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Nigerian Journal of Surveying and Geoinformatics
October 2021 Volume 6 · Number 1

Contents

S/No	Pages	Author(s)/ Paper Title
		Guide to Authors
1		Nnam, V., Nnaji, I., and Ekpote-Edeh, C. Monitoring Shoreline Changes along River Niger Using Remotely Sensed Data and Geographic Information System
2		Musa, A. A., Peter, E. U. and Emmanuel, F. D Database Design and creation for Land parcels of part of a Residential Layout in Jimeta Yola, Adamawa State, Nigeria
3		Idoko, I. A, Ejikeme, J. O and Salifu, J. O. Monitoring of Urban Growth Pattern of Ado-Odo Local Government Area of Ogun State Using Spatio-Temporal Built-Up Area Analysis and Machine Learning Techniques

- 4 Oyinloye, R.O. and Tohozin, C.A.B.
Geospatial monitoring of the dynamics of urban expansion in south western Nigeria
- 5 Oduwole, A.
Acceptance of Digital Technology by Surveying Practitioners in Ogun, oyo and Lagos States of Nigeria
- 6 Tata, H , Nnamani O.J. and Nzelibe I.U
Determining the Fitting Height of Points for Topographic Mapping from Total Station and Levelling Instrument
- 7 Afolabi, J. I. S and Ijaware, V. A.
Geospatial Analysis of Loss of Forested Areas in Akure using Integrated techniques of Remote Sensing and GIS
- 8 Nzelibe, I, U., Ahmadu, H. A and Adebisi, N. I.:
Virtual 3D Modelling by Close Range Photogrammetry Using Non-Metric Camera for As-Built Building Information Model
- 9 Afolabi, J. I. S and Ijaware, V. A.
Evaluation of the Importance of Soil Testing in Planning Efficient Alternative road Location: Case Study of Itaolloorun-Alade- Idanre Road, Ondo State, Nigeria
- 10 Olayinka-Dosunmu, D. N
Modelling the Storage Capacity of River Benue, Nigeria
- 11 Olusina, J. O. and Nnamani, O.J
Land Use and Land Cover Modelling Using Cellular Automata (CA)/Markov Model
- 12 Ahmadu, H. A, Idrees, M. O., Ayanwale, V. O., & Omar, D. M.
Evaluating the Potential of Nikon D3200 and Canon EOS 7D Amateur Cameras for Photogrammetric Point Determination and 3D Reconstruction

Evaluating the Potential of Nikon D3200 and Canon EOS 7D Amateur Cameras For 3D Reconstruction

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Abstract

The growing use of amateur cameras for several photogrammetric applications such as point determination, three-dimension (3D) reconstruction, measurements and archaeological documentation, have ignited studies on the accuracy potential of these categories of cameras. This paper investigates the accuracy potential of Nikon D3200 and Canon EOS 7D amateur cameras for 3D reconstruction of the oldest hostel building in University of Ilorin, Nigeria. Before image collection, a total number of 37 points, 9 controls points for image processing and 28 check points for accuracy assessment, were strategically marked and coordinated on the building using Sokkia Set 520 Total Station. Thereafter, multiple overlapping images of the building façade were taken successively with the two cameras in such a way that adjacent pair have an end lap of between ~80 – 85%. In Agisoft Photoscan, after removing bad images, the photos were aligned. Subsequently, the 3D mesh and textured models were generated. Corresponding model points of the 28 measured check points were extracted for accuracy determination using the root mean square error (RMSE) analysis. The results showed that both cameras have acceptable point accuracy with the Nikon D3200 producing RMSE of 2.55mm, 3.23mm, 2.51mm and Canon EOS 7D yielded RMSE of 2.77mm, 4.76mm, 2.68mm, in xyz respectively.

