Assessment of the Positional Accuracy of Digital Elevation Model Derived from Low-Cost UAV

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Abstract

The objective of this research was to evaluate the positional accuracy of a digital elevation model derived from low-cost Unmanned Aerial Vehicle in the Recreation Park of Burapha University, Mueang district, Chonburi province using 6 ground control points and 24 checkpoints obtained through Real-Time Kinematic (RTK) surveys. The results indicated that the Root Mean Square. Error (RMSE) value at the confidence level of 95%, without using GCPs had a horizontal positional accuracy of 0.073-0.246 meters and a vertical positional accuracy of 0.270-0.429 meters. These values meet the standards set by the National Standard for Spatial Data Accuracy (NSSDA) and the American Society for Photogrammetry and Remote Sensing (ASPRS). Based on these results, the researchers recommend creating a photographic map at a scale of 1:4,000. Additionally, contour range data should be generated with a minimum interval of 100 centimeters. When GCPs were utilized in the process, the RMSE value at the confidence level of 95%, demonstrated the horizontal positional accuracy ranged from 0.054-0.093 meters, while the vertical positional accuracy ranged from 0.114-0.333 meters. These values also complied with NSSDA and ASPRS requirements, allowing for the creation of a 1:1,000 scale photographic map. Additionally, contour range data can be generated with a minimum interval of at least 50 cm. According to this study, digital elevation models from low-cost UAVs can be used both without and with GCPs for applications that do not require very detailed and precise verticality values, such as building elevation surveys, tree height, or the height of large billboards, etc., because the difference in elevation values between features within the study area is still within acceptable criteria.

Keywords : Assessment of the Positional Accuracy, Digital Elevation Modelling, Low-Cost Unmanned Aerial Vehicle

1. Introduction

Unmanned Aerial Vehicle (UAV) is equipped with high definition digital cameras with software to help control automatic flight This makes it possible to record aerial photographs with high resolution at the Mega Pixel (MP) level and can produce numerical elevation data using the Digital UAV Photogrammetry surveying principle by surveying UAV Photogrammetry with three-dimensional coordinate data and using the 3D point cloud classification technique (Pix4D, 2021) to create a Digital Elevation Model, a survey process with aerial photographs from Unmanned Aerial Vehicle. Therefore, it is an alternative that is gaining popularity today to utilize in generating spatial data with centimeter-level high spatial resolution and creating a Digital Elevation Model (Santise et al., 2014; Uysal et al, 2015; Webster et al., 2018).

Unmanned Aerial Vehicle (UAV) is a generic aircraft designed to operate with no human pilot onboard. Recent development in sensors and flying platforms has significantly broadened their application (Raczynski, 2017) and their usage in land surveying has become a common practice. Low quality photographs directly affect the bundle adjustment results together with accuracy and density of generated point clouds and the generated Digital Terrain Model, consequently reducing the accuracy of orthophotos and extracted coordinates (Wierzbicki et al., 2017). Although, no measurement in a survey is exact (Mantey et al., 2022), errors must be kept to a minimum as possible. This study seeks to investigate the appropriate time of the day to achieve the highest positional accuracy when using UAV surveys with emphasis on horizontal coordinates.

The term UAV is used commonly in Geomatics and Computer Science, Robotics and Artificial Intelligence, as well as the Photogrammetry and Remote Sensing communities. Recently, UAVs are equipped with several units and sensors, which has become an integral part of the UAV and helps in the photogrammetric process. To be able to perform autonomous flight with predetermined waypoints or path, a GNSS receiver is introduced in the design of UAV. GNSS is not only used for autonomous steering but also for georeferencing the images. Currently, Real Time Kinematics (RTK) GNSS are being tested for their ability to perform direct georeferencing to eliminate or reduce the necessity of using Ground Control Points (GCPs). Unmanned Aerial Vehicle are widely used in many applications for different purposes. Recent developments in sensor and flying platforms have significantly broadened their application (Raczynski, 2017).

Accuracy is one of the most important factors of land surveys. The purpose of land survey is to accurately determine or establish relative positions of points above, on or beneath the Earth surface (Mantey et al., 2022). Although accuracy of land surveys is very important, surveys have not always been as accurate as they are now as a result of technological advancement in the land survey profession (Hung et al., 2019). Over the years, the fundamental basics of land surveying have hardly changed, however, the technology and methods used have advanced along with the accuracy of surveying. This makes the equipment and methods used an important element that affects the accuracy of surveying.

