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UAV-BASED 3D MODEL OF PART OF UNIVERSITY OF LAGOS MAIN CAMPUS

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ABSTRACT

This study aims at the production of a 3D map of University of Lagos using Unmanned Aerial Vehicle (UAV). Images were acquired using a DJI Phantom 4 Professional camera with 3cm resolution on a multi-rotor UAV at an altitude of 100m. The study area was divided into strips and the flight plan was created automatically with Dronedeploy software using seventy percent (70%) sidelap and endlap. Ground control points were established and distributed within the boundary of the study area. Dronedeploy app provides seamless flights from take-off and right through to landing, while automatically collecting acquired images. Images were calibrated using local coordinates of the Ground Control Points collected using a Real Time Kinematic Global Positioning System (RTK-GPS) technique. The Pix4D image processing software was used for image alignment, generation of precise and georeferenced point cloud, automatic classification of point clouds as well as generation of DTM and DSM. Results presented include the orthophoto, Digital Surface Model (DSM), Digital Terrain Model (DTM) and Contour map of the study area. The 3D model covers all the difficult terrain that could not be mapped for decades due to its inaccessibility by the traditional ground survey method. The horizontal and vertical accuracies of the topographic map produced were 2.764m (RMSE: 1.597m) and 1.360m (RMSE: 0.694m) respectively. These were within allowable misclosure limits according to National Standard for Spatial Data Accuracy (NSSDA, 1998). The study therefore concludes that 3D model will enhance the assessment of current physical developments as well as planning of sustainable developments of the University of Lagos in the future.

Keywords: Uumanned Aerial Vehicle, Mapping, 3D, University of Lagos, images

1. Introduction

In the past, UAV programs and vehicle development were driven mainly by military goals and applications. The main military targets were unmanned monitoring, observation, identification, and mapping of inimical regions (Topan, Buyuksalih & Jacobsen, 2005). The first experience for Geomatics applications was performed three decades ago but only recently, UAVs in the field of Geomatics have become a popular data acquisition platform (Nex, and Remondino 2014). An important means of remote aerial sensing, UAV has been extensively deployed in numerous areas with special technical advantages such as autonomy, usability and low cost (Yun-Yao, Ya-Fen & Shang-En, 2016). UAV is a promising method for the development of these high-resolution multi-time stereo images and optical surface models. Recently, the flight of UAVs has run with a high degree of autonomy via the global positioning system and the onboard digital camera and computer (Topan, Buyuksalih & Jacobsen, 2005). UAV applications have increased dramatically in recent years due to their greater affordability and the miniaturization of sensors, GPS, inertial measuring devices, and other accessories (Mancini *et al*., 2013). This has provided opportunity for re-visitation and re-capture of high-quality and high-resolution images. UAV takes quality imagery of inaccessible areas much faster and at cheaper cost when compared with other traditional methods (Lambers, *et al*., 2007; Laliberte, et al., 2010; and Park, et al., 2014). According to Mancini, et al., (2013) using the structure from motion approach in low-altitude hexa-rotors create point clouds and derived digital surface map representing high topographic accuracy, comparable with data from GPS survey.

University of Lagos in recent times is experiencing environmental challenges such as flooding which could be attributed to the recent developments. This could worsen if no remedial effort is taken urgently. It is therefore important to produce a 3D map of the University so as to have a global assessment of the entire land area as well as plan for future developments. However, a large portion of the University land area is covered by wetland as well as inlets from the Lagos Lagoon. The use of ground-based method for 3D mapping would therefore be more expensive, time consuming and seriously challenging. This makes a remote alternative method of topographic mapping desirable. The study is therefore aimed at producing a 3D map of University of Lagos using Unmanned Aerial Vehicle (UAV) for a sustainable future planning and development.