Keywords: 3D reconstruction, calibration, close range photogrammetry, building, Ilorin

Introduction

Unlike the metric cameras, non-metric (amateur) cameras do not have suitable photogrammetric reference system [11]; [8] consequently, changes in interior orientation usually occur on an image-to-image basis, which may result in loss of accuracy when compared to metric cameras [16]; [10]. Despite this limitation, non-metric cameras have found widespread applications in several projects involving point measurement and determination, due to their simplicity, small size, compactness and cost effectiveness [18]. Images taken with amateur cameras have been used for accident analysis and 3D measurement of historical features, road mapping and traffic studies, estimation of mean traffic speed, and 3D modelling [5]; [12]; [4].

Successes recorded in the use of non-metric cameras have been largely attributed to recent advancements in the design and construction of their optical and mechanical features [13]; [9]. However, the presence of photogrammetric error arising from unstable camera internal parameters and imaging settings (baselines and shooting distance) usually influence the performance of amateur cameras for several measurement purposes [7]; [11]. In practice, camera calibration has been established as a fundamental requirement for accurate measurement from images acquired using amateur cameras [14]; [6]; [21]; nonetheless, the need to ascertain the level of accuracy achievable with this category of cameras makes performance of evaluation a continuous research interest.

The performance of several amateur cameras have been evaluated in several research works. For example, the work of [17] evaluated the performance of JENOPTIK JD11 CCD camera for photogrammetric application. The author used a 3D test field for his experiment, and the results showed that JENOPTIK JD11 CCD produced RMSE of 8.1mm and 15.9mm in planimetry and depth for the target points. In another work, [8] assessed the capability of Lumia 535 and Lumia 950 XL smart phone cameras for deformation measurement of structures. The author concluded that Lumia 950 XL produced better accuracy with RMSE of 0.27mm, 0.25mm, and 0.32mm for the check point coordinates. In a similar study, [22] evaluated the geometric accuracy of five smart phone cameras (I phone5, Nokia C7, Galaxy S3, Galaxy S4 and Sony Xperia 5) and their usability for 3D positioning application. They found that Galaxy S4 produced the best result with RMSE in planimetry and depth of 2.05mm and 2.38mm, respectively.

In this study, we investigate the accuracy achievable with Nikon D3200 and Canon EOS 7D non-metric cameras through 3D building reconstruction from images acquired with them for the purpose of archaeological documentation.

Material and methods

This study employed close-range photogrammetric technique using two models of amateur cameras to reconstruct the reference building in 3-dimensional space for performance evaluation. Figure 1 presents the data collection, processing and performance evaluation work-flow.

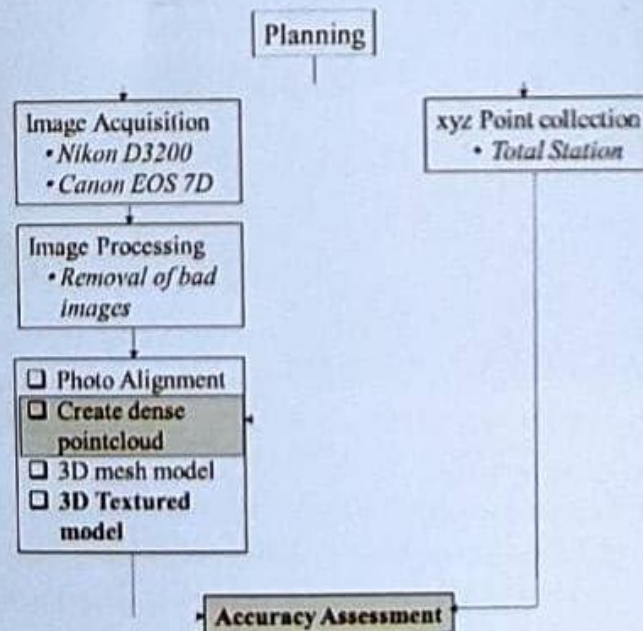


Fig. 1: Data collection and processing work-flow

In this study, two amateur cameras - Nikon D3200 and Canon EOS 7D (Table 1) - were used to collect images of the University of Ilorin Main Campus students' hostel building façade at close range. The building is a story building with only one floor. It is located at the northern part of the university. Dimensionally, the building measures about 62m by 50m by 8m, comprising of twenty-six rooms (Fig. 2).