The preparation of the Digital Elevation Model (DEM) should consider the spatial accuracy of the obtained Digital Elevation Model (DEM) data because the acquisition of the Digital Elevation Model from various processes has a certain level of reliability and reliability different accuracy based on fundamental data, processes and controls, the aerial surveying process is now regarded as highly accurate. But the process of creating a Digital Elevation Model in various ways is quite complex and requires a high knowledge of operations Development is therefore quite limited. In addition, the accuracy problem of the Digital Elevation Model also requires different resolutions depending on the type of application. Therefore, accuracy must be evaluated by considering the RMSE value compared to the reference value. This may be obtained by various methods, such as surveying coordinates with the Global Navigation Satellite System (GNSS) or comparing with the National Standard for Spatial Data Accuracy (NSSDA) at a confidence level of 95 percent or comparing the standard map scale of flat resolution according to the Cartographic Society Standards from the American Society for Photogrammetry and Remote Sensing (ASPRS) (Kanplumjit et a.l, 2020; Laphitchayangkul et al., 2020). Assessment of accuracy of orthophotos can be qualitative or quantitative. Qualitative assessment of orthophotos involves visually inspecting them. Daramola et al. (2017) qualitatively assessed the accuracy of orthophoto by overlaying measured features on the digitized features. Visual assessment of the overlaid feature was done by comparing the digitized feature on Orthomosaic with the area computed through conventional survey. With a qualitative assessment, minor deformations can be detected on the orthophoto and can further be analyzed with the purpose of illustrating the type of error present. Quantitative assessment on the other hand deals with analyzing measurements made on the orthophoto. They consist of parameters such as positional and geometric accuracy (Hung et al., 2019). Positional accuracy includes horizontal and vertical accuracies of checkpoints. Geometric accuracy is also similar to positional accuracy in terms of measurement. The only difference here is that accuracies are assessed on an object level in geometric accuracy. A number of permanent objects are digitized and measured on an orthophoto, and their values are compared with the actual measurements made on the ground (Koeva et al., 2018).

The accuracy of an orthophoto or any final photogrammetric product is dependent on a number of factors (Hung et al., 2019). Variation in these factors in either way affects the final accuracy of the product (Gindraux et al., 2017). These factors range from the data acquisition stage to the production of the final output. Some of the factors which accuracy of orthophotos depend on include initial image quality; accuracy of GCPs; distribution of GCPs; image overlap (forward and side); flight altitude; camera resolution; and software for processing (Mantey et al., 2022). The preparation of the Digital Elevation Model in many studies has used positional data from UAVs to study by Hung et al. (2019), creating a local photo map with a small Unmanned Aerial Vehicle automatically. The study found that they can produce map photographs from small Unmanned Aerial Vehicle in a large scale of 1: 1,000 and produces a contour range of not less than 24 cm (Santise et al., 2014). The study to evaluate the accuracy of the creation of a Digital Elevation Model from UAV aerial photographs at the university campus in Par at the flying height of 70 meters and 140 meters, it was found that at the flying height of 140 meters, the RMSE value was better than that of the flying height of 70 meters, except for some of the roofs of tall buildings. Assessment of the accuracy of positional data results for quality and compliance with standard requirements can be verified by conducting a horizontal accuracy assessment based on the United States National Standard for Positional Data Accuracy (NSSDA) of the Federal Geographic Data Committee (FGDC) and the American Society for Visual Surveying and Remote Sensing (ASPRS) standards (Engineering Institute of Thailand, 2018).

The aim of this study is to assess the positional accuracy of a digital elevation model (DEM) generated from low-cost Unmanned Aerial Vehicle (UAV) in the Recreation Park of Burapha University, located in the Mueang district of Chonburi province. In the case of a small area like the Recreation Park of Burapha University, the conditions for conducting a survey with high-accuracy data, such as establishing precise ground control points (GCPs), can be challenging. High-accuracy GCPs are typically used to improve the positional accuracy of photogrammetric products derived from UAV imagery.

2. Materials and Methods

2.1 Study Sites

This study was conducted in Recreation Park of Burapha University, Mueang district, Chonburi province. The study area covers about 0.15 square kilometers.

