

Effects of Density of Ground Control Points on The Accuracy of Orthophotos Produced Using UAV

BELLO ISAH KONTAGORA¹, MUHAMMAD BALA², JIYA JACOB³

^{1, 2, 3}*Department of Surveying and Geoinformatics, School of Environmental Technology, Niger state polytechnic, Zungeru*

Abstract- Ground control points are needed in the production process of any accurate photogrammetric output. They are used to georeference the acquired images. The aim of this research is to investigate the effects of density and distribution of ground control points on the accuracy of orthophotos produced by UAVs. To achieve this, an area of 15.2 hectares was photographed with DJI Marvic Air UAV. One hundred and eighty (180) images were captured at an altitude of 60m above the ground. Ground control points (GCPs) and check points (CPs) were established using Hi-Target GNSS with external antenna. The images acquired were processed using Pix4Dmapper photogrammetric software. Bundle adjustment was performed with the number of GCPs increased from eight (8) to nineteen (19). The orthophoto generated were analyzed by comparing the ground coordinates with orthomosaic coordinates. Root mean square error (RMSE) analysis was conducted, one for each of the configuration of GCPs. The smaller the RMSE value, the higher the accuracy of the orthophoto. The configuration with 19 GCPs produced the best result with RMSE of 1.2195 m, ± 0.8461 m and ± 0.0129 m for easting, northing and height respectively. It can be concluded that the density and distribution of the GCPs have an effect on the production and accuracy of orthophotos. Difference in accuracy in respects to GSD's should be tested out to obtain the optimal GSD for mapping and number of GCP's for study area consists of differential elevation profile.

Keywords: *Unmanned Aerial Vehicle; Agisoft Photoscan; Digital Elevation Model; Orthophoto*

I. INTRODUCTION

Aerial photogrammetry involves the acquisition of photograph using cameras attached to an Aircraft. Manned aerial vehicle fitted with a digital camera can be used to acquire spatial related data that could be used to produce large scale maps, although the method of producing such maps using aerial photogrammetry can be very expensive (Brynsen and Sukkarieh, 2009). UAV remote sensing offers an alternative way of obtaining the same results with less expense and added

advantages over manned aerial vehicle. UAV's are flexible to operates, it can be operated at any time and day without necessarily relying on the availability of pilot. UAV is very efficient in terms of cost and man power, it is safe and can be flown at a low altitude (Cao et al., 2016). Compared to manned aerial photogrammetric systems, UAV provide a simpler way of achieving a good photogrammetry outcome in short time with less human interference (Jaakkola et al., 2010).

The unmanned aerial vehicle has become a readily available tool that is used for acquiring spatially related data for several application. As much as the UAV is efficient for data capture, it should be noted that utilization depends on a complex system which comprises of the UAV, set of ground controls and a communication system. This system is generally referred to as the unmanned aerial system (UAS). Although term UAS is not commonly used as the term UAV.

A minimum of three ground control points (GCPs) is required for an area of about one hectare, but increasing the number of GCPs will lead to higher accuracy of the final results (Tahar et al., 2014). It is worth mentioning however that increasing the number of ground control points is a time-consuming process both in the field and during computation. Even if the literature is quite overflowing mainly in terms of books and reviewed articles, it is important to update the solutions recently adopted for correcting the effects of density of GCPs on the accuracy of orthophoto produced using UAVs with the latest developments and research studies from around the world.

1.1 Study Area

The study area is located at the university golf course in the precinct of Federal University of Technology

main campus in Gidan Kwano, Minna, extended towards the staff quarters. The site consists of small rocks and open space undulating gradually making it very suitable for the study. A total number of nineteen (19) Ground control points (GCPs) and twelve (12) Check points (CPs) were distributed across the study area. The GCPs and CPs were established and fixed inside the perimeter and coordinated by GNSS.

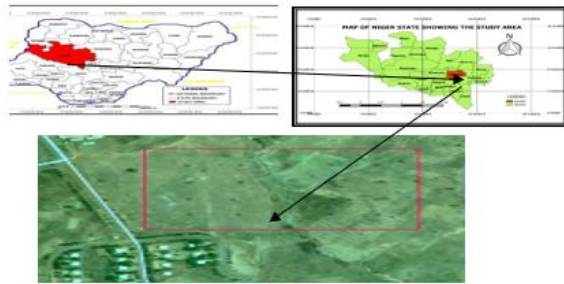


Figure 1.1 The University golf course, located at Federal University of Technology Minna
Source: Author 2025

The related literature that helped in molding this study was reviewed, the aim was to investigate the effect of density of ground control points on the accuracy of UAV based orthophoto. But first it is important to first define UAV, Aerial photogrammetry and ground control points, which will lead to a discussion on how these three are related.

