Assessing the geometric accuracy of UAV-based orthophotos

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Abstract

Attempt has been made in this research to investigate geometric quality of an Unmanned Aerial Photograph from Trimble UX5 Aerial imaging solution for map generation and compilation despite the limited number of control points used and the mode of establishment of the control points. Two important criteria are pivotal to Geometric quality assessment of an Aerial photograph; Geometric accuracy and Object-definition property but this research bothers on the geometric accuracy. In remote sensing and photogrammetric operations, the geometric quality of the imagery basically depends on the relation between pixel size and the map scale, contrast information, atmosphere and the sun elevation, the printing technology, screen resolution and the visual acuity. The Unmanned Aircraft System (UAS) deliverables which are the orthophoto and the digital surface model (DSM) show that UAS (Trimble UX5) can be used for compilation of large scale maps in partly accessible or inaccessible areas according to the map accuracy analysis of the National Standard for Spatial Data Accuracy (NSSDA, 1998). The horizontal accuracy of 3.207m (RMSE: 1.85m) and vertical accuracy of 0.884m (RMSE: 0.45m) were obtained which fall within the allowable misclosure, hence, suitable for Cadastral map compilation.

Keywords: Geometric Accuracy, Object-definition, Image, Map generation, Map compilation, Geometric quality

1. Introduction

In Aerial photogrammetry, orthophotos, topographic maps and other map deliverables have been produced from the aerial photograph acquired using the large format metric cameras. The cost of acquiring the aerial photograph through the traditional means such as manned aircrafts is relatively high and requires critical planning. Ideally, large format aerial cameras are useful for mapping large area but the use of small format digital cameras has helped to achieve the same capacity (A. Ahmad 2006).

The small format digital camera has shown great relevance and application in researches throughout the world for mapping purposes such as topographical mapping and other applications such as land slide mapping, map revision, research and civil engineering designs (A. Ahmad 2006). The small format digital camera offers several advantages above large format metric camera. Some of the advantages include portability, accessibility, ease of use and reduced cost (Mikrut 2016), though the scope of this research does not cover cost analysis of the data acquisition methods.

In this study, a fixed wing Unmanned Aerial Vehicle (Trimble UX5) equipped with a calibrated small format digital camera, global positioning system (GPS), tracking system and inertial navigation system (INS) forms the data acquisition system. Establishment of ground control points helped in improving the aero-triangulation quality and the processing of the data to obtain an orthophoto and a DSM was done on Trimble photogrammetric workstation. This paper investigates the suitability of the data acquisition system (UAV) through the geometric quality of its deliverables.

2. Unmanned Aircraft System

The term UAS is frequently used in the Systems Engineering, Computer Science, Robotics and Artificial Intelligence, Photogrammetry and Remote Sensing World. Besides, names like Remotely Piloted Vehicle (RPV) which was first used in 1970, Remotely Operated Aircraft (ROA) or Remotely Piloted Aircraft (RPA) are used by various authors and researchers (James, Alvah and Susan 1988; Molla and Rahim 2014). The terms ROA and RPA have been used by National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA) in the U.S. in place of Unmanned Aerial Vehicle (UAV) which was first used in 1986 (Colomina, et al. 2008). The Unmanned Vehicle Systems International Association has explicitly defined the remotely controlled and model helicopters as mini, close and medium range UAVs depending on their flight strength, size and flying height range (Eisenbeiss 2004). UAS, as used in photogrammetry and remote sensing stands for the whole system, including the Unmanned Aircraft (UA) with the Sensor on-board and the Ground Control Station (GCS).

UAVs, in contrast to manned aircraft systems have some major advantages. UAVs can be used in high risk situations without endangering human lives and inaccessible areas, at low altitude and at flight profiles close to the objects where manned systems cannot hover (Eisenbeiss 2004). These locations include natural and artificial disaster sites, e.g. mountainous and volcanic areas, mud slides, oil spillage, flood plains, earthquake and desert areas and scenes of accidents (A. Ahmad 2011).

The implementation of GPS/INS systems as well as the stabilization and navigation units allow precise flights, ensuring, on the one hand, sufficient and adequate image coverage and overlap and on the other hand, enabling the robustness of flight planning process

Based on latest development by Trimble Navigation Company, a Trimble Aerial Imaging solution has been invented called UX5 Aerial Imaging Solution (See Figure 1). This system is capable of generating three main survey deliverables namely orthomosaic (maximum ground sampling distance of 2.4cm), digital terrain/ surface model (raster elevation) and point cloud maps.