2. Material and Methods

2.1. Study Area

University of Lagos is located in the mainland area of Lagos. It is reported to be the most populated city in Nigeria with an estimated population of over twenty-one million people in 2015 (LBS, 2010). Figure 1 shows the google earth image of the University of Lagos, Akoka main Campus. It is located on the western part of the Lagos metropolis in Yaba Local Government Area of Lagos State. Geographically University of Lagos is situated between coordinates 721000mN and 718500mN (northings) as well as 542000mE and 545000mE (eastings), with an area of approximately 802 acres (Daramola et al., 2017). It is bordered by the community of Bariga (Shomolu local government area) on the north and northwest; by the Iwaya (Lagos Mainland local government); Akoka on the west and southwest and by the Lagos Lagoon on the east flank

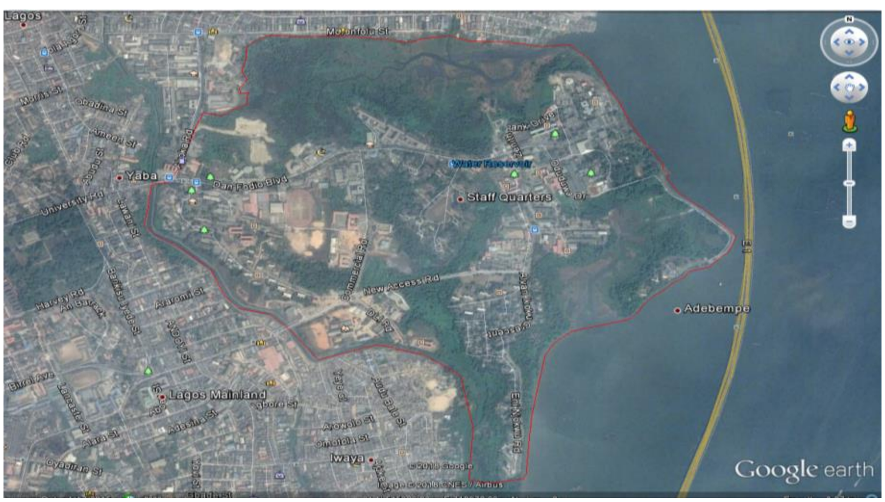

Figure 1: Google earth image of the study area

2.2 Mission Planning

Existing data required for this study includes the coordinates of control points within the study area, acquired from the office of Surveyor General of Lagos State and the Department of Surveying and Geoinformatics, University of Lagos; Lagos street map also acquired from the office of Surveyor General of Lagos State and the Google earth imagery of the study area. The acquired

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Google earth image was used for the mission planning. Global mapper software was used to delineate the study area and the delineated study area was imported into AutoCAD environment. The study area was overlaid on the Lagos street map to ascertain the actual boundary of the study area. DJI Phantom 4 Professional drone with accessories was used for data capture, Trimble R8 DGPS with Full Accessories was also used to collect data for the ground control points. One IPhone 7 plus and Apple Laptop system (525SSD, 16G RAM, 2.4Processor) were used during the study. Software used includes AutoCAD Civil 3D 2018, ArcGIS 10.2, Dronedeploy, Global mapper, Microsoft Excel 2010 and Pix4D mapper.

The study area was divided into strips and the flight plan created automatically with Dronedeploy software using seventy percent (70%) sidelap and endlap. This is more than the 60% endlap and 40% sidelap recommended for creation of a stereo model (Falkner and Morgan, 2002). The percentage overlap (70%) used in this study is to meant to provide large number of key points so as to produce a very accurate 3D map. Although the maximum flight time of one phantom battery is 28 minutes (DJI, 2016), the flight time utilized throughout this study was 20 minutes in order to cater for unforeseen technical challenges. Each flight trip was overlaid on the mission area to determine the number flight trips and the number of days required to cover the study area. The main limitation of DJI Phantom 4 Professional is that take-off and landing must approximately be at the center of the flight trips (DJI, 2016). When it is difficult to access the approximate center of a strip, data acquisition for the particular strip becomes a challenge. Based on this limitation, data could not be acquired in one of the flight trips (marked in light green in Figure 2 below).

Figure2: The flight trips on the study area.

2.3 Ground Control Establishment

For the purpose of post-flight adjustment and processing, the ground control points were established on the vertices of the low wall fence adequately distributed within the boundary of the study area identified using Trimble R8 differential GPS instrument. Table 1 contains the list of GCP and their coordinates while Figure 3 is a typical GCP.