Photogrammetry is a method of measuring coordinates in three dimension which make use of photographs as the basic means for measurements. Aerial photogrammetry involves the acquisition of photograph using digital camera attached to an Aircraft, these photographs are combined together to produce a map. This method of producing a large-scale map using aerial photogrammetry can be very expensive (Brynson and Sukkarieh, 2009).

UAV photogrammetry offers an alternative approach of producing similar large-scale maps with added advantages over aerial photogrammetry using manned vehicle. Some of the advantages are: flexibility, safety, reliability, low flight heights, high precision and large-scale measurements that save manpower and material costs (Cao *et al.*, 2016). Compare to other aerial photogrammetric systems, UAV provide a simpler solution for low budget projects with time constraints

and requires less human interface (Jaakkola *et al.*, 2010).

So many UAVs have been developed by individuals or organizations across the globe including a complete set of UAVs which uses high quality fibers as the materials for plane modeling (Li *et al.*, 2017). The development is in terms of design, research and production of UAV platform (Cesetti *et al.*, 2011). As a result of this development, the demand for aerial photogrammetric products has increased greatly.

Recently, low altitude remote sensing unmanned aerial vehicle (UAV) technology has been developed and it has become an important equipment for spatial data acquisition. Three-dimensional model (DEM and orthophoto) can now be generated using UAV images after going through certain photogrammetric processes. The technology is now utilized in many applications such as surveying, farming, surveillance, road maintenance, recording and documentation of cultural heritage (Hervouet *et al.*, 2011).

The accuracy of orthophoto derived from UAV photogrammetry is affected by some many factors that have been investigated separately. For example, the effects camera's focal length was investigated by Clapuyt *et al.* (2016) and effects of the flight altitude and camera orientation (yaw, pitch and roll) on the photogrammetric product as well as image quality was investigated by Leitao *et al.* (2016).

II. MATERIALS AND METHODS

2.1.1 The DJI Mavic Air

DJI Marvic Air was used at about 60 m above the earth surface to photograph the study area. The UAV is small in size, it has a weight of about 453.6g and can be folded which makes it easy to carry about. It has a smart hand gesture recognition technology, 3 axis gimbal, 4k camera and 3 directions of obstacle detection sensing. The camera and intelligent flight modes allow you to take quick shots from different angles. It can fly for 21 minutes with a maximum flight range of 10 km without wind and maximum height of 500 m above sea level.

The flight plan was designed with dronedeploy software, choosing an overlap of 70% and 60% and the camera was oriented in nadir position.



PLATE II DJI Marvic Air and its Control
 Source: Field survey 2025

2.1.2 High-Target GNSS Receiver Units

The ground control points (GCPs) and check points (CPs) were surveyed and established using Hi-Target GNSS with external antenna (see plate III a). The nearest existing control point close to the study area was GPS 15 (see plate III b), GNSS was used to transferred the coordinates from GPS 15 to the study area.



(a)



(b)

PLATE III:(a) GNSS was used to generate the coordinates of the GCPs (b) GPS 15 (the control whose coordinates was transferred to the study area)

Source: Field survey 2025

2.1.3 Pix4Dmapper Software

In this study, the main photogrammetric processes were performed using Pix4Dmapper software. The reason for using this particular software for processing the images is that, Pix4Dmapper can automatically place the GCPs in their right positions as opposed to the other photogrammetry softwares.

2.1.4 Computer System

The Pix4Dmapper photogrammetric software was installed on a DELL laptop with the following configuration properties; CPU: Intel(R) Core (TM) i7-5600U CPU @ 2.60GHz, RAM: 6GB, GPU: Intel(R) HD Graphics 5500, Windows 10 Pro, with 64-bit operating system.