Table 1: Property of cameras

Camera	Focal Length (mm)	Resolution (mega pixels)	Pixel Array (width x height)	Image sensor size (mm)	Pixel pitch/size (microns)
Nikon D3200	35	24.2	6016 x 4000	23.20 x 15.40	3.86
Canon EOS 7D	24	18	5184 x 3456	22.3 x 14.9	4.29

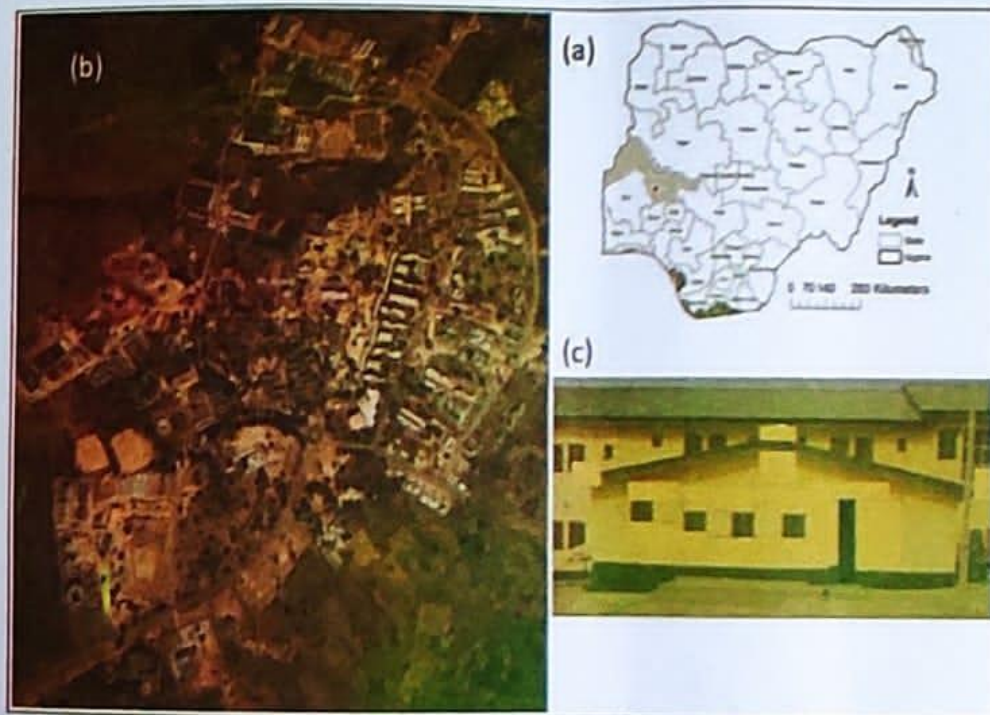


Fig. 2: Study are (a) position of University of Ilorin, (b) Google Earth image of the University and (c) front view of hostel building under study.

The data collection involved image acquisition with Nikon D3200 and Canon EOS 7D and xyz coordinates measurement of the control and check points with Sokkia Set 520 Total Station. Pre-observation procedures were carried out, including selection of control and check points on the building façade using total station, selection of appropriate camera and camera position. The field work started with point data collection during which a total number of 37 points were collected. Nine controls for image processing and 28 check points for accuracy evaluation. Following the point data collection, multiple overlapping images

of the building façade were acquired with the two cameras successively. During image acquisition, we ensured that the camera was kept to fixed focus with sharp aperture setting at average distance of 10 m away from the building. In addition, extra images were taken to increase data redundancy so as to provide adequate coverage. Image acquisition was strategically taken such that convergent pair have an end lap of ~80 – 85%. This percentage of overlap is necessary to ensure that each successive photograph duplicates part of the area coverage of the previous photo [19]. With both cameras, 65 images of the building façade were acquired.