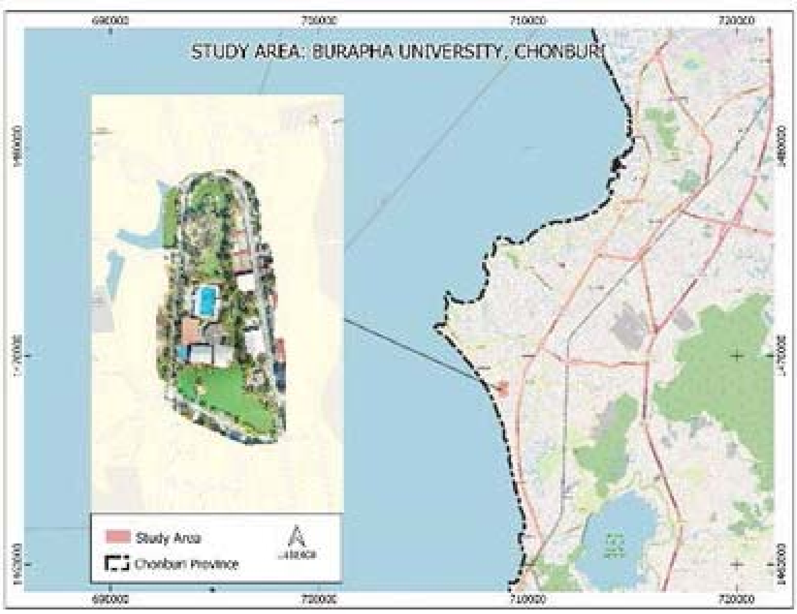


Figure 1 Study site in Recreation Park of Burapha University

2.2 Materials

The materials used in achieving the objectives of this study included GCPs, aerial images, software, GNSS RTK e-Survey (e-300 Pro) equipment and personal computer. The data sources used in this study were entirely primary data. The data included UAV derived images of the area under study as well as measured ground coordinates of points in the study area. The software used in this study was Drone deploy and Open Drone Map (ODM). The primary data was acquired using the following equipment: DJI Mavic 2 PRO Drone with Transmitter (Figure 2); e-300 Pro GNSS RTK receivers (Figure 3).

Figure 2 DJI Mavic 2 PRO Drone

Figure 3 e-300 Pro GNSS RTK receivers

2.3 Methodology

The methods employed in this study were in four phases. The first phase was the data acquisition process, the second phase was the data processing and orthophoto generation, the third phase was the feature extraction from the orthophotos, and the last phase was the accuracy assessment (Figure 4).

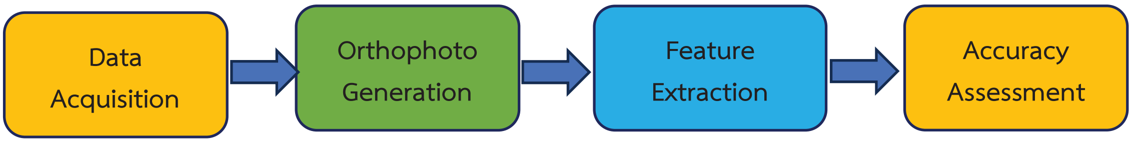


Figure 4 Flow chart of the methodology

2.3.1 Data Acquisition

The data used for this study included surveyed GCPs and aerial images acquired with a UAV (DJI Mavic 2 PRO). Ground coordinates of control points and check points were also determined using static GNSS survey.

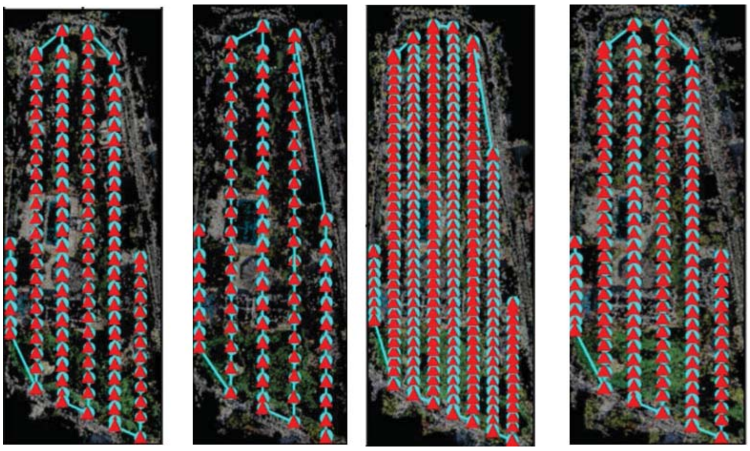
1) Reconnaissance: A preliminary inspection of the study area was first performed. Part of the reconnaissance included identifying an open space that could be used as a safe take-off and landing area. Controls within the study area were also identified to be used as GCPs. Tall buildings, telecommunication masks, electric and network poles, trees, and other obstructions were identified and avoided in planning the flight.

