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Investigation of the Accuracy of Photogrammetric Point Determination Using Amateur/Non-Metric Cameras

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ABSTRACT

With the rapid development in the production of digital cameras and low cost of these amateur cameras, it is important to determine the possibility of using them in digital close-range photogrammetry. The main objective of this work is to investigate the accuracy attainable by using these amateur cameras for point determination, with the accuracy of point determination by total-station instrument as a reference. For this purpose, a building façade was surveyed and processed by photogrammetric and conventional survey methods. The photogrammetric survey was done using four different amateur cameras, and the conventional survey was carried out using total-station. Thirty-seven (37) points within an opened traverse were established on the exterior walls of the structure to serve as standard geo-reference points for all accuracy comparisons and they are referred to as Reference wall points (RWPs). Twenty-eight (28) of these RWPs were used as checkpoints while the other nine (9) points were used as the control points for the models. The 3D coordinates of these reference wall points were then measured with a total-station instrument. After photographs were taken, they were processed with Agisoft PhotoScan photogrammetric software, where different 3D models were constructed for the four set of photographs taken with the amateur cameras. The photogrammetric coordinates of the reference wall points were determined from the respective models. The coordinates measured from each model were then compared with the ones obtained with the total-station to determine their relative discrepancies and accuracies. The accuracy of each model was determined using the Root Mean Square Deviation (RMSD) approach. Based on the type of amateur cameras used, this work has shown that close-range photogrammetric procedure can provide accurate enough result to be used as an alternative

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to measurements by total station in as-built surveys or other relatively small works of similar accuracy requirements.

Keywords**:** Digital close-range photogrammetry, Amateur cameras, RWPs, Point determination, RMSD, 3D models

1. INTRODUCTION

In a general sense, surveying (geomatics) can be regarded as that discipline which encompasses all method for measuring and collecting information about the physical earth and our environment, processing the information, and disseminating a variety of resulting products to a wide range of clients. Photogrammetry falls under one of the classifications of surveying based on the instrument used and has been a very important method of data acquisition for Geographic Information System. Photogrammetry has been dealing with 2D image analysis and direct 3D imaging technology in the last three decades. However recent technical advances toward inexpensive computing power and high-resolution cameras have converged with traditional photogrammetric theory to make photogrammetry a feasible approach for many applications.

Principally, photogrammetry can be divided into aerial photogrammetry and close-range photogrammetry. Terrestrial photogrammetry has in recent years been taken to be close-range photogrammetry although the term also includes laser scanning. Close range photogrammetry (CRP) is the science, art, and technology of obtaining geometric measurements (mapping) of terrestrial objects using photographs taken from a camera that is hand-held or mounted on any terrestrial platform, where the imaging camera can be within 250 meters from the object. Currently, close-range photogrammetry can be applied in many applications like in industry, architecture, car accident reconstruction, aerospace and forensic, etc.

Image acquisition is an important component of close-range photogrammetric work. Measurement with cameras necessitates knowing the characteristics of the camera before using it for a job. Amateur cameras as classified in CRP are those cameras whose orientation elements are unknown as their internal geometry is unstable. Photographing a test field with many control points and at a repeatable fixed distance setting (for example at infinity), a calibration of the camera can be done. In this case, the four corners of the camera frame function as fiducials. However, the precision will never reach that of metric cameras. Therefore, they can only be used for purposes where no high accuracy is demanded.

The major imperfection of amateur cameras is the limited resolution or limited field of view (FOV). However, cameras whose resolution is about 15 megapixels have already been announced. Up-to-date technology is employed for digital image processing. In close-range photogrammetry, charge-coupled device (CCD) cameras are commonly used for surveys of buildings, restoration of architectural monuments, documentation of buildings, reconstruction of the details of traffic accidents, mobile mapping as well as fast and low-cost mapping applications from light aircraft or helicopter. Present-day digital technology can provide non-metric images by using digital amateur cameras that are relatively widely employed in close-range photogrammetry. The development of a low-cost photogrammetric system using an amateur digital camera and smartphone cameras is one of the important tasks for the non-topographic photogrammetry. Now the amateur digital cameras, which have high-resolution sensors, are increasingly expected to contribute to the digital photogrammetry. Currently, the resolution (number of pixels) of amateur cameras has been rapidly increasing. At present, various kinds of amateur digital cameras are now in the market for usage.