Data processing

The images were processed in Agisoft Photoscan® - a fully automated 3D modelling solution technology developed by Agisoft LLC, for 3D geometry reconstruction from 2D images [1]. One of the advantages of Agisoft Photoscan is the capability to process images taken from any position. As a measure to ensuring quality 3D reconstruction, the initial task was to remove poor quality images from the loaded raw photographs [1]. This was done by visually accessing the images one after the other after loading them in the processing package. Agisoft Photoscan include a self-calibrating system that utilizes the camera parameters and image coordinates to produce pre-calibrated values. This is usually done during alignment of the photographs where photoscan automatically estimate both the internal and the external camera orientation parameters based on the approximate values derived from the images' EXIF, and camera lens specifications [1]. The estimated orientation parameters were utilised as initialization constraint for parameter refinement during in subsequent processing stream [1].

Prior to 3D reconstruction, the loaded photographs must be aligned. Using the align photos module in Photoscan, relative orientation using photo conjugate points (pass points and tie points) from overlapping photographs. Once the photographs are aligned, the images are ready for 3D geometric reconstruction. The process of 3D model reconstruction involves three steps – generation of dense point cloud, building mesh model and the texture model.

The dense point cloud was generated based on the camera position and orientation derived for each photo. At this stage the images are ready for geometric reconstruction using the control points established on the building façade to georeference the 3D model. Mesh model is formed from point clouds through a surface reconstruction process that usually involves the use of techniques such as Delaunay triangulation, in which a network of triangles is built over the existing vertices of the point cloud [2]. The texture model is formed through a texture mapping process that involves; a mesh partitioning, mesh parameterization, texture transferring, correction and optimization [15].

Accuracy evaluation

Agisoft photoscan enables measurement of direct distances, coordinates, areas and volumes on reconstructed 3D model. Measurement of check point coordinates was done on the reconstructed texture model through markers placed on each point. Coordinates of the twenty-eight check points extracted from the textured models ($X_{m1}, Y_{m1}, Z_{m1}; X_{m2}, Y_{m2}, Z_{m2}$) were compared with their corresponding reference coordinates measured on the building (X_r, Y_r, Z_r) with the Total Station (Table 2) and the accuracy evaluated using Root Mean Square Error (RMSE) obtained using equations (1 – 3) [3].

$$rmsX = \sqrt{\frac{\sum_{i=1}^n (X_{it} - X_{iph})^2}{n}} \quad (1)$$

$$rmsY = \sqrt{\frac{\sum_{i=1}^n (Y_{it} - Y_{iph})^2}{n}} \quad (2)$$

$$rmsZ = \sqrt{\frac{\sum_{i=1}^n (Z_{it} - Z_{iph})^2}{n}} \quad (3)$$

Where:

n is the total number of points; X_{it} , Y_{it} , and Z_{it} are observed/true coordinates of point

i and X_{iph} , Y_{iph} and Z_{iph} are photogrammetric coordinates of point i .

Table 2: Measured and extracted coordinates of check points

No	Reference			NIKON D3200 (Model)			CANON EOS 7D (Model)		
	X_r	Y_r	Z_r	X_{m1}	Y_{m1}	Z_{m1}	X_{m2}	Y_{m2}	Z_{m2}
1	684108.990	939103.740	352.160	684108.991	939103.745	352.168	684108.977	939103.706	352.148
2	684111.790	939103.250	351.750	684111.787	939103.248	351.758	684111.771	939103.266	351.754
3	684112.880	939102.840	351.760	684112.885	939102.836	351.769	684112.878	939102.882	351.767
4	684112.810	939102.630	350.630	684112.808	939102.633	350.636	684112.817	939102.689	350.644
5	684114.400	939102.250	351.500	684114.390	939102.251	351.506	684114.389	939102.310	351.504
6	684115.490	939101.860	351.520	684115.520	939101.857	351.517	684115.518	939101.918	351.518
7	684114.300	939102.030	350.320	684114.298	939102.032	350.318	684114.315	939102.105	350.326
8	684115.430	939101.680	350.320	684115.436	939101.654	350.325	684115.450	939101.712	350.334
9	684118.220	939100.900	353.160	684118.221	939100.902	353.162	684118.215	939100.963	353.149
10	684118.460	939100.820	353.160	684118.464	939100.817	353.159	684118.439	939100.838	353.140
11	684117.850	939101.060	351.580	684117.855	939101.056	351.583	684117.848	939101.097	351.584
12	684116.630	939101.260	350.320	684116.634	939101.237	350.390	684116.649	939101.297	350.397
13	684117.780	939100.850	350.390	684117.780	939100.849	350.395	684117.783	939100.894	350.402
14	684119.160	939100.640	351.670	684119.158	939100.628	351.673	684119.145	939100.654	351.671
15	684120.300	939100.240	351.670	684120.298	939100.245	351.666	684120.296	939100.266	351.665
16	684119.070	939100.410	350.490	684119.073	939100.413	350.479	684119.077	939100.450	350.482
17	684121.470	939099.820	351.620	684121.471	939099.821	351.630	684121.467	939099.824	351.629
18	684122.700	939099.400	351.630	684122.695	939099.412	351.631	684122.704	939099.392	351.628
19	684127.710	939097.430	352.440	684127.714	939097.579	352.444	684127.685	939097.288	352.434
20	684122.780	939099.290	351.170	684122.783	939099.304	351.167	684122.790	939099.289	351.166