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Table 1: GCP coordinates as measured with GPS

	GCP	Easting (m)	Northing(m)	Height (m)
1	GCP_DLI	543220.449	719885.615	26.872
2	GCP_MED	543926.813	720008.462	29.471
3	GCP_GATE	542690.711	720498.158	25.341
4	GCP_NEWH	543273.498	720592.895	28.817
5	GCP_JAJA1	543957.573	720297.793	29.621

Figure3: Locating a GCP in the study area.

2.4 Image Acquisition

The Dronedeploy Software is an elegant tool that enables the user to pre-programme an automated flight plan for the UAV (Azmi, Baharin & Anuar, 2014). Dronedeploy app provides seamless flights from take-off and right through to landing, while images are automatically collected by the camera mounted on the UAV. With these, it is possible to create a variety of visualized data from 2D maps to 3D models. DroneDeploy app on mobile device allows login of account as well as setting the flight parameters for automatic flight control of the UAV (Laliberte *et al.,* 2010). In this study, DroneDeploy app was used to set the coverage area, flight altitude, flight direction, speed and percentage of image overlap. When all the flight control parameters had been set, then the drone was ready for takeoff. As a part of the takeoff process, the app carries out an internal safety check to ensure stable connection between app and drone which includes, sufficient battery life to execute the mission, flight boundary not too far from the takeoff point, flight mission coverage area and stable GPS connection on drone (Allouch, *et al*., 2019). While executing the flight mission, the drone was controlled in automatic pilot mode using the Dronedeploy app. It maintained its altitude throughout the mission and navigate to the take-off position after a completed mission. Using the Dronedeploy interface, the pilot was able to monitor the position of the drone as well as other parameters such as battery life, flight speed, flight height and number of images captured. Figure 4 shows the Dronedeploy interface during flight while Table 2 shows the flight parameters of each mission.

Figure 4: Dronedeploy interface for monitoring UAV during flight trip

Table 2: Parameters of each flight mission

Mission	Date	Take off Time	Flying Height (m)	Number of Images Acquired
1	7/19/2018	10:43am	100	108
2	7/24/2018	09:55am	100	676
3	7/30/2018	10:08am	100	508
4	7/31/2018	10:21am	100	349
5	7/31/2018	05:28pm	100	422
6	8/1/2018	11:02am	100	351
7	8/1/2018	05:44pm	100	378
Total Images acquired				**2792**

2.5 Image Processing

The processing of the imagery was achieved using the Pix4Dmapper software. The software was able to detect the coordinate system used by the UAV as well as the altitude and positions at which the images were captured. Images were downloaded to the computer system for processing. Each flight produces a large number of overlapping photographs amounting to large datasets (the image size is about 8mb). A minimum of 100 images were captured in each flight trip, the actual number of images depends on the size of the flight area. The GCPs were used to adjust Tie Points (Aero-triangulation). Georeferencing was carried out by aligning the UAV image to the GCPs. Image registration and image rectification were carried out using Pix4Dmapper software. The GCP (X, Y, and Z) file was imported into Pix4Dmapper environment. For accurate geo-referencing, the absolute coordinates of GCPs were measured to an accuracy equivalent to the Ground Sampling Distance (GSD) of the imagery. As a measure of quality control, the Pix4Dmapper software compares the user requirements and manufactured image product thereby identifying and eliminating the faulty images. The Pix4D image processing software performs the operation of image alignment by converting thousands of images into a georeferenced 2D mosaic and 3D

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models. It was therefore possible to exploit hundreds of images so as to generate precise and georeferenced point cloud. Automatic classification of point clouds was done to place the points into groups with useful and logical characteristics that includes points on tarred surface, roof tops and vegetation among other groups. In generating DTM and DSM, the software automatically finds large numbers of common points between overlapping images. When two common points (also referred to as keypoints) on an image are correctly matched with two common points on another image, a 3D point is generated. High overlap therefore allows for the generation of large number of keypoints, which in turn produces more accurately computed 3D Points. The GCPs were used to adjust Tie Points (Aero-triangulation), subsequently point clouds, Orthophoto, Digital Terrain Model (DTM), Digital Surface Model (DSM) and contour lines were created.

2.6 Methodology for Data Analysis

Quantitative assessment was carried out by calculating root mean square error (RMSE) of the Ground Control Points (GCPs) and Check Points (CPs). The general formula for computing RMSE is as given is Equation 1.