2.2 METHODS

In this research, the methodology was sub-divided into stages, data collection, and data processing, and results analysis. This can be depicted by a chart in the figure 3.1

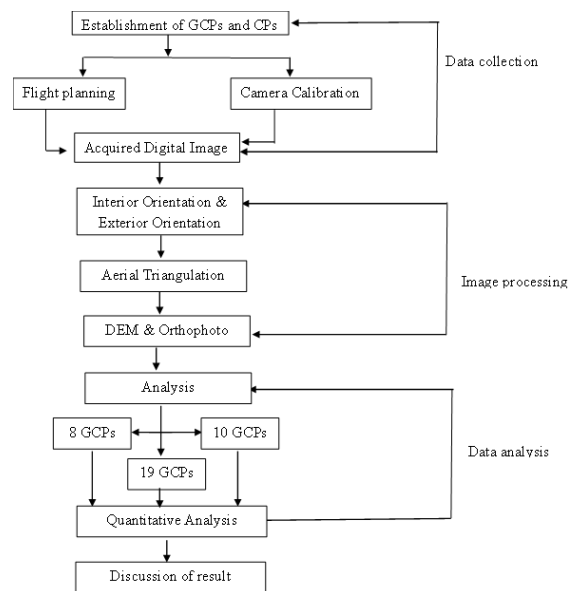


Figure2.1: Flowchart of the Methodology of the Research

Source: Author 2025

The methods adopted in this research for the creation of UAV based map in line with the objectives requires the establishment of GCPs and CPs, aerial

photographs and digital terrain model as input. In the following sub-sections, the procedure is described.

2.3 Project Planning and Data Pre-processing

This stage involved the selection of the study area, software and UAV platform selection. The images were process using photogrammetry software (Pix4Dmapper) which was used to produce the orthophoto of the study area. GNSS was used to establish the ground control points and check points used for accuracy assessment.

2.4 Establishment of Ground Control Points

Ground control points can be avoided or minimize to some extend if the UAV has dual frequencies GNSS receiver on board, this is to ensure that the precise camera station coordinates are determined for each photograph. The DJI Mavic Air that was used for this research has a single frequency, hence the need for GCPs. The GCPs were established before the aerial photography mission. Nineteen (19) crosses PVC were used as GCPs which enclosed the study area, they were arranged in such a way that at least four GCP are visible on each image acquired. The GCPs were fixed inside the perimeter and coordinated by GNSS techniques. Nineteen points were used as GCP with full 3D (XYZ) coordinates points.

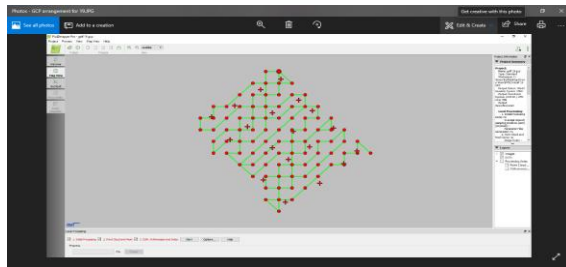


PLATE V: UAV Image with the Location of the 19 GCPs

The GCPs that was used were surveyed using Hi-Target GNSS with external antenna (see Plate III above). The Hi-Target GNSS with external antenna were used for the establishment of the GCPs and check points in rapid static survey model with about 14-minute occupation time, 19 GCPs were established to enhance the georectification quality. The reference system used was WGS84 reference ellipsoid in UTM zone 32N projected coordinate system. The GCPs coordinates obtained are presented in the table 3.1

2.5 Aerial Photo Acquisition

DJI Marvic Air was used at about 60 m above the earth surface to photograph the study area. The UAV has an in-built camera equipped with image sensor which has a camera resolution of 12 MP and 4056x3040 pixels. The flight plan was designed with dronedeploy software, choosing an overlap of 70% and 60% and the camera was oriented in nadir position. A total of 180 images were acquired with 2.35 cm/pixel GSD, during a single flight grid. The strip of the images was captured in JPEG format and they were later transferred to a computer system for processing.

Table 2.4 Image Data Properties

Number of images acquired	180
Image dimension (Pixel)	4912 × 3264
Image resolution	4056 x 3040
Bit depth	24
Image format	JPEG
Ground dimension per image	2.35cm/pixel

2.6 Data Processing

The merit of this research is in the establishment of GCPs for each of the photogrammetric configuration. Three experimental tests were conducted for each GCP configuration to identify the effects of GCP configuration in photogrammetric outcomes. The GCPs were used to relocate images into local coordinates systems. In this research two main outcomes were produced DEM and Orthophoto. DEMs were generated from the aerial triangulation points based on the size of the cell, the processing time can be increased if the cell size is smaller. After the generation of DEM, then the orthophoto can be generated. Orthophoto is produce from the single orthoimages, therefore mosaicking process need to be performed to get a final orthophoto result.