21	684123.350	939099.130	351.170	684123.348	939099.127	351.169	684123.367	939099.090	351.171
22	684122.750	939099.220	350.690	684122.755	939099.221	350.687	684122.767	939099.204	350.681
23	684120.810	939100.010	351.280	684120.681	939100.012	351.170	684120.682	939100.026	351.170
24	684121.270	939099.810	351.170	684121.267	939099.813	351.173	684121.274	939099.818	351.175
25	684120.650	939099.860	350.710	684120.650	939099.930	350.709	684120.657	939099.951	350.707
26	684121.240	939099.720	350.710	684121.238	939099.733	350.715	684121.249	939099.741	350.713
27	684118.210	939100.920	352.750	684118.215	939100.910	352.755	684118.192	939100.938	352.739
28	684118.440	939100.830	352.750	684118.456	939100.825	352.752	684118.433	939100.845	352.734

Results and Discussion

Results of the image processing and 3D reconstruction process is presented in Figure 3. Successful alignment of the photographs allowed production dense point cloud (Fig. 3a) through the process of searching and matching of common points on the overlapping images. Search and matching algorithm results to generation of similar points from overlapping or neighbouring photos for accurate photo alignment. Basically, 3D geometric reconstruction is based on the estimated camera positions obtained during photo alignment. Camera parameter estimation for photo alignment is a critical process that requires reasonable level of expertise in image processing because the accuracy of the resulting 3D model depends on the accuracy with which the camera parameters is recovered [14].