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

Where N_i is observed values, N_j is reference values and n is number of points. The Ground control points (GCPs) used for this project are the points marked within the area of flight and established by DGPS and are as presented in Table **1.** The check points used for this study were the control points existing within the study area. The check point coordinates were marked on the Orthomosaic and the root mean square error (RMSE) was computed using the National Standard for Spatial Data Accuracy (NSSDA, 1998) method for evaluating maps accuracies stated as follows:

$$\mathrm{RMSE}_X = \sqrt{\sum (\mathrm{X_i} - \mathrm{X_j})^2 / n} \quad (2)$$

$$\mathrm{RMSE}_Y = \sqrt{\sum (\mathrm{Y_i} - \mathrm{Y_j})^2 / n} \quad (3)$$

$$\mathrm{RMSE_r} = \sqrt{\sum[(\mathrm{X_i} - \mathrm{X_j})^2 + (\mathrm{Y_i} - \mathrm{Y_j})^2]/\mathrm{n}} \quad = \sqrt{(\mathrm{RMSE_X})^2 + (\mathrm{RMSE_Y})^2} \quad (4)$$

$$\mathrm{RMSE}_Z = \sqrt{\sum (\mathrm{Z_i} - \mathrm{Z_j})^2 / n} \quad (5)$$

Where $\mathrm{X_i}$ = the easting coordinate of observed check point
$\mathrm{X_j}$ =the easting coordinate of the Orthophoto check point
$\mathrm{Y_i}$ = the Northing coordinate of Observed check point
$\mathrm{Y_j}$ = the Northing coordinate of the Orthophoto check point
$\mathrm{Z_i}$ = the height of Observed check point
$\mathrm{Z_j}$ = the height of the Orthophoto check point
n = the number of check points

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3. Results and discussions

This section discusses the output of this study. Therefore, orthophoto of the study area, DTM, DSM and contour map are presented and discussed.

3.1. Orthophoto/Orthomosaic

The orthophoto of the study area obtained from processed images is presented in Figure 5. The area of the University where land is still available for development is towards the northern part of the University. However, this area is mostly wetland and development could be more expensive. Secondly, the area around the boundaries of the University still appears to be under-developed except in the South-western part where the University is bounded by a Lagos community (Iwaya). This again could be as a result of the fact that these areas are predominantly water area, the canal that runs from the western part as well as the Lagos Lagoon in the Southern and the Eastern part. Since it is desirable that the University still preserves its serene environment, it would be necessary to consider the environmental impacts of new developments in the University.