2) Flight Planning: The Drone deploy software was used in planning the mission of the UAV. Parameters set in the drone deploy software remained the same for all flights. Reconnaissance before the mission planning helped in choosing parameters for the flight. Batteries of the drone were fully charged and calibrated. Before flight, Pre-flight tests were also carried out to ensure proper functioning before proceeding to take-off. Flight lines were designed for the area under study on a digital map embedded in the software. The photography plan was divided into 4 case studies including defining 2 levels of flying height, such as flying height at 70 and 90 meters and defining front overlap and side overlap in 2 types, such as 80% front overlap and 70% side overlap; and 70 % of

the front overlay and 60 % of the side overlay, which obtained the number of images in each case study as shown in Table 1.

Table 1: Parameters used in planning the flights

Parameters	Case 1	Case 2	Case 3	Case 4
Flight height or altitude	70 m	90 m	70 m	90 m
Time of flight	12 min 22 sec	9 min 38 sec	23 min 13 sec	15 min 48 sec
GSD	4.5 cm/px	5.8 cm/px	4.4 cm/px	5.9 cm/px
Front overlap	70%	70%	80%	80%
Side overlap	60%	60%	70%	70%
Number of images per flight	123	83	247	146



Case 1 Case 2 Case 3 Case 4

Figure 5 Flight Planning in four case study

3) Measurement of Ground Control Points (GCPs) and Check Points: GCPs are included in aerial surveys to enhance the accuracy of the final product and can be avoided or minimized if the UAV has a dual frequency GNSS onboard. Precise survey pillars were used as GCPs. This was due to the fact that GCPs were placed on the ground. before flight would not persist for the whole period of the image acquisition due to human activities. Conspicuous existing natural and artificial features on the ground were also used as check points considering their clarity on the aerial photographs. The precise coordinates of the control points and check points were all surveyed using differential GNSS technique in the static mode. Six GCPs and 24 check points were distributed in the study area and used as testing and correction points. The coordinates of the GCPs are shown in Table 2 and Figures 6.

4) Image Acquisition: In preparation for the flight, the UAV, the Radio Connection transmitter, and an iPad tablet were connected. The drone only took off after ensuring that all checklists had been verified. These checklists consisted of: Connection of transmitter (controller) to drone; Drone GPS satellites; Camera is ready; Drone is calibrated; and Mission uploaded to drone. Other important factors such as the battery levels for both the transmitter and drone among others were also checked.

The drone images of the study area were acquired in four case studies (Flight height at 70 m and 90 m, Front overlap/ Side overlap 80/70 and 70/60) During the aerial survey, the number of satellites visible to the onboard GNSS ranged between 14 to 19.

Table 2 Coordinates (in UTM Zone 47N) of GCPs and Check Points

Point Name	UTM WGS84		
	E (m.)	N (m.)	H (m.)
GCP00	708748.833	1468480.848	2.603
GCP01	708778.296	1468649.755	2.694
GCP02	708901.540	1468371.027	2.569
GCP03	708789.684	1468246.296	2.470
GCP04	708937.977	1468231.691	2.705
GCP05	708754.902	1468628.714	2.623
GCP06	708735.375	1468307.249	2.301
GCP07	708739.847	1468365.089	2.475
GCP08	708883.905	1468519.340	2.443
GCP09	708748.210	1468244.379	2.184
GCP10	708904.616	1468163.821	2.637
GCP11	708867.849	1468177.522	2.403
GCP12	708747.277	1468506.142	2.710
GCP13	708755.081	1468562.429	2.612
GCP14	708930.091	1468285.770	2.870
GCP15	708771.813	1468428.123	2.270
GCP16	708881.442	1468586.660	2.556
GCP17	708812.392	1468459.613	2.477
GCP18	708892.287	1468261.163	2.690
GCP19	708840.852	1468409.599	1.939
CP20	708742.747	1468419.431	2.840
GCP21	708839.262	1468354.172	2.100
GCP22	708856.666	1468304.228	1.932
GCP23	708794.893	1468597.772	2.389
GCP24	708759.460	1468309.825	2.191
GCP25	708904.189	1468437.146	2.426
GCP26	708798.659	1468498.349	1.977
GCP27	708857.659	1468625.320	2.731
GCP28	708784.368	1468227.542	2.294
GCP29	708865.263	1468599.843	2.682

