in Annex 3. Keeping the above-mentioned criteria 12 wooden pegs were monumented throughout the study area to establish ground control points. Then these points were covered by a GCP marker board. These boards helped to identify the control points on the images taken by the drone.

Table 1. UAV specification.

Specification	Details
Brand	DJI
Type	Quadcopter
Camera Model Name(s)	L1D-20c_10.3_5472x3648 (RGB)
Remote	2.4GHz wireless remote control
Aperture	F2.8-F11
Shutter speed	8-1/8000s
Max. image size	5472*3648
Maximum takeoff altitude	6000m
Max flight time	31 minutes
Geolocation	Onboard GPS

3.2. Establishment and processing of GCP

The Ground Control Points and Checkpoints are established before the aerial photography. Based on the above-mentioned criteria Using the Differential Global Positioning System (DGPS), 12 ground control points (vertical and horizontal) of fourth order were established. The coordinates of these control points were determined by static DGPS survey using Stonex S8 Plus. The raw data (dat file) were transferred from the instrument to the computer. The dat file was converted to a Rinex file using static to Rinex converter. The Observation file was renamed as (1000. O) and was emailed to CSRS PPP, which is a Canadian website, to calculate the coordinates of the base station. A Trimble business center was used for post-processing the raw data files. During post-processing in TBC, the coordinate system was changed to UTM 45 N and the horizontal datum to WGS 1984. For distance measurement, the unit was changed to a meter and GPS time was from local to GPS. Baseline processing was used to calculate the distance and direction of the other control point reference to the base station whose coordinates were obtained from the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service.

3.3. Flight planning and image acquisition

Before imaging the study area, suitable flight plans that contain many variables, such as flight height, GSD, and the total number of photos, are designed. Flight planning is conducted with the DJI Pilot App, a mobile phone application for drone flight planning. Within this application, the user must specify several parameters, such as the area of interest, photograph overlap percentage, and flight height or desired GSD. The digital aerial imagery is collected using a camera mounted in a UAV. The aerial photographs are acquired in such a way, resulting in a series of digital aerial photographs with a percentage of overlap.

3.4. Image processing

After the geotagged images were captured, they were processed to get the outputs like Orthophoto, contour lines, DTM, DSM, etc. The images were prepared before processing by removing unnecessary and tilted photographs through visual inspection. Then filtered images were added to Pix4d Software (trial version) for processing. The overlapped and geotagged images were processed utilizing image-matching algorithms like the SIFT algorithm [17,18]. The output of the initial processing is the tie points initially matched by this algorithm. These tie points are generated by matching the same feature within the overlapped images. The first part of this is that it finds thousands of contrasting features in each image, which are saved as key points. It then compares key-point patterns between images to identify and create automatic tie points (ATPs). Once the ATPs are identified, the software uses aerial triangulation to estimate the camera calibration parameters and to refine the image coordinates. Doing so improves the accuracy of the 3D model and products [15]. Image orientation was done using 7 ground control points (GCPs). Figure 3 shows the 12 points statically surveyed on the ground using a DGPS/GNSS receiver. These points were marked using a notable GCP marker during image acquisition. Out of the 12 points, seven were selected as GCP for the exterior orientation process, and 5 were considered Check Points for the accuracy assessment of orthophoto. It was ensured that each point got marked in at least six images to avoid distortion [19].

4. Results and Discussion

The processed coordinates that were obtained with mean root mean square (RMS) error of 0. 012 m. the coordinates of GCPs (Table 2), which were used to georeferenced the images, whereas Table 3 represents the coordinates of CPs used for the horizontal accuracy assessment of the orthophoto.

4.1. Orthophoto

After the point cloud and mesh generation DSM (Figure 4) is obtained and finally, the georeferenced orthophoto (Figure 5) of the study area has been generated based on orthorectification in pix4D. the orthophoto with 2.4 cm/pixel resolution was produced as shown in 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. The elevation of DSM ranges from 1461.23 m to 1538.55 m.

Table 2. GCP coordinates.

GCP	Easting (m)	Northing (m)	Elevation (m)
1000	355802.59	3055780.31	1516.122
1001	355909.6	3055684.34	1503.161
1002	355935.224	3055814.76	1487.662
1003	355811.562	3055894.42	1523.546
1005	355762.658	3056029.14	1500.202
1006	355598.916	3055878.11	1483.878
1007	355597.231	3055670.47	1497.402
1009	355396.553	3055643.22	1469.869

Table 3. Control points.