This paper investigates the use of amateur cameras for determining the three-dimensional coordinates of points. The work consists of two broad parts. The first part is data acquisition (including the camera calibration), the second part consists of data processing and result generation. In this study, camera calibration (self-calibration) and the point determination are done using the Agisoft Photoscan, a stand-alone software product that performs photogrammetric processing of digital images and generates the 3D spatial data based on the principle of close-range photogrammetry. Finally, the accuracy of the photogrammetric point determination on the building façade is investigated.

2. MATERIALS AND METHODS

The figure below shows the breakdown of the major tasks involved in the study:

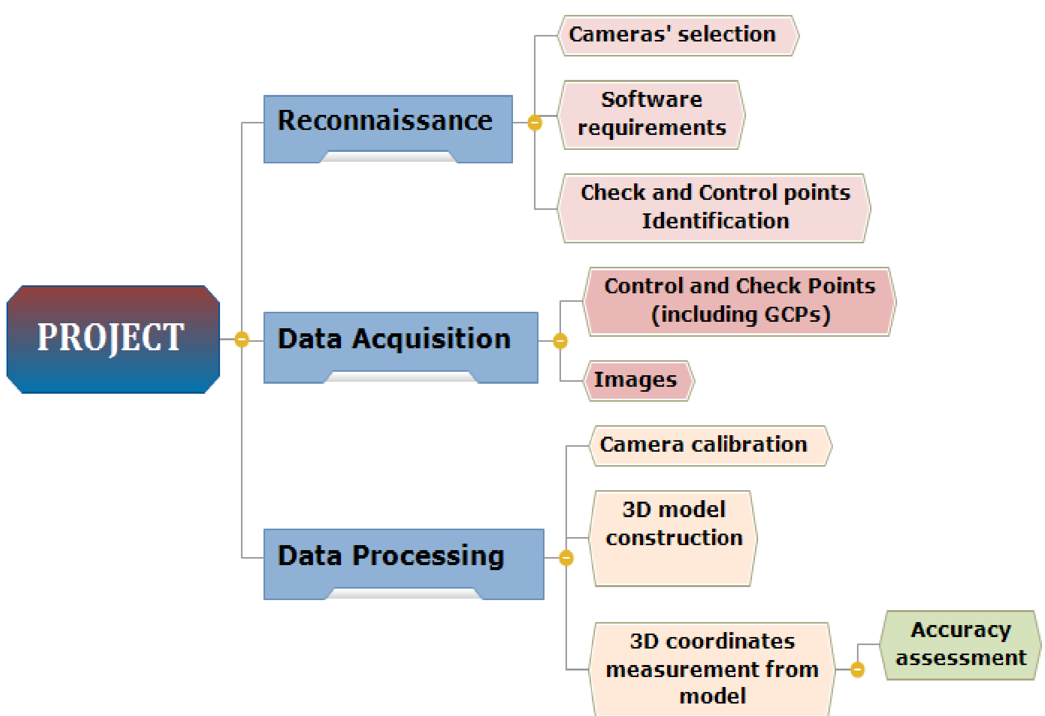

Figure 2.1. Work breakdown structure showing major tasks involved in the work.

2. 1. Reconnaissance

This involves general assessment of the layout of the building, choosing of optimum positions for the photography, choice of photogrammetric software product and cameras, selection of suitable location of control and checkpoints. During planning, what to know about the building was known as well as the best time suitable to capture photographs during sunlight was determined by initially taking information and various test photographs of the building. The check and control points to be used for the work were identified and the site was prepared (clearing the surroundings, etc.) for photography.

2. 2. Data Acquisition

Data acquired for this work is of two types;

- Coordinates of the GCPs and Reference wall points.
- Overlapping Images to cover the building façade.