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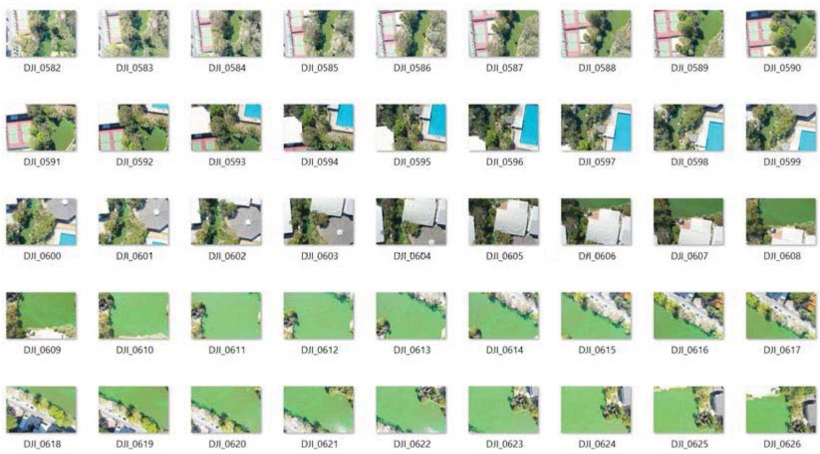
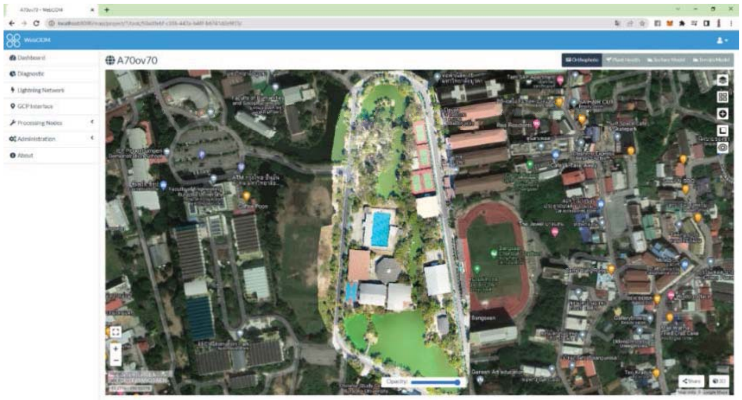
2.3.2 Orthophoto Generation (Data Processing)

Data processing and orthophoto generation was done using an Open Drone Map (ODM) and QGIS Desktop Software. A series of procedures were undertaken in the software before the orthophotos were produced. The first step in creating the orthophotos was to load the UAV acquired images in the Open Drone Map. It involved selecting images from the appropriate folder for further processing. The next step after adding photos in the software was to align the uploaded images. At this stage software finds the camera position and orientation for each photo and builds a sparse point cloud model. In the software, alignment is done with the Structure for Motion (SfM), technique. SfM detects geometrical similarities with specific details that serve as image feature points. The movement of these points throughout the whole sequence in the workspace is thereby monitored giving an estimation of feature point positions and subsequently rendered as three-dimensional point cloud. When these are identified, the software refines camera calibration parameters to create point cloud data and a set of camera positions [16], generate and visualize a Digital Elevation Model (DEM). A DEM was rasterized from the dense point cloud for higher accuracy. DEM is required in the production of orthophoto since software uses the Triangular Irregular Network (TIN) surface to correct for displacement and calculated exterior orientations for georeferencing in the orthorectification process Orthomosaic were built based on the generated DEM.

Figures 6 The distribution of GCPs and check points in the study area



Figures 7: Aerial images acquired with a UAV



Figures 8: Orthophoto generation

2.3.3 Extraction of Coordinates and Accuracy Assessment

Evaluation of the positional accuracy of the Digital Elevation Model In this study, the accuracy of the horizontal and vertical positional data was compared using 2 methods:

1) Positional accuracy analysis without using ground control points (GCPs) and using GCPs by taking the horizontal and vertical coordinates of all test points Let's read the coordinates of the same location with a geospatial program. and calculate the Root Mean Square Error (RMSE) of the ground image control point. and check point using the following equation:

$$RMSE_x = \sqrt{\Sigma(x_{data} - x_{Gnss})^2/n} \quad [1]$$

$$RMSE_y = \sqrt{\Sigma(y_{data} - y_{Gnss})^2/n} \quad [2]$$

$$RMSE_{total} = \sqrt{(RMSE_x)^2 + (RMSE_y)^2)} \quad [3]$$

$$RMSE_z = \sqrt{\Sigma(z_{data} - z_{Gnss})^2/n} \quad [4]$$

Then use the RMSE value obtained to calculate the positional accuracy at the confidence level of 95 percent according to the NSSDA standard as in equation 4-5.

Horizontal positioning accuracy (Accuracy H)

Accuracy 95% = 1.7308×RMSE [5]

Vertical positioning accuracy (Accuracy Z)

Accuracy 95% = 1.9600×RMSE [6]

The positional accuracy at the 95% confidence level was compared with the standard ASPRS [17], which is a criterion for positional accuracy on the map scale which will show that the Digital Elevation Model that is in the ASPRS standard, which scale map is suitable for production.