CP	Easting	Northing	Elevation
1004	355824.502	3055988.345	1500.606
1008	355689.318	3055801.706	1487.794
1010	355817.104	3055753.569	1513.776
1011	355772.97	3055780.097	1514.345
1012	355717.808	3055737.732	1491.353

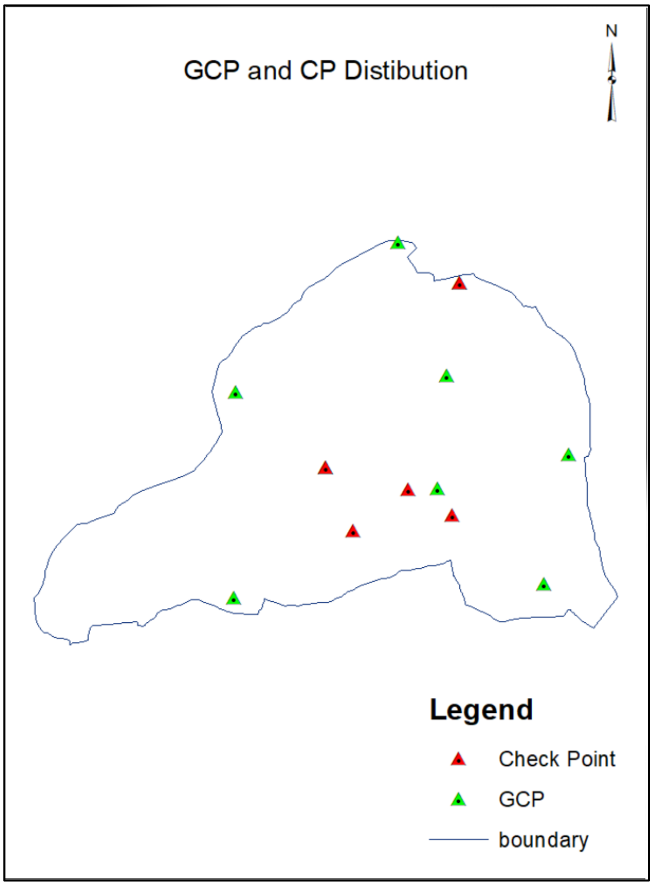

Figure 3. GCP and CP distribution.

4.2. Feature extraction and topo map creation

The final orthophoto and the DSM are very useful for manual or semi-automatic feature extraction for map creation and updating. The orthophoto was then used to extract features to produce a topographical map of study area (Figure 6). During feature extraction a geodatabase is created assigning different feature class and datasets for the features to be digitized. There after each feature were digitized manually. While digitization topological rules were followed to minimize the topological errors such as silver polygons. Similarly, contours were used with 2m interval to show the shape of the Earth's surface. The high resolution and level of detail of the UAV orthophoto enables additional objects of interest to be visible. This provides the opportunity for creating new vector datasets representing topological features (such as drainage and narrow footpaths, electric poles), potentially enabling a more informed decision-making for planning activities. Finally, the topographical map of Kathmandu university at a scale of 1:1250 is produced. In total, 21921.44 m^2 of permanent school buildings, 90428.71 m^2 of Open area, 21295.24 m^2 of forest and 45169.84 m^2 of vegetation were digitized.

