LEVERAGING UAV TECHNOLOGY IN LOCAL GEOID MODELING

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ABSTRACT

TLeveraging UAV (Unmanned Aerial Vehicle) technology in local geoid modeling is a promising approach, particularly in areas with challenging terrain and sparse GNSS, leveling and gravity infrastructure. In this study, UAV was utilized to capture high-resolution images of the area surrounding the Land Management Training Center (LMTC) from an altitude of about 120 meters. These aerial images were carefully georeferenced using a coordinate set of ellipsoidal height (h) and orthometric height (H). A sufficient number of points were then generated from these images, which included both ellipsoidal and orthometric height data. The next step involved calculating the geoid height (N). This calculation provided the point-specific geoid heights, which were then used to construct a comprehensive geoid model for the region. The evaluation of this geoid model was done by comparing it with the recent global gravity model. This assessment demonstrated that UAV technology can be useful for local geoid modeling, offering accurate and reliable data for understanding geoid variations on a local scale.

KEYWORDS: UAV, GGM, Geoid, DEM, Orthometric height

1. INTRODUCTION

Geoid is a complex surface yet the most relevant physical figure of the Earth. The significance of geoid modeling is well comprehended from former times. However, it is not an easy task to determine an accurate geoid model, it involves complex methods that are often time-consuming, costly and tedious (Timilsina. S., et al., 2021). In the field of geophysics and geodesy, the geoid is a vital reference surface that represents the shape of the Earth under the influence of gravity and rotation, which serves as the basis for measuring elevations and is essential for various applications, such as mapping, navigation, and environmental monitoring. To construct accurate geoid models, precise measurements of the Earth's surface, gravity, and topography are necessary. For this, satellite measurements, terrestrial surveys, and gravimetric data have been relied upon to gather such information. The advancement of GGMs, particularly with the help of satellite missions, has significantly enhanced our understanding of the Earth's gravitational field and determination of geoid (Barthelmes. F, 2014). In geoid modeling, GGMs are essential because they provide high-resolution gravity data that allow for accurate determination of the geoid.

The advent of unmanned aerial vehicles (UAVs) has brought a significant breakthrough in 3D modeling, which has also aided in geoid modeling. Geoid modeling has gotten simpler with the advancement of technologies like UAV and LIDAR. This involves the acquisition of a rich amount of accurate data in a very short time and processing them automatically to compute continuous models of the earth such as DEM and geoid (Raufu. (I.O., et al., 2023).

The UAV is a powered aerial vehicle that does not require a human pilot. This technology's ease of use, portability, and fascinating hardware, as well as its capacity to support a broad range of applications including military, agricultural, search and rescue, surveying, and mapping, have been contributing to its increasing popularity. For mapping local regions that are comparatively smaller in area, UAV technology can provide a cost-effective solution.

The major good aspect of using this technology is that it is a close-range sensing technology providing a platform for different sensors (visible, infrared, LiDAR) with high data acquisition speed and automation of data processing, providing accurate geoinformation. When coupled with surveyed ground control points (GCPs), UAV technology can capture spatial data with a richness of detail that can meet high accuracy standards.

2. OBJECTIVE OF THE STUDY

The objective of this study was to assess the applicability of UAV technology in local geoid modeling.

3. STUDY AREA

The study area for this study was Bhakhundol -4 of Dhulikhel municipality in Nepal. The total area of the project covers around half a square kilometer (0.552 sq.km). The flight for UAV was taken from the roof of the administration building of the Land Management Training Center (LMTC). The UAV used for the data acquisition was DJI Mavic 2 Interprise quadcopter. The Ground Control points were established using GNSS instruments for registration of aerial images.

4. METHODOLOGY

4.1 GNSS Observation

GNSS observations were done at five points. These points were used as ground control points for UAV image acquisition, processing and georeferencing. These points were accurately determined and processed using precise ephemeris and differential observation. The three-dimensional coordinates with ellipsoid height were computed for each point.

4.2 Precise Levelling

Precise leveling was conducted in order to obtain the orthometric height on the above-mentioned five ground control points. Each set of ground control points contained latitude, longitude, ellipsoid height and orthometric height.

4.3 UAV operations

4.3.1 Mission Planning

Effective mission planning is crucial to ensure the safe and efficient success of any UAV operation. After selection of the appropriate UAV, a single grid flight plan considering environmental factors was designed and pre-flight checks were performed. Five Ground Control Points (GCP) were established in the Area of Interest (AOI). The large forward overlap of 80% and cross/side overlap of 60% was planned to be used in order to compensate for aircraft instability and subsequent generation of the dense point cloud.

4.3.2 Image Acquisition

The presence of GNSS/INS onboard is usually exploited to guide the image acquisition. During flight, the platform is normally observed with a control station which shows real-time flight data such as position, speed, attitude and distances, GNSS observations, battery or fuel status, rotor speed, etc. GNSS coordinates and elevations were recorded for each image with the roll, pitch, and heading of the platform.

4.4 Processing and Output Generation

Image processing of UAV was done using Pix4D (photogrammetric software package) for initial data processing, point cloud densification and 3D model generation. The initial processing was done for 840 images of AOI and five ground control points to obtain an average Ground Sampling Distance of 3.02 cm. Point cloud (each point has an associated elevation) was generated from UAV images containing elevation data. High-density point clouds were automatically generated through image matching. Large overlaps and high visuals content led to better results, generating around 66 million 3D points with an average density of 152.72 m^3.