2) Comparison of accuracy in pixel units without using GCPs and using GCPs was analyzed by converting RMSE value to RMSE/ GSD which shows accuracy in pixel unit in form of radiance discrepancy. The results were then compared with the ASPRS standard, which determined that the horizontal positioning accuracy, both the east (E) and north (N) values that are less than or equal to 1 pixel are orthophotos that can be used in the highest accuracy work, if less than or equal to 2 pixels are orthophotos that can be used. In Standard Mapping and GIS work and if more than 3

orthophoto points are low quality orthophotos, can be used in Visualization and less accurate work to know if the Digital Elevation Model is in the ASPRS standard.

3. Result

Evaluation results of positional accuracy of the Digital Elevation Model both horizontally and vertically. The research findings are as follows:

1) The results of the horizontal and vertical positional accuracy analysis (RMSE) without using GCPs and using GCPs showed that the use of GCPs resulted in both horizontal and vertical positional accuracy than not using GCPs as shown in Table 3.

Table 3 Comparison of positional accuracy without GCPs and with GCPs

Case Study	Horizontal Accuracy		Vertical Accuracy	
	Without GCPs	With GCPs	Without GCPs	With GCPs
1	0.042	0.035	0.138	0.117
2	0.061	0.054	0.159	0.124
3	0.099	0.031	0.219	0.058
4	0.142	0.051	0.19	0.17

When taking the RMSE value of the horizontal and vertical positional coordinates to calculate the positional accuracy at the confidence level of 95 percent according to the NSSDA standard, it was found that without using GCPs, the horizontal positional accuracy was 0.073-0.246 m, and when using the GCPs, the horizontal positional accuracy was 0.054. -0.093 meters at the 95% confidence level. When without using GCPs, the vertical positional accuracy is 0.270-0.429 meters and when using the GCPs, the vertical positional accuracy is 0.114-0.333 meters at the 95% confidence level. 95 results are shown in Table 4.

Table 4 Horizontal and Vertical Positional Accuracy Values at the confidence level of 95%

Case Study	Horizontal Accuracy		Vertical Accuracy	
	Without GCPs	With GCPs	Without GCPs	With GCPs
1	0.073	0.061	0.270	0.229
2	0.106	0.093	0.312	0.243
3	0.171	0.054	0.429	0.114
4	0.246	0.088	0.372	0.333

When the results of horizontal and vertical positioning accuracy at the confidence level of 95 percent are compared with the map scale according to the ASPRS Class 1 standard, the results are shown in Table 5.

Table 5 Map Scale Comparison According to Horizontal Positional Accuracy and standard vertical ASPRS (Class 1)

Case Study	Horizontal Accuracy		Vertical Accuracy	
	Without GCPs	With GCPs	Without GCPs	With GCPs
1	1:500	1:500	1:4,000	1:4,000
2	1:500	1:500	1:4,000	1:4,000
3	1:1,000	1:500	1:10,000	1:1,000
4	1:1,000	1:500	1:10,000	1:10,000

Comparing the map scale according to the horizontal position accuracy according to the ASPRS standard (class 1) found that without using the GCPs, case studies 1 and 2 were able to make a plane map at a scale of 1:500 with x and x deviations, y is not more than 0.125 m, and case studies 3 and 4 can make a flat map at a scale of 1:1,000 with a x and y error of not more than 0.25 m. When using GCPs, all case studies can make a flat map at a scale 1:500 with x and y tolerances of not more than 0.125 m.

When comparing the map scale according to the ASPRS standard vertical positioning accuracy (class 1), it was found that without using GCPs, case studies 1 and 2 were able to make a vertical map on a scale of 1:4,000 with no x and y deviations exceeds 0.33 m, produces contour intervals of not less than 1.0 m, while case studies 3 and 4 can produce a vertical map at a scale of 1:10,000 with x and y deviations of no more than 0.67 m, producing contour intervals, the height is not less than 2.0 m. For the use of GCPs, case study 3 can make a vertical map at a scale of 1:1,000 with x and y deviations of not more than 0.17 m, producing contour range data of not less than 0.5 m. In case studies 1 and 2, a vertical map can be made at a scale of 1:4,000 with an x and y error of not more than 0.33 m. The contour range data can be produced at least 1.0 m. A vertical map with a scale of 1:10,000 has an x and y error of not more than 0.67 m, producing data with a contour range of not less than 2.0 m.

2) The comparison results of accuracy in the unit of image pixels without using GCPs and using GCPs were analyzed by converting RMSE to RMSE/ GSD by comparing the results with ASPRS standards. The results are shown in Table 6.