2. 2. 1. Control and Check Points Acquisition

Ground control points (GCPs) are necessary for photogrammetry to transform the image coordinates into real-world coordinates, i.e., used to establish the position and orientation of the camera at the instant of exposure. For the purpose of this work, ground control points (GCPs) were already available close to the work area so there was no need for Ground control establishment. The three-dimensional coordinates (X, Y, Z) of three ground control points in the vicinity of the work area were obtained from the Department of Surveying and Geo-informatics, Federal University of Technology, Akure, as shown in the table below:

Table 2. 1. Coordinates of the controls used (GPS 2nd-order control points)

POINTS	NORTHINGS	EASTINGS	HEIGHT
G13/05	807729.178	735560.299	378.908
G14/17	808073.707	735557.487	387.661
G14/16	808252.490	735536.015	384.920

Since the accuracy of the model depends on the accuracy of the points used in controlling the solution, it is very important to ascertain the reliability of the field procedures of these control points and the working condition of the Total station instrument. In view of this, in-situ test for the control points was performed.

Model control points were also located on the building so as to orient the 3D model to be constructed for the building to real-world coordinates. These control points should be clearly visible on the photographic images and recorded to approximately the desired final accuracy of the photogrammetry product. The figure below shows the location of the selected points:

The field survey for 37 reference wall points (9 control points and 28 checkpoints) was carried out by conventional surveys using total station where the three-dimensional coordinates (X, Y, Z) of these points were obtained using the of total station instrument (as shown in Figure 2.2 and Figure 2.3 below) in reflector-less mode. The control points were distributed evenly on the building façade to control and reference the model while the checkpoints were also selected on the building façade to be used for investigating the accuracy of the point determination. The points selected were majorly window corners and points on some features on the wall

Figure 2.2. Location of points

Table 2.2. 3D Coordinates of points used to control the model

S/N	Point ID	Northing (m)	Easting (m)	Height (m)
1	CP1	808245.707	735560.910	384.766
2	CP2	808236.238	735569.391	387.493
3	CP3	808232.210	735581.400	384.115
4	CP4	808231.958	735581.689	382.252
5	CP5	808245.872	735561.764	381.177
6	CP6	808244.618	735563.214	383.387
7	CP7	808241.706	735565.973	384.343
8	CP8	808236.604	735569.776	384.428
9	CP9	808237.808	735568.297	381.999

Table 2.3. 3D Coordinates of the Checkpoints used for the investigation

Point ID	Northings (m)	Eastings (m)	Height (m)
P1	808242.758	735565.378	383.878
P2	808242.766	735565.388	382.729
P3	808244.606	735563.221	382.701
P4	808237.433	735568.769	383.976
P5	808235.809	735570.724	383.992
P6	808235.801	735570.731	382.821
P7	808237.416	735568.773	382.803
P8	808235.355	735577.695	384.076
P9	808234.763	735578.281	384.077
P10	808234.766	735578.293	383.43
P11	808235.342	735577.69	383.43
P12	808234.498	735578.858	384.081

P13	808233.863	735579.377	384.075
P14	808233.869	735579.385	383.429
P15	808234.396	735578.741	383.428
P16	808233.511	735579.901	384.117
P17	808232.942	735580.502	384.116
P18	808232.94	735580.512	383.454
P19	808233.478	735579.858	383.444
P20	808232.765	735580.742	384.114
P21	808232.211	735581.4	383.465
P22	808232.768	735580.745	383.459
P23	808242.311	735565.911	383.674
P24	808237.809	735568.295	383.093
P25	808245.861	735561.724	384.513
P26	808242.307	735565.912	382.664
P27	808231.907	735581.656	383.941
P28	808242.321	735565.909	381.509

2. 2. 2. Image acquisition

The increased flexibility provided by CRP is most completely realized in the image acquisition. Because many of the rigors imposed by traditional photogrammetric processing are removed from CRP, almost any person who can take good quality photographs can take the photos necessary for 3D data processing. The images should be obtained using a convergent image pair configuration with an overlap of 80-85%. If multiple image pairs are combined to mosaics, an appropriate overlap between adjacent convergent pairs can be 5-10%. Image acquisition constraints such as maximum camera to object distance, object size, number and distribution of image points should be properly optimized as per work requirement.

For any ideal close range photogrammetric work, the baseline/distance ratio i.e., the distance between two camera positions while taking photographs to the distance between the cameras to the object ratio should be within reasonable limits. It should not be too small. The values of this ratio should be between 1/15 and 1/20. If the building façade is large, then the camera is kept at large distance from the building.