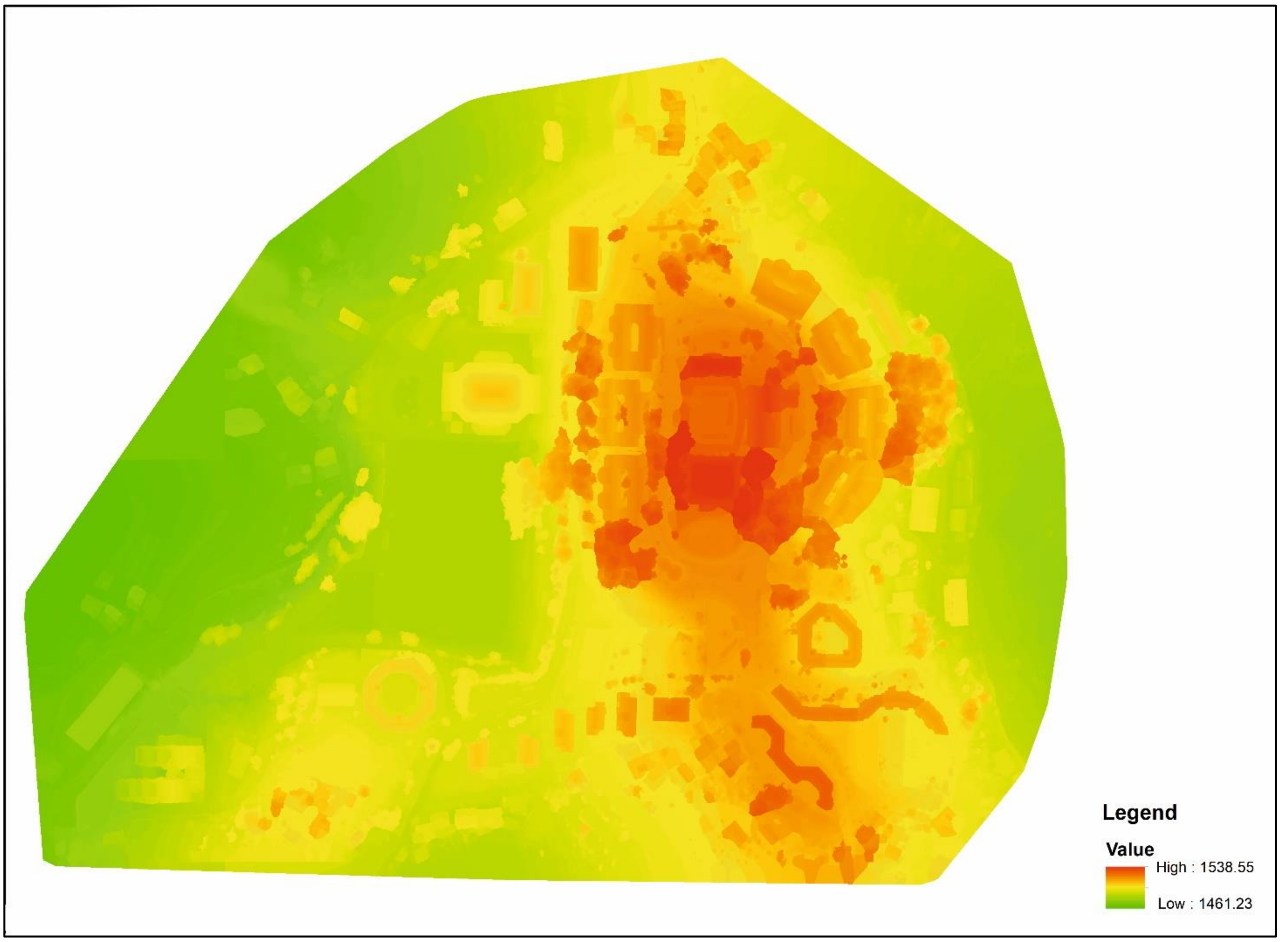

Figure 4. DSM.

4.2. Accuracy assessment of orthophoto

For qualitative assessment of orthophoto visual inspection was made which indicates that of the image was suitable for visual interpretation, as features are clearly visible and objects can be easily extracted. The quantitative assessment of the orthophoto consists of two aspects: (i) the planimetric accuracy assessment at the measured control points and (ii) the geometric accuracy of objects measured in the orthophoto. The RMSE of 5.37 cm in X and 4.94 cm in Y and 6.1 cm in Z as shown in Table 4. According to the horizontal accuracy standard mentioned in [20], the obtained error meets the requirements for the horizontal accuracy class of 7.5 cm (Table 5) [20].

5. Conclusion

This work demonstrates that UAVs provide promising opportunities to create a high-resolution and accurate orthophoto, thus facilitating map creation and updating. Through an example in Kathmandu University premises, 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. The study showed that the UAV photogrammetry for large scale topographic mapping could replace other methods effectively such as GPS and Total station because the accuracies obtained were within the limits of specifications. In addition to that, the time required are reduced remarkably, more extensive coverage capability, less human interference, different types of output at the same time, and finally, the aerial images are permanent documents that can be referred to at any time in future. UAVs are currently more suitable for map updating projects over a limited study area and incremental map updating.

The article emphasizes the benefits of UAV technology, such as cost-effectiveness and speedy data acquisition. Nevertheless, it also faces constraints like restricted coverage, weather-related interruptions, cost factors, and the requirement for precise ground control points.