The Digital Surface Model (DSM) was obtained using the inverse distance weighting method and Orthomosaic of resolution 3.02cm was generated in GeoTIFF format.

5. RESULTS AND DISCUSSION

Two digital elevation models were generated using two set of GCPs. At first the generation of DSM using point cloud and 3D Ground control points with ellipsoid height was done. A DEM (DEM_ell) was then generated then by removing non ground points from the model and is shown in figure 1. For this, WGS-84 was chosen as the vertical and horizontal reference datum.

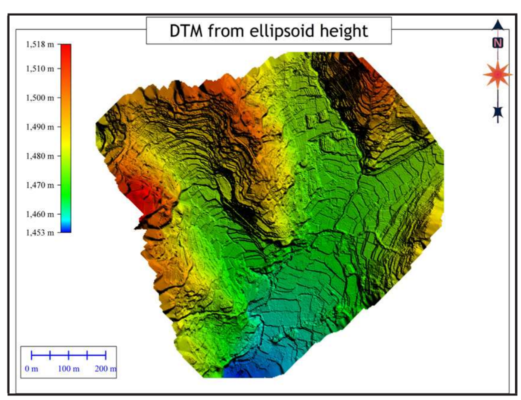

Figure 1. DEM from ellipsoid height

On the other hand, another DSM was generated by using point cloud and 3D ground control point with orthometric height (the orthometric height was computed by using differential leveling). The DEM (DEM_orth) was then generated by removing ground control points from the derived model and is shown in figure 2.

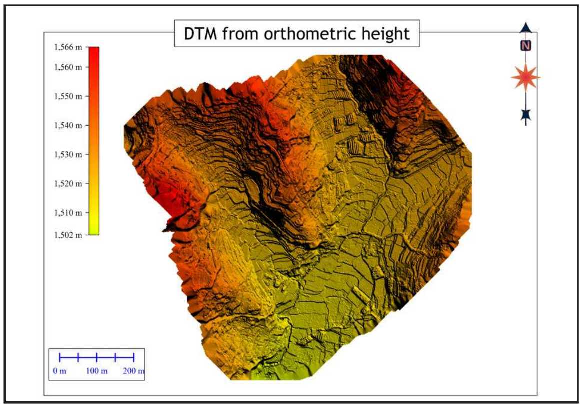

Figure 2. DEM from orthometric height

EGM_2008 was chosen as the vertical reference date. The DEM_ell contains each point/cell with ellipsoid height (h) and the DEM_orth contains each point/cell with orthometric height (H). The corresponding difference between these two points or models is h-H, which is the difference between ellipsoid height and orthometric height, commonly known as geoid height (N). The difference between these two models principally generates a geometric geoid model.

6. ACCURACY ASSESSMENT

The accuracy assessment of the obtained geoid model was done by comparing it with geoid height from the latest global gravity model XGM2019e. XGM2019e is a combined global gravity field model represented through spheroidal harmonics up to d/o 5399, corresponding to a spatial resolution of 2′ (~4 km). As data sources, it includes the satellite model GOCO06s in the longer wavelength area combined with terrestrial measurements for the shorter wavelengths (Zingerle, P. et al., 2019).

Thirty geoid height points were taken as test points from a geoid model derived from UAV and their corresponding geoid height points were computed from XGM2019e using MATLAB (Bucha B. et al., 2014). They were then compared to assess the reliability of the geoid model. The comparison result showed the overall variation of 27 cm with minimum of 5mm and maximum 89 cm as shown in figure 3.

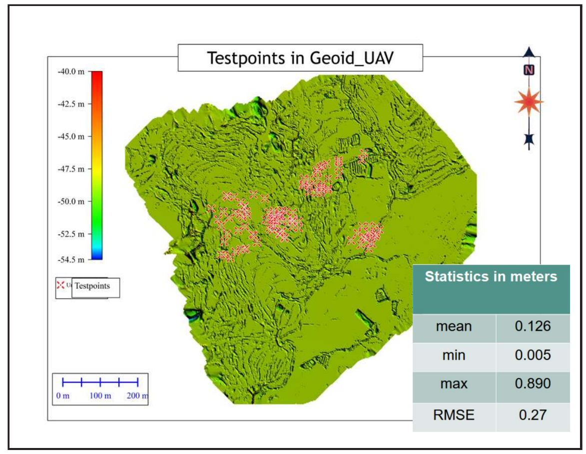

Figure 3. Geoid model from UAV with test points (pink)

7. CONCLUSION

The advancement of UAV technology in 3D modeling has shown a promising future in modeling of continuous surfaces such as geoid. The differences between UAV-derived ellipsoid height and UAV-derived orthometric height can be used to determine the geometric geoid at the local level. The UAV-derived geoid model, while compared with the global model, showed a good result. Geoid can be determined in a short time, less and less tedious, using UAV technology.

The number of ground control points for this study was very limited. A larger number of control points can be used for more accurate results. Further, the establishment of reliable GNSS-Levelling points for proper validation of the geoid model can assess its reliability even more accurately. For larger areas, LIDAR sensor data can be used in developing similar geoid models.

Although this method is not the most accurate method to compute a geometric geoid model, the results have shown that UAV technology can be a cost-effective solution for modeling of local geoid as it reduces time, cost and effort.

8. WAY FORWARD

Nepal is a mountainous country where large portions contain hills and mountains, creating smaller than obvious variations in gravity. Surface gravity observations to quantify these variations in all places might not be practical. In order to take this mass and density variation into account and comprehend the terrain effect, deploying UAV technology can be a way forward in local modeling of geoid.

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