For this study, a total of one hundred and twenty (120) images of the building façade were captured with four different cameras as specified below;

(a) Nikon D40 DSLR camera – 33 images
(b) Kodak EasyShare Z740 camera – 37 images

(c) Gionee marathon M5 camera – 24 images
(d) Infinix Hot4 Lite camera – 26 images.

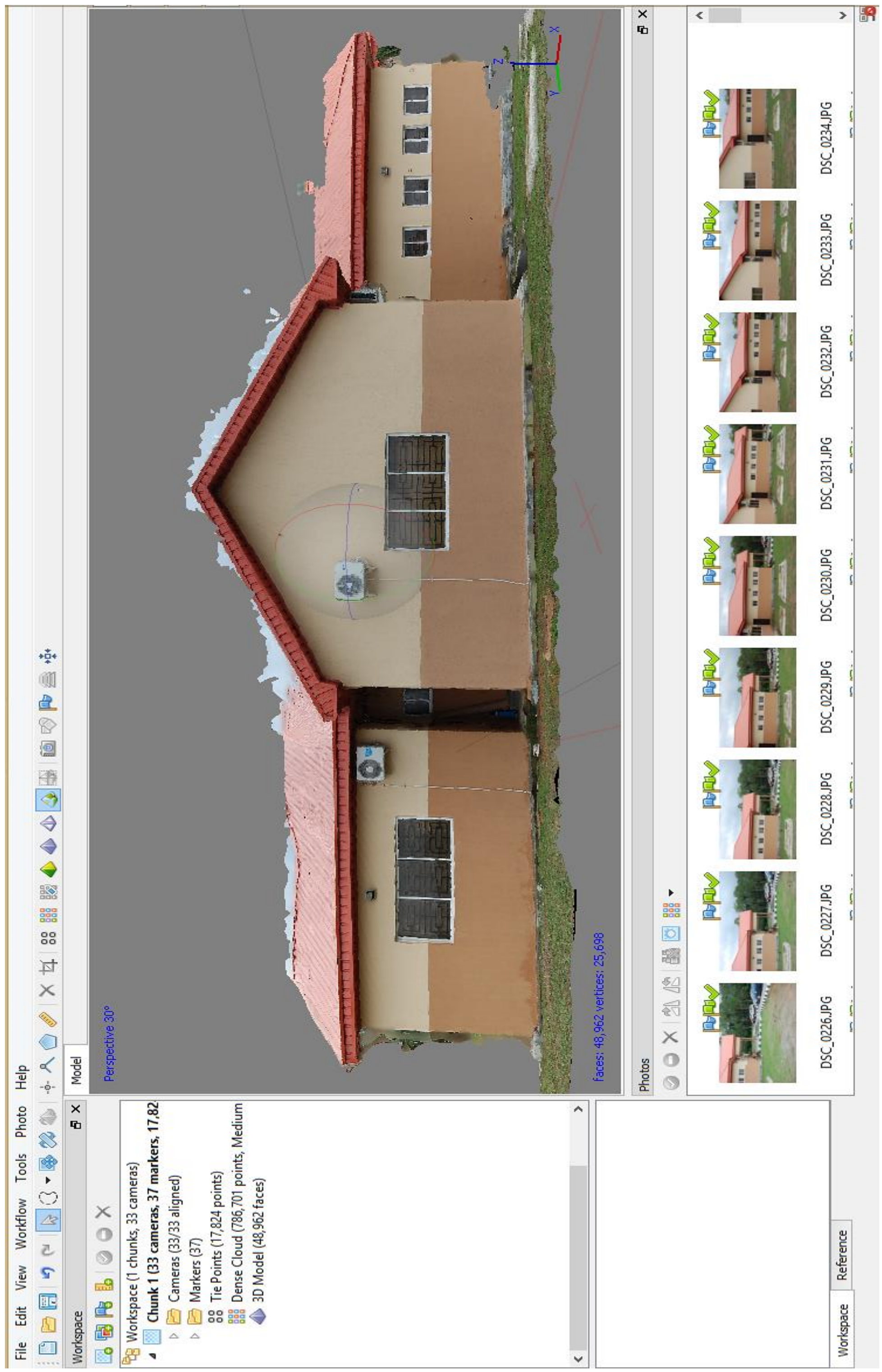

Figure 2.3. Constructed 3D model texture of the building façade

2. 2. 2. 1. Technical specification of the cameras

The table below shows the technical specification of the cameras selected for the study:

Table 2.4. Technical Specifications of the cameras

Camera	Focal Length (mm)	Resolution (Mega-Pixels)	Pixel Array (Width x Height)	Image Sensor size (mm)	Pixel pitch/size (microns)
Nikon D40 DSLR	26.0	6.1	2256 × 1496	17.55 × 11.65	7.78 µm
Kodak EasyShare Z740	6.3	5.0	2576 × 1932	5.75 × 4.32	2.23 µm
Gionee Marathon m5	3.5	13.0	3120 × 4160	4.84 × 6.45	1.55 µm
Infinix Hot4 Lite	3.5	8.0	2448 × 3264	2.74 × 3.66	1.12 µm

2. 3. Data processing

The photogrammetric software package used in processing the acquired images is the *Agisoft PhotoScan Professional, Version 1.3.2.* The operations involved in determining points' coordinates are; Camera calibration. 3D model construction and Model measurement. Agisoft Photoscan performed self-calibration automatically during the Align Photos stage, basing on the initial values derived from the image EXIF, so for the amateur cameras used for the work, pre-calibration was not carried out. The figure below shows one of the constructed 3D models Figure 2.3. Before any measurement in PhotoScan, the 3D model of the building must be constructed. Suitable photos for 3D model construction were selected among the acquired images and loaded into PhotoScan without editing since PhotoScan operates with unmodified photos and four (4) different 3D models for the four cameras used were constructed.

3. RESULTS

The results of this work are the photogrammetric coordinates of twenty-eight (28) points which were measured from the 3D model textures constructed from the images acquired with the amateur cameras (as shown by Figure 3.1), and check measurements from total station were used to evaluate accuracy.

The accuracy of the photogrammetric point determination using the PhotoScan software was then investigated using the Root Mean Square Deviation (RMSD) analysis which measures the difference between values measured from the constructed models (PhotoScan) and values actually observed (with total station) from the building façade that was modelled. These individual differences are also called residuals, and the RMSD serves to aggregate them into a single measure of predictive power. The figure below shows the 3D coordinates measurement table from a constructed 3D model textures:

Figure 3.1. 3D coordinates'measurement from the constructed 3D model

The smaller the value of the RMSD estimate the better the accuracy attainable with the photogrammetric coordinates measured from the constructed 3D model textures and vice versa. The estimates of the RMS spatial residual along the X,Y, and Z directions i.e., Eastings, Northings and Heights respectively were calculated for the four models constructed with PhotoScan.

For this study, *n* (*i* = 1 - 28) check points on the test field (building façade) were used, i.e., points whose true coordinates are known but not used in the photogrammetric processing. Then if *Xit*, *Yit*, and *Zit* are the observed/true coordinates of the checkpoints and *Xiph*, *Yiph* and *Ziph* are photogrammetric coordinates, estimates of the root mean square spatial residual along the X, Y, and Z directions i.e., Eastings, Northings, and Heights respectively are given by the following formulae;

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

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

The Z-direction: $$rmsZ = \sqrt{\frac{\sum_{i=1}^{n}(Z_{it} - Z_{iph})^2}{n}}$$

where:

n is the total number of points;

Xit, Yit, and *Zit* are observed/true coordinates of point ***i***; and

Xiph, *Yiph,* and *Ziph* are photogrammetric coordinates of point *i*.

The table below shows a typical comparison between the obtained results (observed coordinates and photogrammetric coordinates) and its computed Root Mean Square Deviation (RMSD).