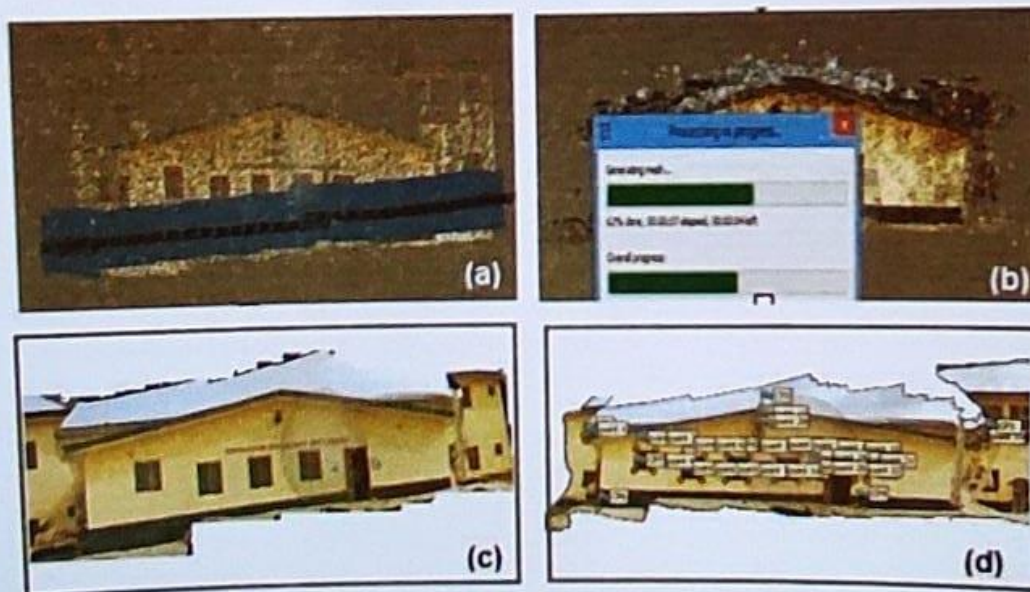


Fig. 3: 3D model reconstruction – Front view of (a) photo alignment and dense point cloud (b) 3D mesh (c) texture model and (d) check points.

Interpolation of the point cloud produced the mesh model (Fig. 3b). Mesh model comprises of connecting triangles linking the point cloud together to form an irregular network of triangles and polygons [20]; [2].

By combining the point cloud and mesh model, texture of the façade attached to each point is applied resulting into the textured model (Fig. 3c), which provides realistic model of the building. The process of transition from the mesh to reality model builds solid surface that replicates the existing visual characteristics of the reality through colour interpolation and redering [15]. This is particularly important for archaeological documentation where detail preservation of the relics are significant culturally and semantically. The performance of the cameras was evaluated using relative measure of the reference points (measured) and derived points from the textured model (Fig. 3d) as presented in Table 3.

Table 3: Comparison of measured (reference) and derived coordinates and their RMSE.

NIKON D3200 (Model 1)						CANON EOS 7D (Model 2)					
Difference in Coordinates			Square of Difference			Difference in Coordinates			Square of Difference		
$X_r - X_{m1}$	$Y_r - Y_{m1}$	$Z_r - Z_{m1}$	$(X_r - X_{m1})^2$	$(Y_r - Y_{m1})^2$	$(Z_r - Z_{m1})^2$	$X_r - X_{m2}$	$Y_r - Y_{m2}$	$Z_r - Z_{m2}$	$(X_r - X_{m2})^2$	$(Y_r - Y_{m2})^2$	$(Z_r - Z_{m2})^2$
-0.001	-0.005	-0.008	0.0000	0.0000	0.0001	0.013	0.034	0.012	0.0002	0.0012	0.0001
0.003	0.002	-0.008	0.0000	0.0000	0.0001	0.019	-0.016	-0.004	0.0004	0.0003	0.0000
-0.005	0.004	-0.009	0.0000	0.0000	0.0001	0.002	-0.042	-0.007	0.0000	0.0018	0.0000
0.002	-0.003	-0.006	0.0000	0.0000	0.0000	-0.007	-0.059	-0.014	0.0000	0.0035	0.0002
0.010	-0.001	-0.006	0.0001	0.0000	0.0000	0.011	-0.060	-0.004	0.0001	0.0036	0.0000
-0.030	0.003	0.003	0.0009	0.0000	0.0000	-0.028	-0.058	0.002	0.0008	0.0034	0.0000
0.002	-0.002	0.002	0.0000	0.0000	0.0000	-0.015	-0.075	-0.006	0.0002	0.0056	0.0000
-0.006	0.026	-0.005	0.0000	0.0007	0.0000	-0.020	-0.032	-0.014	0.0004	0.0010	0.0002
-0.001	-0.002	-0.002	0.0000	0.0000	0.0000	0.005	-0.063	0.011	0.0000	0.0040	0.0001
-0.004	0.003	0.001	0.0000	0.0000	0.0000	0.021	-0.018	0.020	0.0004	0.0003	0.0004
-0.005	0.004	-0.003	0.0000	0.0000	0.0000	0.002	-0.037	-0.004	0.0000	0.0014	0.0000
-0.004	0.023	-0.070	0.0000	0.0005	0.0049	-0.019	-0.037	-0.077	0.0004	0.0014	0.0059
0.000	0.001	-0.005	0.0000	0.0000	0.0000	-0.003	-0.044	-0.012	0.0000	0.0019	0.0001
0.002	0.012	-0.003	0.0000	0.0001	0.0000	0.015	-0.014	-0.001	0.0002	0.0002	0.0000
0.002	-0.005	0.004	0.0000	0.0000	0.0000	0.004	-0.026	0.005	0.0000	0.0007	0.0000
-0.003	-0.003	0.011	0.0000	0.0000	0.0001	-0.007	-0.040	0.008	0.0000	0.0016	0.0001
-0.001	-0.001	-0.010	0.0000	0.0000	0.0001	0.003	-0.004	-0.009	0.0000	0.0000	0.0001
0.005	-0.012	-0.001	0.0000	0.0001	0.0000	-0.004	0.008	0.002	0.0000	0.0001	0.0000
-0.004	-0.149	-0.004	0.0000	0.0222	0.0000	0.025	0.142	0.006	0.0006	0.0202	0.0000
-0.003	-0.014	0.003	0.0000	0.0002	0.0000	-0.010	0.001	0.004	0.0001	0.0000	0.0000
0.002	0.003	0.001	0.0000	0.0000	0.0000	-0.017	0.040	-0.001	0.0003	0.0016	0.0000
-0.005	-0.001	0.003	0.0000	0.0000	0.0000	-0.017	0.016	0.009	0.0003	0.0003	0.0001
0.129	-0.002	0.110	0.0166	0.0000	0.0121	0.128	-0.016	0.110	0.0164	0.0003	0.0121
0.003	-0.003	-0.003	0.0000	0.0000	0.0000	-0.004	-0.008	-0.005	0.0000	0.0001	0.0000
0.000	-0.070	0.001	0.0000	0.0049	0.0000	-0.007	-0.091	0.003	0.0000	0.0083	0.0000
0.002	-0.013	-0.005	0.0000	0.0002	0.0000	-0.009	-0.021	-0.003	0.0001	0.0004	0.0000
-0.005	0.010	-0.005	0.0000	0.0001	0.0000	0.018	-0.018	0.011	0.0003	0.0003	0.0001
-0.016	0.005	-0.002	0.0003	0.0000	0.0000	0.007	-0.015	0.016	0.0000	0.0002	0.0003
Sum of square			0.0182	0.0292	0.0177	Sum of square			0.0215	0.0634	0.0201
RMSE (m)			0.0255	0.0323	0.0251	RMSE (m)			0.0277	0.0476	0.0268
			2.55mm	3.23mm	2.51mm				2.77mm	4.76mm	2.68mm