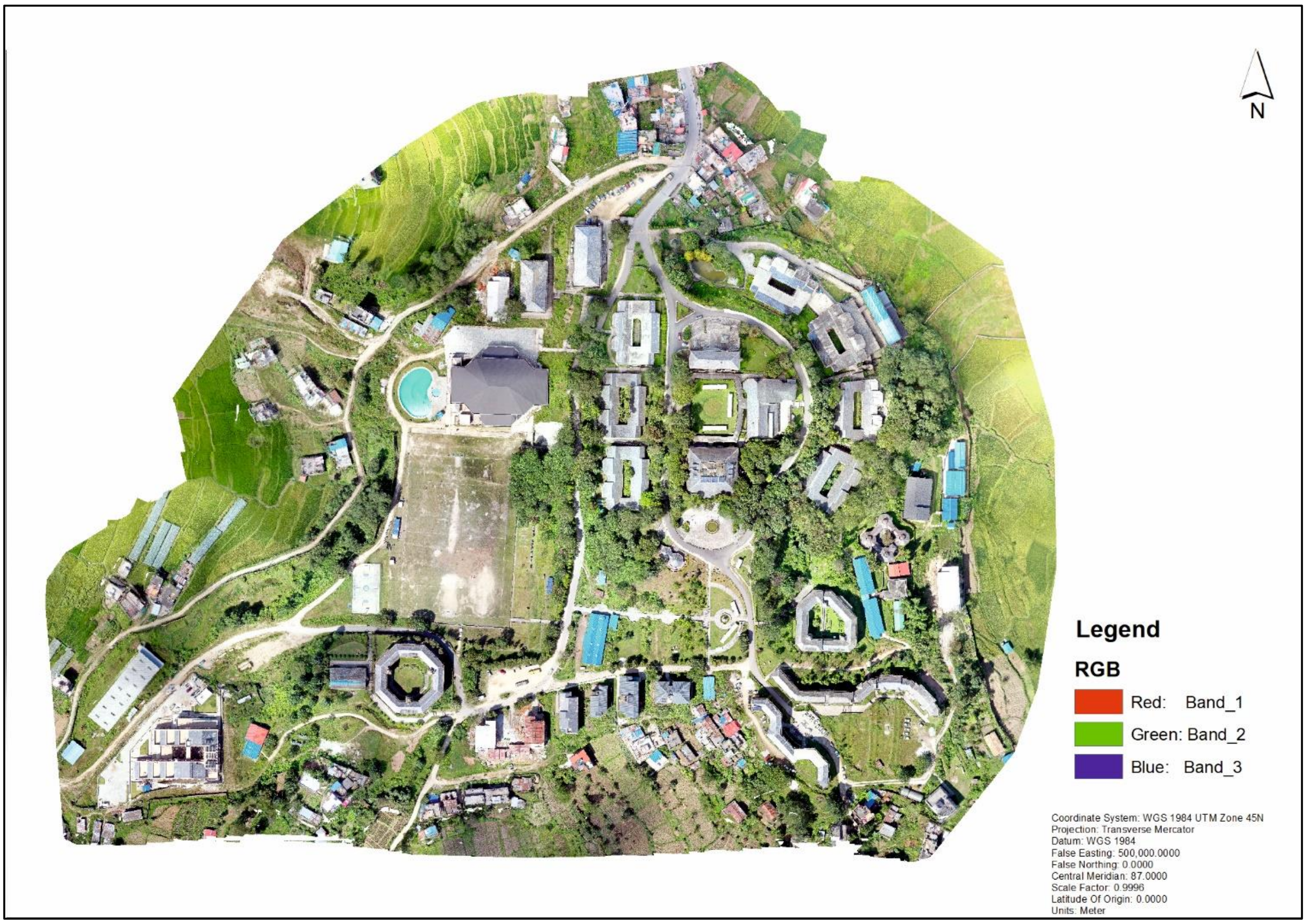

Figure 5. Orthophoto.