Table 3.1. Typical RMSD in X-coordinate for one of the models

Xit	Xiph	(Xit - Xiph)	(Xit - Xiph)^2
735565.378	735565.378	0.000	0.0000
735565.388	735565.401	-0.013	0.0002
735563.221	735563.255	-0.034	0.0011

735568.769	735568.785	-0.016	0.0003
735570.724	735570.735	-0.011	0.0001
735570.731	735570.766	-0.035	0.0012
735568.773	735568.808	-0.035	0.0012
735577.695	735577.588	0.107	0.0114
735578.281	735578.239	0.042	0.0018
735578.293	735578.261	0.032	0.0010
735577.69	735577.631	0.059	0.0035
735578.858	735578.696	0.162	0.0262
735579.377	735579.351	0.026	0.0007
735579.385	735579.372	0.013	0.0002
735578.741	735578.731	0.01	0.0001
735579.901	735579.84	0.061	0.0037
735580.502	735580.499	0.003	0.0000
735580.512	735580.499	0.013	0.0002
735579.858	735579.862	-0.004	0.0000
735580.742	735580.733	0.009	0.0000
735581.4	735581.379	0.021	0.0004
735580.745	735580.756	-0.011	0.0001
735565.911	735565.894	0.017	0.0003
735568.295	735568.29	0.005	0.0000
735561.724	735561.692	0.032	0.0010
735565.912	735565.893	0.019	0.0004
735581.656	735581.68	-0.024	0.0006
735565.909	735565.879	0.03	0.0009

$$rmsX = \sqrt{\frac{\sum_{i=1}^{n}(X_{it} - X_{iph})^2}{n}} = 0.0450\text{m} = 4.50\text{cm}$$

Table 3.2. Accuracy assessment (summary of RMSDs of the Photogrammetric coordinates)

Model (Camera)	***rms*X** (cm)	***rms*Y** (cm)	***rms*Z** (cm)
Model 1 (Nikon D40 DSLR Camera)	± 4.50	± 4.47	± 4.52
Model 2 (Kodak EasyShare Z740 camera)	± 5.76	± 6.23	± 5.00
Model 3 (Gionee M5 marathon camera)	± 4.92	± 6.39	± 8.43
Model 4 (Infinix HOT4 Lite camera)	± 28.59	± 31.74	± 4.98

4. CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

- The accuracy of the model constructed for measuring 3D coordinates of points varies with the camera pixel pitch and resolution. The highest accuracy was achieved with camera having the highest pixel pitch and resolution. The accuracy is much less in case of the model constructed with images of small pixel pitch and resolution. Therefore, the accuracy of the photogrammetric point determination is largely influenced by the resolution and pixel pitch of the images used in the photogrammetric processing.
- Since the best accuracy obtained during this investigation of close-range photogrammetric point determination with amateur cameras was about 5cm, the adoption of this method is a good alternative to traditional survey techniques when accuracies required were greater than 6cm. Based on the accuracy requirement of 0.3ft (~ 9cm) established by the California Department of Transportation as the lowest accuracy for surveys that will be used for engineering design and for GIS products, the application of close-range photogrammetry with amateur cameras (Nikon D40 DSLR and Kodak EasyShare Z740 CCD cameras, Gionee m5 smartphone camera) for as-built surveys and few other engineering works is valid.
- Theoretically, every point of the object should be covered in at least two photographs from different vantage points. However, redundancy in the photographs increases the accuracy of the model. Therefore, more than two photographs per object are recommended.
- Changes in lighting between images may cause problem when aligning the images. The software can compensate for a great deal of difference in brightness between images, but changing the light source location changes the shape of shadows, which can cause difficulties aligning the images.
- Control points which are to be used to reference the model should be distributed evenly over the target object so as to accurately control and reference the model and provide accurate results.

The availability of digital cameras and the increasing capabilities of computers and analytical software have dramatically expanded the variety of resource applications to which photogrammetry may be applied, while simultaneously decreasing the costs of acquisition, processing, and analysis. Close range photogrammetry applications demonstrated using amateur cameras are a powerful tool for gathering full-field 3D coordinate (non-contact) information about an object or test structure and also low cost compared to advanced real-time full-field measurement systems.

References

[1] Dai, Fei, Abbas Rashidi, Ioannis Brilakis, and Patricio Vela, Comparison of Image-Based and Time-of-Flight-Based Technologies for Three-Dimensional Reconstruction of Infrastructure. *Journal of Construction Engineering and Management,* Vol. 139, (2013) 69-79

[2] Dai, Fei, and Ming Lu, Assessing the Accuracy of Applying Photogrammetry to Take Geometric Measurements on Building Products. *Journal of Construction Engineering and Management,* Vol. 136, No. 2 (2010) 242-250