From Tables 3, it can be seen that both the measured and derived values are very close. The analysis gives xyz RMSE values of 2.55mm, 3.23mm, 2.51mm; and 2.77mm, 4.76mm, 2.68mm, for the NIKON D3200 and CANON EOS 7D camera respectively. The finding has revealed that NIKON D3200 performs better than CANON EOS 7D; however, both cameras have the level of accuracy required for photogrammetric point determination and 3D reconstruction for the purpose of documentation and accurate measurement as observed by [23]. In comparison with the work of [8] in which smart phone camera (Lumia 950 XL with RMSE of 0.27mm, 0.25mm 0.32mm) was investigated, the cameras used in this study has lower accuracy. The reason for this marked discrepancy may be connected to the pixel resolution of the cameras. For instance, Lumia 950 XL has a resolution of 30 megapixel compared to NIKON D3200 and CANON EOS 7D with resolution of 24.2 and 18 megapixel respectively. Nevertheless, we believe that the accuracy of point determination can be improved upon if a more robust camera calibration process is applied.

Conclusion

In this study, we employed Nikon D300 and Canon EOS 7D nonmetric cameras models to reconstruct the first student hostel built on the University of Ilorin main campus to determine the suitability of both cameras for 3D building reconstruction and photogrammetric point determination. Our finding has shown that both cameras have RMSE values between 2.51 mm and 4.76 mm for the xyz component. The study has also revealed that both cameras are suitable for producing acceptable results for photogrammetric applications, however, with NIKON D3200 performing slightly better than Canon EOS 7D model. The authors believe that future studies are necessary to determine the impact a more dynamic camera calibration procedure will have on the accuracy achievable within the close-range observation.

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Declaration of Interest

The Authors declare no known conflict of interest.

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