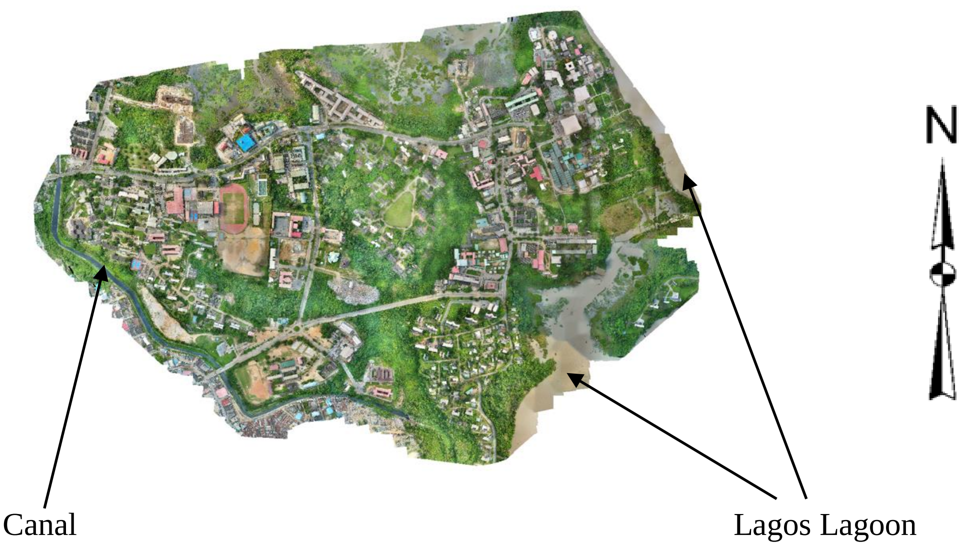

Figure 5: Orthophoto/Orthomosaic

3.2. Digital Surface Model (DSM)

The image shown in figure 6 shows Digital surface model where all the features are depicted in their relative elevations. Senate house which happens to be the tallest building in the university is highlighted in black. The Digital Surface Model is depicted in 3D as shown in Figure 7. From Figure 7, difficult terrains which ordinarily could pose serious challenge to ground survey method and could incur huge cost if traditional photogrammetric approach is used have been mapped with the UAV. The 3D DSM compliments the orthophoto in that further development in the study area could be better analyzed vis-a-vis its environmental impact assessment. At a glance, areas suitable for development or redevelopment as the case may be could easily be identified. Areas liable to waterlogging as well as channelization that is requited to support new development can easily be identified.

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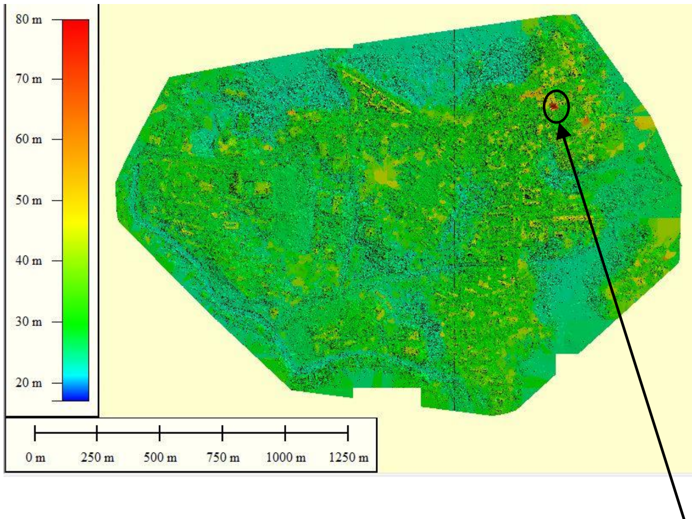

Figure 6: Digital Surface Model (DSM).

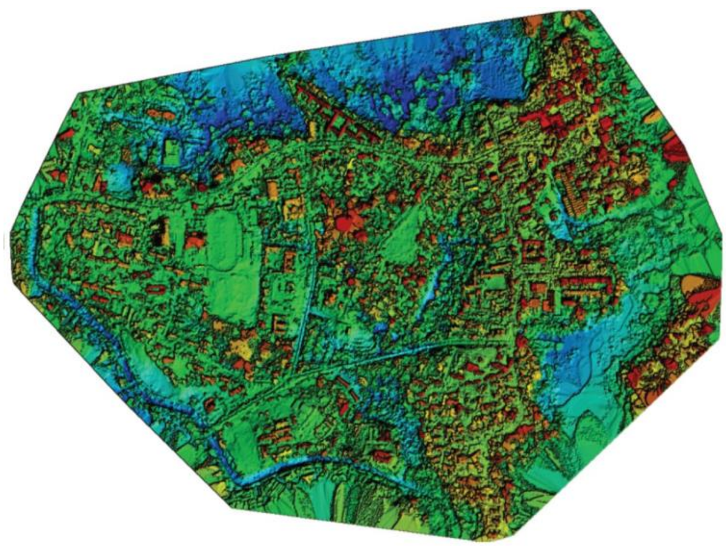

Figure 7: 3D Digital Surface Model (DSM)

3.3. Digital Terrain Model (DTM)

The Digital Terrain Model of the study area as obtained from the UAV processed images is as presented in Figure 8. The DTM would be very helpful in Civil and Construction Engineering activities within University of Lagos. The DTM produces a better and more accurate understanding of the bare surface which in turn enhances the design of optimum performing buildings and constructions. The locations seen with high elevations in the figure are around the Vice-Chancellor's lodge and new halls (student hostel). Prior to the execution of this project, highest elevation was believed to be around the faculty of education. This change could be linked with various developments that have taken place in the University over the years.