[3] Surendra Pal Singh, Kamal Jain, and V. Ravibabu Mandla, Virtual 3D Campus Modeling by Using Close Range Photogrammetry. *American Journal of Civil Engineering and Architecture* 1, no. 6 (2013): 200-205. doi:10.12691/ajcea-1-6-9

[4] Chapman D.P., Deacon, A.T.D., Hamid, A., HAZMAP: a remote digital measurement system for work in hazardous environments. *Photogrammetric Record,* 14 (83) (1994) 747-758

[5] Grussenmeyer, P, T Landes, T Voegtle, and K. Ringle. Comparison Methods of Terrestrial Laser Scanning, Photogrammetry, and Tacheometry Data for Recording of Cultural Heritage Buildings. *The International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences,* Vol XXXVII, Part B5 (2008) 213-218

[6] Singh, Surendra Pal, Jain, Kamal, Mandla, V. Ravibabu, Image based virtual 3D campus modeling by using CityEngine. *American Journal of Engineering Science and Technology Research*, Vol.2, No.1, (2014) 1-10.

[7] Pottler, K., Lüpfert, E., Johnston, G. H. and Shortis, M. R., Photogrammetry: A powerful tool for geometric analysis of solar concentrators and their components. *Journal of Solar Energy Engineering,* 127(1) (2005) 94-101

[8] Demir, N., Bayram, B., Alkış, Z., Helvaci, C., Çetin, I, Vögtle, T, Ringle, K., Steinle, E., Laser scanning for terrestrial photogrammetry, alternative system or combined with traditional system? *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXV, part B5, (2004) 193-197

[9] Remondino, F. and S. El-Hakim. Image-based 3D modeling: A review. *Photogrammetric Record* 21(115), (2006) 269-291

[10] El-Hakim, S. F., Semi-automatic 3D reconstruction of occluded and unmarked surfaces from widely separated views. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34(5) (2002) 143-148

[11] Sužiedelytė-Visockienė, Jūratė, Renata Bagdžiūnaitė, Naglis Malys, and Vida Maliene, Close-Range Photogrammetry Enables Documentation of Environment-Induced Deformation of Architectural Heritage. *Environmental Engineering and Management Journal*, Vol. 14, No. 6, (2015) 1371-1381

[12] Hanke, K., Oberschneider, M. The Medieval Fortress Kufstein, Austria - An Example for the Restitution and Visualization of Cultural Heritage. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. 34 (5) (2002) 530-533.

[13] Thomas Luhmann, Close range Photogrammetry for Industrial applications. *ISPRS Journal of Photogrammetry and Remote Sensing* 65(6) (2010) 558-569

[14] Waldhäusl P., Ogleby C., 3 x 3 Rules for simple photogrammetric documentation of architecture. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXX, Part 5, (1994) 426-429

[15] Yakar, M, H M Yilmaz, and O Mutluoglu, Close range photogrammetry and robotic total station in volume calculation. *International Journal of the Physical Sciences*, Vol. 5(2) (2010) 86-96

[16] Shashi M. and Jain Kamal, Use of Photogrammetry in 3D modeling and visualization of buildings, Asian Research Publishing Network (ARPN). *Journal of Engineering and Applied Sciences*, Vol. 2, No. 2, (2007) 37-40

[17] Paul E Debevec., et al, Image-based modeling and rendering of architecture with interactive photogrammetry and view-dependent texture mapping, *Proceedings of the IEEE International Symposium on Circuits and Systems*, Vol. 5, (1998) 514-517

[18] Armin Grün, Remondino, F. and Zhang, L., Photogrammetric reconstruction of the Great Buddha of Bamiyan, Afghanistan. *The Photogrammetric Record*, 19(107) (2004) 177-199

[19] Brenner, C., Haala, N., Fast production of virtual reality city models. *International Archives of Photogrammetry and Remote Sensing*, 32(4) (1998) 77-84

[20] Pollefeys M., Koch R., Vergauwen M., Van Gool L., Automated reconstruction of 3D scenes from sequences of images. *ISPRS Journal of Photogrammetry & Remote Sensing*, 55 (2000) 251-267

[21] El-Hakim, S., Brenner, C., Roth, G., An approach to creating virtual environments using range and texture. *International Archives of Photogrammetry and Remote Sensing*. 32(5) (1998) 331-338