Table 6 Comparison of pixel accuracy without GCPs and using GCPs

Case Study	Horizontal Accuracy (RMSE/ GSD)		Vertical Accuracy (RMSE/ GSD)	
	Without GCPs	With GCPs	Without GCPs	With GCPs
1	<=1	<=1	<=3	<=3
2	<=1	<=1	<=3	<=3
3	<=2	<=1	<=3	<=2
4	<=3	<=1	<=3	<=3

Accuracy in pixel according to standard ASPRS standard (class 1) without GCPs. Case study 1 and 2 are orthophoto that can be used in highest accuracy work. Case study 3 is orthophoto that can be used in Standard Mapping and GIS work and case study 4 is a low-quality orthophoto that can be used in Visualization and less accurate work when using GCPs highest accuracy. It is an orthophoto that can be used in mapping and geographic information. When comparing the map scale according to the ASPRS standard vertical positional accuracy (class 1), it was found that the non-GCPs were low quality orthophotos. It can be used for applications that do not require high accuracy, and when using GCPs, Case Study 3 is an orthophoto that can be used for mapping and geographic information. Case studies 1, 2, and 4 were low-quality orthophotos. It can be used in applications that do not require a lot of accuracy.

4. Conclusion and Discussions

This evaluation of the positional accuracy of the Digital Elevation Model from a low-cost UAV has determined factors in flight planning to suit the terrain, to obtain a precision positional accuracy by setting factors such as altitude, flight front overlay and side stacks that different effects on modeling. The study found that setting the flying height at 70 and 90 meters and setting the front and side overlaps to 80% and 70% and 70% and 60%, respectively, can provide good image quality and not much difference. When creating a Digital Elevation Model, it was found that planning a flight with 80% frontal overlap and 70% side overlapping would give the best results according to the results of the study in Case Study 3, which had a flying height equal to 70 meters and set the front and side overlaps to be 80% and 70% has the best horizontal and vertical positioning accuracy which corresponds to Hamilton (2017) has done research on Aerial photography using Unmanned Aerial Vehicle for archaeological applications. It was found that 75% front overlay and 95% side overlap would be effective in creating a Digital Elevation Model. However, the limitations of high-level modeling, to be highly accurate is to collect both horizontal and vertical positional data to cover the area. and set the front overlay and side overlays to suit the area conditions.

When comparing the accuracy of spatial data horizontally and vertically using 2 methods, namely 1) analyzing the positional accuracy without using GCPs points and using GCPs points and 2) comparing the accuracy in unit of image pixel without using GCPs and using GCPs, it was found that using GCPs would be accurate in both horizontal and vertical positions than without using GCPs. It was found that when GCPs were not used, the horizontal discrepancy was less than 25 cm. and the vertical discrepancy was not more than 70 cm., which is consistent with the study of Villanueva (2019) which uses 24 GCPs and has a discrepancy of 12 cm and the study of [20] that GCPs are important for mapping aerial photographs low cost unmanned and it is necessary to produce maps with centimeter accuracy.

Evaluation of the validity of the numerical height model by evaluating positional accuracy at 95% confidence level. It is a method to verify the position accuracy according to NSSDA standard by using standard error (RMSE) at 95% confidence level. In case of not using GCPs Digital Elevation Model points that are in the NSSDA standard in the map scale of 1: 4,000 and when using the GCPs

Digital Elevation Model points that are in the NSSDA standard in the map scale of 1:1,000 and compared with the ASPRS standard. It was found that the obtained Digital Elevation Model was able to be used in mapping and geographic information. This is consistent with the research of Kanplumjit (2020), which assessed the accuracy of the numerical topographic model. using the NSSDA standard and the ASPRS standard as well.

Comparison of the accuracy in image pixel units without GCPs and with horizontal GCPs found that it can create an orthophoto that can be used in the work with the highest accuracy. While accurate in vertical pixel units, the use of GCPs can create an orthophoto that can only be used in mapping and geographic information applications. This is in line with the research of Nagendran et al. (2018) which has taken the positional accuracy compared to the ASPRS standard. It can also be used for work with the highest accuracy. According to this study, digital elevation models from low-cost UAVs can be used both without and with GCPs for applications that do not require very detailed and precise verticality values, such as building elevation surveys, tree height, or the height of large bill-boards, etc., because the difference in elevation values between features within the study area is still within acceptable criteria. In the future UAV studies should consider incorporating multi-probe sensors mounted on the aircraft for more comprehensive Digital Elevation Model (DEM) assessments. The use of DEM assessments is crucial in environmental studies, providing valuable information about the topography of the terrain, which is important for various applications such as land use planning, flood modeling, and environmental impact assessments.