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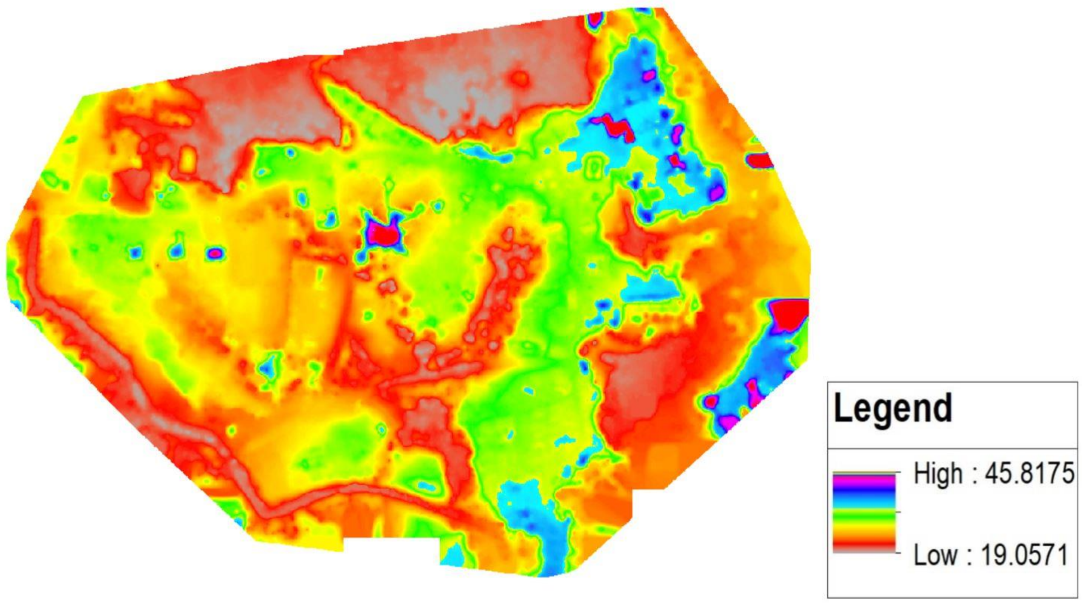

Figure 8: Digital Terrain Model (DTM).

The contour map of the study area produced from the acquired UAV images is shown in Figure 9. This supports and enhance the interpretation obtainable from Figure 8. Places of equal heights can be identified on the map while regions of high and lowland are clearly depicted. With the complimentary results of Figure 8 and Figure 9, further development within the University of Lagos can be sustainable.

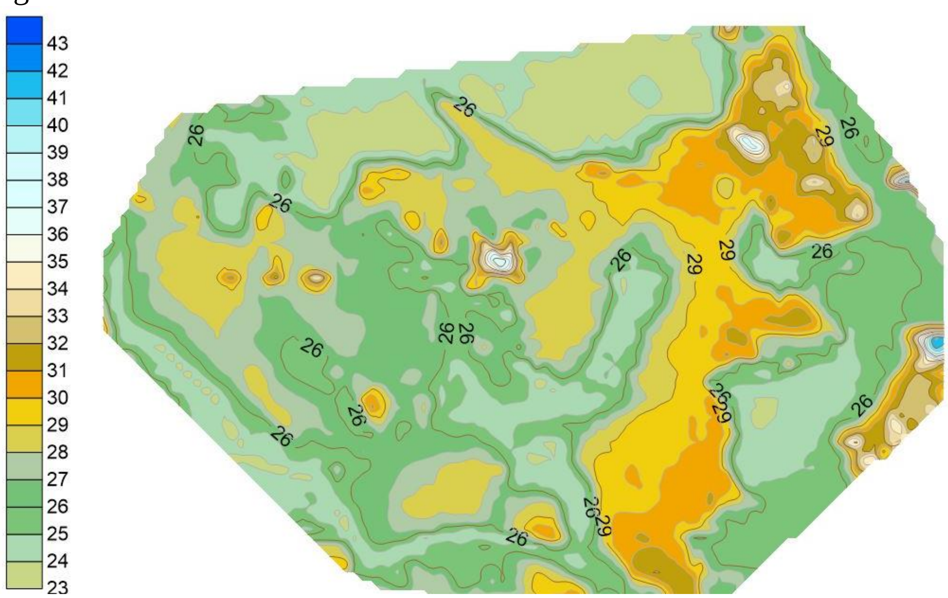

Figure 9: Contour lines

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3.5. Results of Quantitative analysis

Using the approach presented in section 2.6, the results of the quantitative analysis are in this section.