(a) (b)

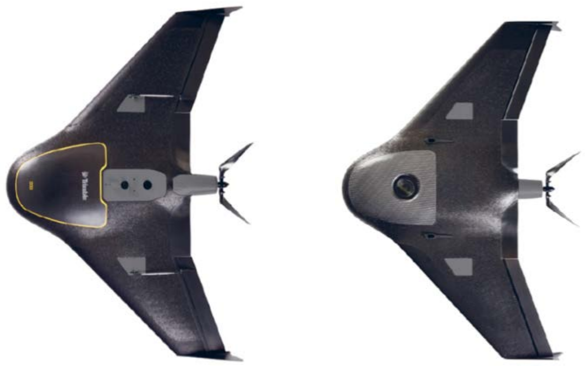

Figure 1. Trimble UX5 views: (a) Top view (b) Bottom view

3. Study Area

The research study area is part of the University of Lagos, Akoka Campus. It is situated on the western part of the Lagos metropolis in Yaba local government area of Lagos State. The University is geographically located between Northings 721000mN and 718500mN, and Easting 542000mE and 545000mE and has an approximate area of 3.25Km^2 (802 acres). It is bordered on the north and north-west by Bariga community (Shomolu local government area); on the western and south-west by Iwaya community and Akoka village respectively; on the Eastern flank, it is bordered by the Lagos lagoon

The study location encompasses the Sport Complex and the Faculty of Environmental Sciences at the western part of the Institution.

Figure 2. Location of the study area, University of Lagos, Akoka.

4. Research Methodology

4.1. Initial flight planning

The initial flight planning entailed the use Google Earth (GE) to execute an initial review and demarcation of the project area which was then saved as kemler file format. It was also essential to do initial flight planning as the GE imagery does not show dangerous obstructions such as cell towers, power lines or other objects that could impede the flight plan. Part of the reconnaissance includes identifying an open, reasonably central location that can be used as the take-off and landing area as well as obstructions like utility poles, trees and buildings. There were no airspace laws in the study area and this sped up the planning process.

4.2. Mission and Flight Planning

Onboard the UX5 rover was a Sensor (Calibrated Camera) having a focal length of 15mm, forward and side overlaps of 80% and flown at a height of 100m above the ground giving us a GSD of 3.2cm. Mission and Flight planning was done with the aid of a software package, called Trimble Access Aerial Imaging. Flight plans were edited both in the graphical and the tabular sections of the screen. The Mission planning was carried out on Trimble Access Aerial imaging software.

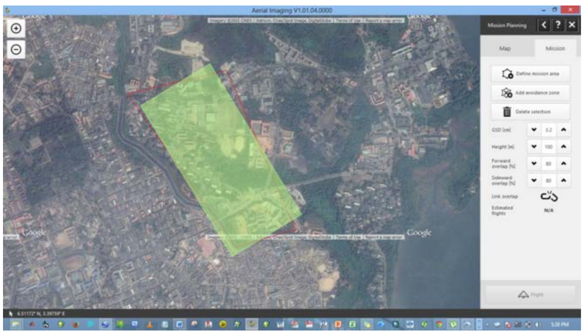

Figure 3. Trimble Access Aerial Imaging Software showing the desired GSD, flying height and Overlap

4.3. Establishment of Ground Control Points

Ground controls can be avoided or drastically minimized if the UAV has a dual frequency GNSS on board so that precise camera station coordinates are determined for each photograph but in this case, the GNSS onboard the UAV is of single frequency hence, the Ground control points were pre-marked immediately across the project area before the flight (Hughes, McDowell and Marcus 2005). The GCPs were surveyed using Trimble R8 GNSS (Azmi, Ahmad and Ahmad 2014). A default ground signal recommended by Trimble Navigations was used (See Figure 5).

Conspicuous existing natural or artificial features on the ground were used as Check points (ChP) considering the clarity on the aerial photographs (Hughes, McDowell and Marcus 2005). The precise coordinates of all the GCPs were determined in a defined spatial reference frame (Azmi, Ahmad and Ahmad 2014). Trimble R8 differential GNSS receivers were used for the establishment of the GCPs and ChPs in Rapid Static survey mode with about 15minutes occupation time, 5GCPs were established to considerably enhance the georectification quality though it's insufficient for rough terrains. The spatial reference system used was WGS84 reference ellipsoid in UTM zone 31N projected coordinate system. GCP coordinates obtained are presented in Table 1.