5. Reference

ASPRS. (2015). **ASPRS Positional Accuracy Standards for Digital Geospatial Data**. Retrieved 10 Mar 2022, from https://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy Standards_Edition1_Version100_November2014.pdf.

Daramola, O., Olaleye, J., Ajayi, O.G. and Olawuni, O. (2017). Assessing the Geometric Accuracy of UAV Based Orthophotos. **South African Journal of Geomatics, 6**(3), 395.

Engineering Institute of Thailand. (2018). **Unmanned Aerial Survey Standards for Engineering**. Bangkok. The Council of Engineers Thailand (COET). (in Thai)

Gindraux, S., Boesch, R., and Farinotti, D. (2017). Accuracy Assessment of Digital Surface Models from Unmanned Aerial Vehicle' Imagery on Glaciers. **Remote Sensing, 9**, (2), 186.

Hamilton, S. (2017). **UAV (drone) Aerial Photography and Photogrammetry and its Utility for Archaeological Site Documentation, Lakehead University**. Retrieved 10 Mar 2022, from http://www. apaontario.ca/resources/Documents/APA_ OccasionalPaper2_DroneTesting_2017. pdf. t.

Hung, I-Kuai., Unger, D., Kulhavy, D., & Zhang, Y. (2019). Positional Precision Analysis of Orthomosaics Derived from Drone Captured Aerial Imagery. **Drones, 3**(2), 46.

Kanplumjit, T., Ketthong, W., Poonphakdee, N., Phrommet, S. (2020). **Application of UAVs Surveying for Rock volume measurement at Khao Bandai Nang quarry Songkhla Province**. NCCE25. 250:SGI04. https://conference.thaince.org/ index. php/ncce25/article/view/611. (in Thai)

Koeva, M., Muneza, M., Gevaert, C., Gerke, M. and Nex, F. (2018). Using UAVs for Map Creation and Updating: A Case Study in Rwanda”, **Survey Review. 50**(361), 312-325.

Mantey, S., & Michael Soakodan Aduah. S. (2022). Assessment of positional accuracies of UAV-based coordinates derived from orthophotos at varying times of the day- A case study. **South African Journal of Geomatics, 10**(1), 46–59. https://doi.org/10.4314/sajg.v10i1.4

Nagendran, S. K., Tung, W. Y., & Mohamad Ismail, M. A. (2018). Accuracy assessment on low altitude UAV-borne photogrammetry outputs influenced by ground control point at different altitude. **IOP Conference Series: Earth and Environmental Science**, 169, 012031.

Laphitchayangkul. T., Pasada. A., Wangyao, K. (2020). Application of Low-cost Unmanned Aerial Vehicle for Accurate Mapping:Case Study at King Mongkut’s University of Technology Thonburi, Ratchaburi. Residential College. **KMUTT R&D Journal 3**, 2020, 311-324. (in Thai)

Pix4D. (2021). **Ground control points: why are they important?**. Retrieved 10 Mar 2022, from https://www.pix4d.com/blog/why-ground-control-points-important.

Raczynski, R.J. (2017). **Accuracy analysis of products obtained from UAV-borne photogrammetry influenced by various flight parameters**. Master’s thesis, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology. Norway.

Santise, M., Forlani, G. and Roncella, R. (2014). Evaluation of DEM generation accuracy from UAS imagery. The International Archives of the Photogrammetry, **Remote Sensing and Spatial Information Sciences** XL-5, 529-536.

Uysal, M., Toprak, A. S. and Polat, N. (2015). DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hil. **Measurement: Elsevier, 73**, 539-543.

Villanueva, J.K.S. and Blanco, A.C. (2019). Optimization of Ground Control Point (GCP) Configuration for Unmanned Aerial Vehicle (UAV) Survey using Structure from Motion (SfM). ISPRS - International Archives of the Photogrammetry, **Remote Sensing and Spatial Information Sciences**, XLII-4/W12, 167-174.

Volkmann, W. and Barnes, G. (2014). Virtual Surveying: Mapping and Modeling Cadastral Boundaries Using Unmanned Aerial Systems (UAS). **Proceedings XXV FIG Congress 2014**, Kuala Lumpur, Malaysia 16-21 June 2014.

Webster, C., Westoby, M., Rutter, N., & Jonas, T. (2018). Three-dimensional thermal characterization of forest canopies using UAV photogrammetry. **Remote Sensing of Environment, 209**, 835-847.

Wierzbicki, D., Kedzierski, M. and Fryskowska, A. (2015). Assessment of the Influence of UAV Image Quality on the Orthophoto Production. The International Archives of Photogrammetry, **Remote Sensing and Spatial Information Sciences, 40**, 1, 8.

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