Table 3: Ground Control Points marked/verified on the Orthomosaic with the root mean square error (RMSE)

GCP Name	Accuracy XY/Z(m)	Error X(m)	Error Y(m)	Error Z(m)	Projection Error (pixel)	Verified/Marked
GCP_GME 04 (3D)	0.020/0.020	-0.071	0.14	0	0.124	19/19
GCP_JAJA1 (3D)	0.020/0.020	0.003	-0.183	0	0.493	21/21
GCP_GATE (3D)	0.020/0.020	-0.002	0.073	0.048	0.846	4/4
GCP_DLI (3D)	0.020/0.020	0.086	0.006	0.003	1.277	8/8
GCP_MED (3D)	0.020/0.020	0.5	1.252	-0.081	0.795	4/6
Mean (m)		0.103371	0.257595	-0.005956		
Sigma (m)		0.204696	0.508775	0.041727		
RMS Error (m)		0.229316	0.57027	0.04215		

Table 4: Check points positional errors with the Root mean Squares and the root mean square error (RMSE)

Check Point Name	Error X(m)	Error Y(m)	Error Z(m)	Projection Error (pixel)	Verified/Marked
GCP_06	-0.8596	0.0115	-0.8363	0.271	16/16
Check point_GME 05	-0.4383	-0.1677	-0.6244	0.6404	21/22
Check point_GME 17/4	-2.5875	0.0091	-0.5953	0.8167	28/28
Mean (m)	-1.295114	-0.049045	-0.685306		
Sigma (m)	0.929867	0.083941	0.107438		
RMS Error (m)	1.594357	0.097218	0.693677		

$$\text{Horizontal Accuracy} = \mathbf{1.7308 \times RMSE_r} \qquad (6)$$
$$\text{Vertical Accuracy} = \mathbf{1.96 \times RMSE_Z} \qquad (7)$$

$\text{RMSE}_X = 1.594357 \qquad \text{RMSE}_Y = 0.097218$

$\mathbf{RMSE_r} = \quad = \sqrt{1.594357)^2 + (0.097218)^2} \;=\; \mathbf{1.597318247}$

$\text{Horizontal Accuracy} = \mathbf{1.7308 \times RMSE_r}$

$\text{Horizontal Accuracy} = \mathbf{1.7308 \times 1.597318247}$

$\text{Horizontal Accuracy} = \mathbf{2.76463844\ cm}$

$\mathbf{RMSE_Z = 0.693677}$

$\text{Vertical Accuracy} = \mathbf{1.96 \times RMSE_Z}$

$\text{Vertical Accuracy} = \mathbf{1.96 \times 0.693677}$

$\text{Vertical Accuracy} = \mathbf{1.35960692\ cm}$

The horizontal (radial) accuracy at the 95% confidence level was 2.7646 while vertical accuracy of Non-Vegetated Vertical Accuracy (NVA) at 95% Confidence Level = 1.3596 cm which both falls under accepted accuracies based on **NSSDA, (1998)** accuracy standard. Therefore, the results obtained from the processed images are suitable for engineering applications and sustainable future developments at the University of Lagos.

7. Conclusions

This study successfully produced the 3D models of the main campus of University of Lagos using images acquired from UAV. The DTM and DSM produced would be very helpful in making a sustainable future planning and development at the University of Lagos. The UAV approach used in this study was very helpful in mapping the difficult terrain of the University. Based on the findings from this analysis, it can be inferred that the UAV images are of tremendous assistance for topographic map production. Considering their relatively low cost and ease of service, UAVs are becoming increasingly popular as photogrammetric platforms for civilian use. They have the potential to produce reliable data at higher ground resolution, more cost-effectively, and most critically, cloud-free UAV images. The products of this study will in no small way assist the University in future developments.

References

Allouch Azza, Koubaa Anis, Khalgui Mohamed, and Abbes Tarek (2019) Qualitative and Quantitative Risk Analysis and Safety Assessment of Unmanned Aerial Vehicles Missions Over the Internet. IEEE Access, Vol 7, pp. 53392 - 53410

Anders, Niels, Rens Masselink, Saskia Keesstra, Juha Suomalainen (2013), High-Res Digital Surface Modeling using Fixed-Wing UAV-based Photogrammetry, Geomorphometry.org, O- 2-1-O-2-4.