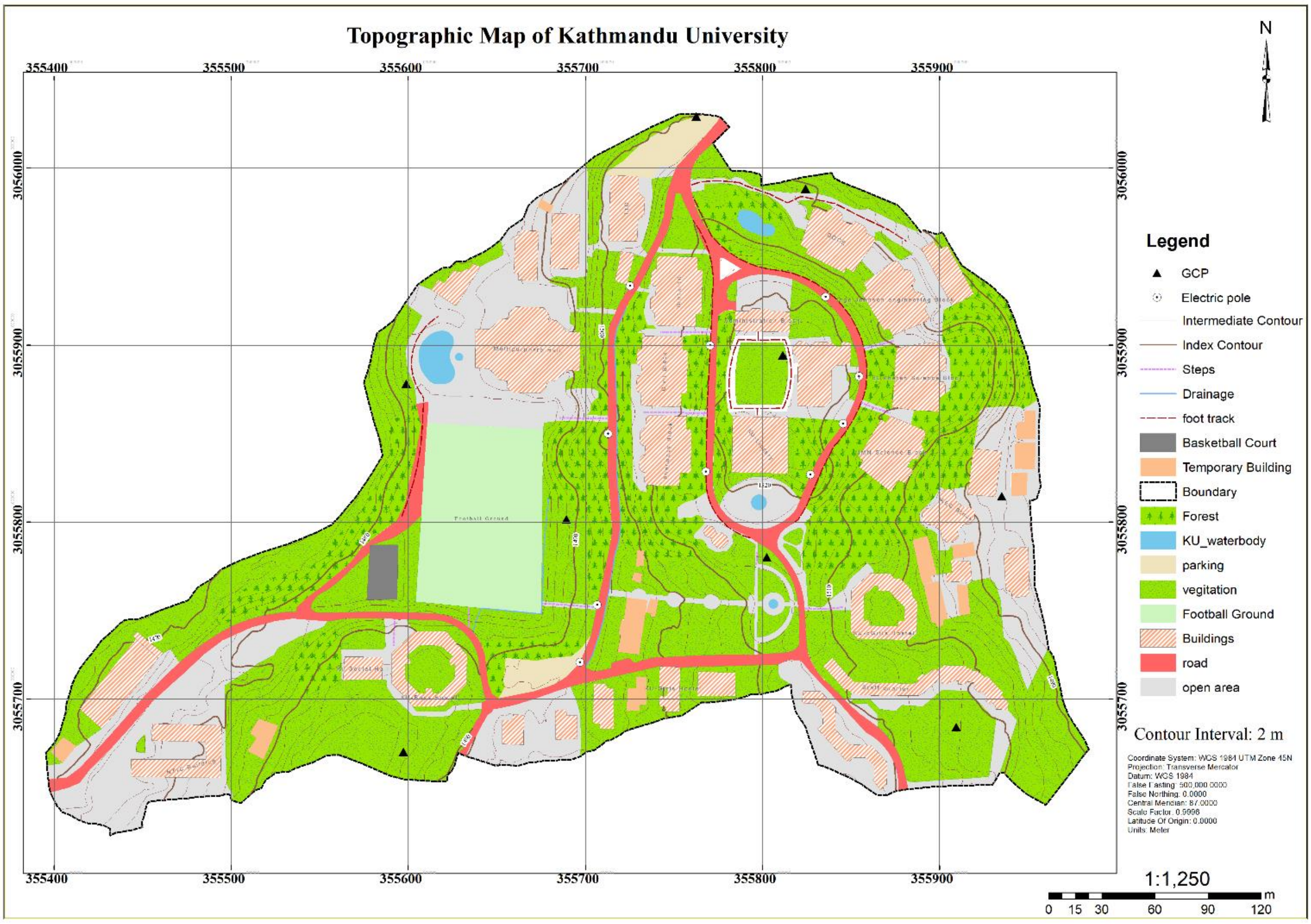

Figure 6. Topographic Map.

Table 4. Checkpoints error.

Station	Error in x	Error in y	Error in z
1004	-0.003	-0.064	0.04
1008	-0.004	-0.033	-0.12
1010	0.002	-0.013	-0.05
1011	-0.005	0.0059	-0.06
1012	0.12	0.012	-0.01
RMSE(CM)	5.373	4.94392	6.10508

Table 5. Length measured on ground and orthophoto.

Feature	L Field (m)	L Ortho (m)	Error	Relative Error
1	15.400	15.404	0.004	0.03%
2	29.120	29.157	0.037	0.13%
3	2.620	2.631	0.011	0.42%
4	2.450	2.458	0.008	0.33%
5	7.420	7.428	0.008	0.11%

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Author contributions

Sagar Pathak: Conceptualization, Methodology, Software, **Samrat Acharya and Ujjowl Thapa:** Data curation, Writing-Original draft preparation, Software, Validation, Visualization, **Gaurab Karn and Saugat Bk:** Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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