In this study, 19 GCPs were used for the UAV image processing, the remaining 12 points were used as check points for assessing the accuracy of the output. These 19 GCPs were distributed, then the number was decreased to 10 GCPs clustered to one side and finally 8 GCPs were distributed randomly. In each case, the

effects of the distribution of the GCPs on the orthophoto was observed.

2.7 The Test for Configuration of GCPs

This project envisaged three configurations of GCP in the processing of the UAV images. To determine the effect of the distribution and density of the GCPs, the accuracy of each of the configuration is first calculated. The first configuration involves 19 GCPs, second configuration involves 10 GCP and the third involves 08 GCPs. These GCPs were distributed within the area. The analysis section explains the effect of each configuration in easting, northing and height coordinates. Each configuration represents the different number and location of GCP used during Image processing. Hypothetically, each GCP configuration gives a different photogrammetry outcome because GCPs are used to locate the processed UAV images to the local coordinate system. The figures3.3 shows the GCP configuration which was applied in this research.

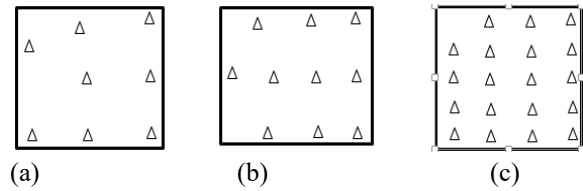
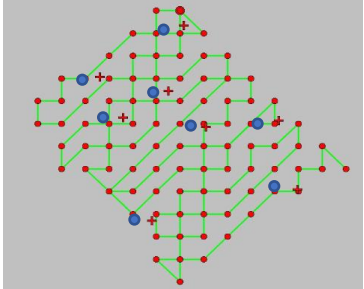
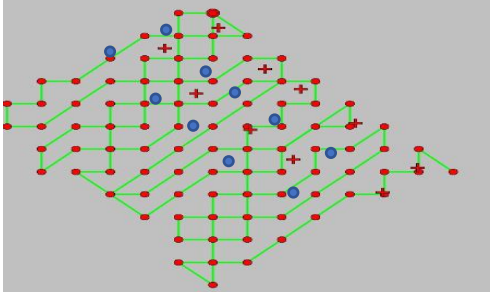


Figure 3.3 Ground control points configuration: (a) 8GCPs (b) 10GCPs (c) 19GCPs

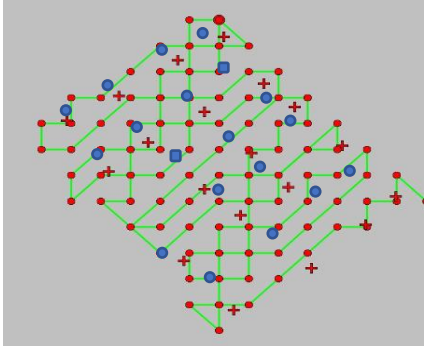
2.8 GCPs Density Experimental Tests

It has already been established that sufficient number of the GCPs with good configuration improve the accuracy of the orthophoto. It therefore became necessary to have a prior knowledge of how the accuracy of the orthophoto would be affected by the GCPs distribution. In this research three experiments were performed to determine how the number and spatial distribution of GCPs affect the accuracy of orthophoto. These tests are described in the table 3.6, in each experiment, Pix4Dmapper was used to perform the photogrammetric processing (tie point generation, block bundle adjustment and camera calibration).

Table 3.6 Experimental test to verify the effects of number as well as the distribution of GCPs

Test Label	Figure	Descriptions
GCP test 1		Number of GCPs 08 Description Distributed unevenly across the study area
GCP test 2		Number of GCPs 10

Description Cluster to one side of the study area
 *evenly distributed

GCP test 3		Number of GCPs	19
		Distribution	Covering the whole study area *Evenly and well distributed

2.9 Data Analysis Techniques

The quantitative analysis was performed by using Root Mean Square Error (RMSE). The CPs derived using Hi-Target GNSS were compared with similar point estimates established by photogrammetry.