Table 1. GCPs measured using Trimble R8 GNSS Solution

GCP	Easting (m)	Northing	Height (m)
SPT01	543042.943	720108.592	5.570
CTH01	542947.904	720435.987	7.265
EDU01	542675.963	720386.820	11.176
ISL02	543292.521	719729.031	7.617
ISL01	543132.339	719695.927	6.531

4.4. Image Acquisition

A single flight was preferably selected which covered the study area to alleviate the stress of processing the images due to the processing system configuration. Wind direction, take-off and landing location were defined on the site on the UAV Ground control station (GCS) before flight.

In preparation for the flight, the UAV, the Radio Connection (RC) transmitter and GCS were connected and the flight mission plan was uploaded to the UAV Autopilot fixed in the E-bay section. The UAV was launched after being fully armed and covered the study area in about 30minutes before landing. The flight was ended on the GCS after which the log data was downloaded as well as the images captured. The Data properties are in Table 2.

Table 2. Image Data properties

Number of Images Acquired	669
Image dimension (Pixel)	4912 × 3264
Image resolution	350dpi
Bit depth	24
Image format	JPEG
Ground dimension per image	157.18×104.45m

4.5. Image Processing

The flight was designed with generous overlaps of 80% (forward) and 80% (side) which produced 669 overlapping image frames amounting to large set of image data of about 4-5MegaBytes per image frame. Consequently, the processing part of the UAS methodology is the most time-consuming image files and performs a procedure referred to as photo alignment, tie point adjustment, Digital Elevation Model (DEM) creation and Orthophoto production. The processing was done on Trimble Business Center Photogrammetry Module application (Version 3.30) installed on an HP laptop with the following configuration properties; 4GB RAM, Intel® Core™ i3-3110M CPU @ 2.40GHz processor, 64Bits operating system and 500GB hard drive disk

The data was post-processed in UTM 31N projected coordinate system referenced to the WGS84 global ellipsoid. The 5GCPs were used for the adjustment of Tie points (Aero-triangulation) succeeded by the production of Digital Elevation Model and Orthophoto.

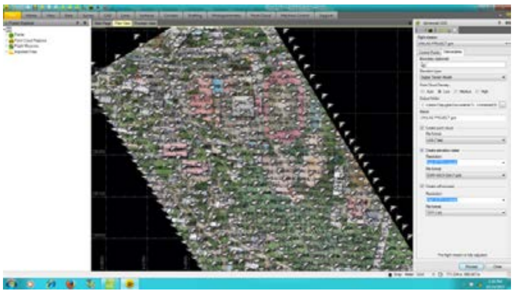

Figure 4. Orthophoto generation on Trimble Business Center Photogrammetry

5. Results and Analysis

This section reveals the output of the research work and contains the various deliverables obtained in the course of the data acquisition and data processing. It involves the measurement of the Geometric accuracy of the orthomosaic after the performance of aerial triangulation (adjustment of tie points) and map generation.

5.1. Results

The raster elevation map was used to generate Digital Surface Models such as contour map on ArcGIS as well as 3D wireframe on Surfer10. These products are shown below:

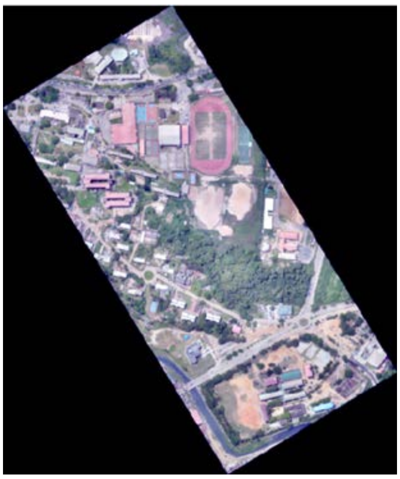

Figure 5. orthophoto map of the study area

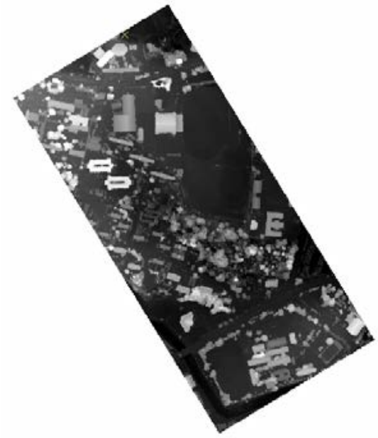

Figure 6. Digital Surface Model of the study area

Figure 7. point cloud map of the study area in 3D view on TBC3.3

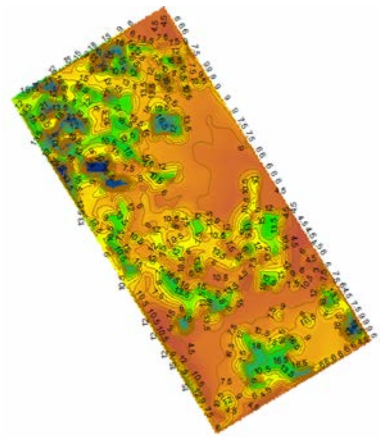

Figure 8. Contour map from ArcMap

5.2. Analysis

The analysis puts into consideration the positional accuracy of the Orthomosaic map, the linear accuracy by linear measurements on the map related to ground measurement and the spatial resolution of the Orthophoto map obtained. The details of this assessment are presented in subsequent subsections.