ASPRS (2014) Accuracy Standards for Digital Geospatial Data, PE&RS.

Azmi, S. M., Baharin Ahmad & Anuar Ahmad, (2014), Accuracy assessment of topographic mapping using UAV image integrated with satellite images. 8th International Symposium of the Digital Earth (ISDE8) IOP Conf. Series: Earth and Environmental Science 18.

Daramola Olagoke, Olaleye James, Ajayi Oluibukun Gbenga and Olawuni Oladayo, (2017), Assessing the geometric accuracy of UAV-based orthophotos. South African Journal of Geomatics, Vol. 6. No. 3, pp. 395 – 406.

DJI (2016) PHANTOM 4 User Manual. DJI Technology Co., Ltd, Shenzhen, China, 518057

Guyer, J. Paul (2015), An Introduction to Survey Methods and Techniques Continuing Education and Development, Inc., New York.

Jacobsen K (2002a), Comparison of High-Resolution Mapping from Space. University of Hannover.

Jacobsen K (2002b) Geometric Potential of IKONOS- and QuickBird-Images University of Hannover.

Lagos Bureau of Statistics (LBS) (2010), "Lagos State GDP Projections". Lagos Bureau of Statistics (LBS), Ministry of Budget and Economic Planning, Lagos State, pp. 1-21.

Laliberte, A. S., Herrick, J. E., Rango, A. S. & Winters C., (2010), Acquisition, orthorectification, and object-based classification of Unmanned Aerial Vehicle (UAV) imagery for Rangeland monitoring. Photogrammetric Engineering & Remote Sensing 76, 661-672.

Lambers, K. H., Eisenbeiss, M Sauerbier, D Kupferschmidt, T Gaisecker, S Sotoodeh & T

Hanusch, (2007), Combining photogrammetry and laser scanning for the recording and modeling of the late intermediate period site of Pinchango Alto, Palpa, Peru. Journal of Archaeological Science 34, 1702-1712.

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S.and Gabbianelli, G., (2013), Using Unmanned Aerial Vehicles (UAV) for High-Resolution Reconstruction of Topography: The Structure from Motion Approach on Coastal Environments, Remote Sens. 2013, 5, 6880-6898; doi:10.3390/rs5126880.

Nex, Francesco, and Remondino, Fabio (2014), UAV for 3D mapping applications: a review. *Applied Geomatics*, Vol. 6, pp. 1–15.

NSSDA (1998). “Geospatial Positioning Accuracy Standards.” Federal Geographic Data Committee, Virginia.

Omogunloye O. G., OtavboruoB. E., Abiodun O. E., Olunlade O.A.and Emesiani E. G. (2018), Application of GIS technology to geospatial location of Lagos State fire stations, Nigeria. Journal of Geomatics Vol 12 No. 1 pp. 54 – 62.

Park, Hong Lyun, Se-Young Park, Chang-Uk Hyun, Hyun-Cheol Kim, Soon Gyu Hong, Ryong Lee, (2014), UAV Based Very-High-Resolution Imaging on Barton Peninsula Antarctica. EARSeL 34th Symposium Proceedings, 16-20.

Topan, H., Buyuksalih, G. & Jacobsen K., (2005), Information contents of High Reolution Satellite Images, Zonguldak Karelmas University and University of Hannover, Germany.

University of Lagos (2020), History of University of Lagos www.unilag.edu.ng

Visockiene J. Suziedelyte, Puziene R., Stanionis A., and Tumeliene E. (2016), Unmanned Aerial Vehicles for Photogrammetry: Analysis of Orthophoto Images over the Territory of Lithuania. International Journal of Aerospace Engineering Volume 2016, pp. 1- 9 http://dx.doi.org/10.1155/2016/4141037

Yun-Yao Chi, Ya-Fen Lee, Shang-En Tsai (2016). Study on High Accuracy Topographic Mapping via UAV-based Images, World Multidisciplinary Earth Sciences Symposium (WMESS 2016) IOP Conf. Series: Earth and Environmental Science 44.