The RMSE was carried out using the following equation:

$$RMSE = \frac{\pm\sqrt{\sum(N_i - N_j)^2}}{n} \quad (3.1)$$

N_i = Observed values

N_j = Reference values

n = total number of points or stations

Resultant root means square error RMSEr

$$= \sqrt{(RMSE_x)^2 + (RMSE_y)^2} \quad (3.2)$$

Where $RMSE_x = \frac{\pm\sqrt{\sum(X_i - X_j)^2}}{n}$ (3.3)

and

$$RMSE_y = \frac{\pm\sqrt{\sum(Y_i - Y_j)^2}}{n} \quad (3.4)$$

Where:

X_i = the Easting coordinate of observed check point

X_j = the Easting coordinate of the Orthophoto check point

Y_i = the Northing coordinate of Observed check point

Y_j = the Northing coordinate of the Orthophoto check point

n = the number of check points

Horizontal and vertical accuracy of the orthophoto generated was determine from the formula :Horizontal accuracy = $1.7308 \times RMSE_r$ and Vertical accuracy = $1.96 \times RMSE_z$

III. RESULTS AND DISCUSSION

The main objective of the study is directed towards examination of the effects of the density of GCPs on the accuracy of the UAV based orthophoto. This section present the result of the geometry corrections using eight, ten and nineteen control points and also examine test in term of root mean square error (RMSE).

3.1 Result of Data Analysis Performed with Distributed GCPs

The check points used for this research are the points within the flight area which were established for the purpose of validation of the ground control points. The check points were generated from the orthophoto. Table 4.1 shows the comparison of the check points and the corresponding coordinates extracted from the orthophoto, Horizontal accuracy of the map was 0.4204 m and vertical accuracy was 1.3252 m.

Table 3.1 RMSE of Digital Aerial Imagery Orthophotos based on GCPs Configuration

RMSE (m)			
GCPs	Easting (m)	Northing (m)	Height (m)
19	±1.2195	±0.8461	±0.0129
10	±1.6807	±0.8527	±0.0178
08	±1.3690	±1.2130	±0.0160

Based on the table 4.1, it can be seen that the values of average RMSE for minimum and maximum GCPs varies slightly (0.1732m). The 19 GCPs configuration produced the best result in terms of the RMSE of ±1.2195 m, ±0.8461 m, and ±0.0129 m (for easting, northing and height respectively)

IV. CONCLUSION AND RECOMMENDATION

4.1 CONCLUSION

Based on this study, the digital aerial imagery collected by a rotary wing DJI Marvic Air can be used for large scale topographic mapping. The sub meter accuracy produced by 19 set data based on the variation in GCPs configuration is relevant for various applications with low cost expenditure and less manpower. The flexibility nature of the DJI Marvic Air will provide a very efficient solution for a real time mapping, this is because it can take off and land at a limited open space or area with autopilot controlling. The orthophoto is define in terms of the horizontal and vertical accuracy; 19 GCPs configuration provided the best result with RMSE of ± 1.2195 m, ±0.8461 m and ±0.0129 m (for easting, northing and height respectively). It can be concluded that the density and configuration of the GCPs has a direct impact upon the production and accuracy of the orthophoto. In other words, the achievable accuracy was found to be dependent upon other photogrammetric factors such as camera calibration and control points coordinates related to the ground station network.

4.2 RECOMMENDATION AND SUGGESTIONS FOR FUTURE RESEARCH

In research any ideas a researcher has for future research work can be discussed as this provides leads for other researchers towards area deemed to be important after acquiring experience with the current research project. From this study, a number of topics emerged that may require further attention in investigating factors that affect the accuracy of UAV-based orthophoto that were not cover in this study. It is therefore recommended that similar studies be conducted that will include other factors, this would provide a complete outlook on how the accuracy of the UAV-based orthophoto can be improved in other to achieve a better result. The problem that could be considered for future research are as follows:

- i. In most of the previous researches ground control points (GCPs) were established by total station and Real-time Kinematic Global Positioning System for georeferencing the data, no special attention was given to Continuously Operating Reference Station (CORS) method of georeferencing. Compared with the real-time kinematic global positioning satellite (RTK-GPS) method, the CORS-GPS method is more stable and reliable, which improves the accuracy of the GCPs (Stella *et al.*, 2018).
- ii. Also, most researchs focuses on the configuration of the GCPs, without looking at the angular effects. The angle between GCPs can also have an effect during image processing because the angle between GCPs will be calculated during bundle adjustment process (Tahar *et al.*, 2012).
- iii. Analysis between surface roughness and orthophoto is also yet to be investigated.
- iv. UAV image acquisition and SFM-MVS image procession need to be integrated. This is important if source of errors is to be minimized when acquiring dataset.
- v. Difference in accuracy in respects to GSD's should be tested out to obtain the optimal GSD for mapping and number of GCP's for study area consists of differential elevation profile

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