5.2.1. Quantitative Analysis

Quantitative analysis deals with assessment of the values obtained using suitable statistical tools. This aspect of the analysis was actualized by computing the root mean square error (Colomina, et al. 2008).

$$RMSE = \sqrt{\frac{\Sigma(N_i - N_j)^2}{n}} \quad [1]$$

Where, N_i = Observed values, N_j = Reference values and
n = Number of points or stations

The check points used for this project were the control points within the flight area established for other purposes. In ArcMap 10.2 software, the check point coordinates were obtained from the orthomosaic (ChPs) and the root mean square error (RMSE) was computed for this analysis. Table 3 shows the comparison of check points and having the map horizontal accuracy 3.207m and vertical accuracy, 0.884m. According to the National Standard for Spatial Data Accuracy (NSSDA 1998) method for evaluating maps accuracies;

Table 3. Comparing coordinates of Check Points using GPS post-processed and Orthomosaic

ChP	GPS PP			Orthomosaic (ArcMap)			Difference		
ID	X (m)	Y (m)	Z(m)	X (m)	Y (m)	Z(m	ΔX	ΔY	ΔZ
ChP1	542594.8	720393.5	12.53	542595.7	720393.9	12.5	-0.94	-0.40	-0.01
ChP2	542571.4	720355.0	12.20	542572.5	720355.2	12.1	-1.15	-0.18	0.06
ChP3	542900.6	720388.1	8.46	542900.8	720389.8	8.43	-0.15	-1.67	0.03
ChP4	543060.5	720259.8	5.91	543061.0	720261.7	5.88	-0.47	-1.90	0.03
ChP5	543111.5	720253.4	5.35	543111.9	720255.4	5.57	-0.36	-1.94	-0.22
ChP6	543264.1	719810.7	7.44	543266.0	719812.3	7.96	-1.84	-1.66	-0.53
ChP7	543256.3	719839.2	6.86	543258.1	719840.5	6.97	-1.83	-1.38	-0.12
ChP8	542885.1	720002.9	7.03	542887.1	720003.4	7.00	-1.93	-0.51	0.03
ChP9	543235.4	719894.2	7.35	543237.0	719895.7	6.08	-1.59	-1.57	1.27
ChP10	542621.4	720383.3	11.98	542622.4	720383.8	12.2	-0.96	-0.43	-0.28
Vertical Accuracy =			0.884m		RMSE =		±1.28	±1.33	±0.45
Horizontal Accuracy =			3.207m		$RMSE_r$ =		±1.8529		

$$Horizontal\ Accuracy = 1.7308 \times RMSE_r \quad [2]$$

$$RMSE_X = \sqrt{\sum (X_i - X_j)^2 / n} \quad [3]$$

$$RMSE_Y = \sqrt{\sum (Y_i - Y_j)^2 / n} \quad [4]$$

$$RMSE_r = \sqrt{\sum[(X_i - X_j)^2 + (Y_i - Y_j)^2]/n}$$

$$= \sqrt{(RMSE_X)^2 + (RMSE_Y)^2} \quad [5]$$

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

$$Vertical\ Accuracy = 1.96 \times RMSE_Z \quad [6]$$

$$RMSE_Z = \sqrt{\sum (Z_i - Z_j)^2 / n} \quad [7]$$

The GCPs established by GPS observations and GCPs on the orthomosaic map were compared. The horizontal accuracy is 0.292m and the vertical accuracy is 0.231m as shown in Table 4.

Table 4. Comparing coordinates of GCP using GPS post-processed and ArcGIS (GCP accuracy)

GCP ID	GPS PP			Orthomosaic (ArcGIS)			Difference		
	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	ΔX	ΔY	ΔZ
SPT01	543042.94	720108.59	5.570	543043.16	720108.57	5.621	-0.219	0.014	-0.051
CTH01	542947.90	720435.98	7.265	542947.64	720435.82	7.522	0.262	0.166	-0.257
EDU01	542675.96	720386.82	11.17	542676.09	720386.97	11.16	-0.136	-0.153	0.01
ISL02	543292.52	719729.03	7.617	543292.52	719729.13	7.608	-0.003	-0.103	0.009
ISL01	543132.33	719695.92	6.531	543132.25	719695.72	6.558	0.086	0.207	-0.027
Vertical Accuracy =			0.231m		RMSE		±0.16	±0.144	±0.117
Horizontal Accuracy =			0.292m		$RMSE_r$ =		±0.1688		

5.2.2. Qualitative Analysis

Qualitative assessment of the orthophoto was done by overlaying measured or observed ground features on the digitized features. Visual assessment of the overlaid features was done by comparing digitized features on orthomosaic with the area computed through conventional survey. This method of analysis deals with the polygonal accuracy of the aerial photograph. From Figure 9, there is a slight difference in the feature mapping and this difference occurred due to errors in data acquisition, tie point adjustment and deliverable generation (Simon, Peter and Kyriacos 2003). The area and perimeter of the feature on the orthophoto map are 804.654square meters and 120.425meters respectively while from ground survey, 802.007square meters and 120.177meters. The areal difference in the results of both platforms is 2.647square meters and this makes the aerial platform (UAV) fit for large scale mapping where much significance is not placed on millimeter accuracy of mapping area. On the other hand, the linear difference (lateral displacement) in the results of both platforms is 0.248meters; hence, it affirms the suitability of the aerial platform for large scale mapping such as cadastral information system, construction surveys and layout surveys.

From the analysis, diverse factors attributed to the errors procured during acquisition of positional data and aerial photograph. Some can be attributed to human imperfectness or frailties, while others to external factors. It could be caused by visual acuity or resolution which varies with each photogrammetric technician or personnel in the course of point picking for tie point adjustment. However, this may affect the vertical map accuracy of the orthophoto. The cause of the large RMSE value may be attributed to inadequate number of GCPs for the tie point adjustment and the observation mode of control establishment (Vericat, et al. 2008). The generous percentage of overlaps helped to optimize the vertical accuracy through multiple matches (Haala 2011; Haala, et al., 2012; Gruber, et al., 2004)

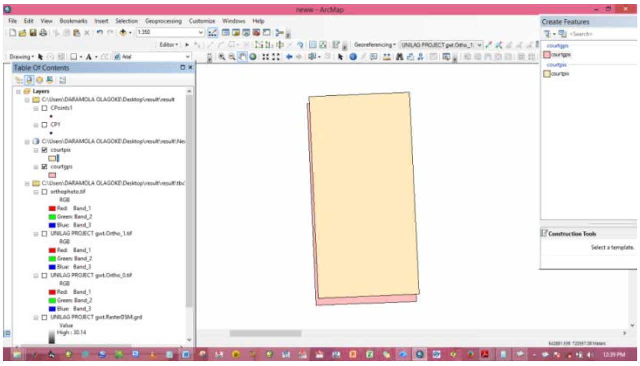

Figure 9**.** Results of overlapped features on ArcMap 10.2

6. Conclusion

The technological preferment in photogrammetry is concocted in the realms of software and hardware intelligence. It is sufficiently necessary to appraise the solution capabilities to spur the developers to further improve on the components of their respective software where necessary.

In this study, orthophoto, point cloud and raster elevation maps were successfully generated from photogrammetric data using Trimble Business Center Photogrammetry Software.

Conclusions can be made from the results and analysis obtained from this study, that the Unmanned Aircraft system images can be employed for updating and revision of topographic maps with minimal number of GCPs and a high percentage of forward and side overlaps (Gruber, et al., 2004; Haala, 2011). This research affirms the suitability of UAVs in areas that are partly accessible or inaccessible.

The map accuracy is defined in terms of the horizontal and vertical accuracy; they are 3.207m (RMSE= 1.85m) and 0.884m (RMSE= 0.45m) respectively (Table 3). It can be concluded that orthophoto generated from Trimble Aerial Imaging Solution should be employed in order to achieve accurate mapping because it falls below the maximum allowable RMSE according to the American Society for Photogrammetry and Remote Sensing (Lawali and Dauda 2014) and National Standard for Spatial Data Accuracy. This paper has been able to look into the geometric quality through geometric accuracy and resolution of its products which makes it fit for compilation of topographical map, cadastral maps, engineering survey maps and applied in project progress monitoring, civil & heavy earthworks in mining industry, oil & gas, environmental and landfill, agriculture & forestry in the aspects of crop population, forest classification and vegetation health mapping, resource and asset mapping, as-built survey, disaster analysis and close-range photogrammetry in the area of accident reconstruction

7. Acknowledgments

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