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Camera Calibration Performance on Different Non-metric Cameras

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ABSTRACT

In recent years, digital cameras have become one of the tools used by the new generation due to their unique advantages in capturing and processing data and usage in many applications, such as crop growth, forest monitoring and archaeological investigation. The quality of images captured by digital cameras originate from accurate measurements which are allied to the digital internal camera parameters. Instability of geometric cameras require consideration to achieve good accuracy in measurement. Therefore, camera calibration becomes an important task to ensure the stability of all internal camera parameters. This research is aimed to assess the internal camera parameters of non-metric cameras. The quantitative method was adapted by this research, which required an experimental implementation achieve quality in data acquisition. Several camera parameters needed to be emphasised in regard to camera calibration, which consisted of focal length, offset main point, radial lens distortion, and distortion of tangent lenses. The offset main point represents the image centre coordinates while the distortion of tangent lenses ensures image quality during image acquisition. The study found that Nikon SLR D60 camera provided a higher accuracy as compared to DJI 4 pro and iPad

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mini 4 cameras. In conclusion, all non-metric cameras can be used for mapping but it will provide various accuracy levels.

Keywords: Camera, parameter, self-calibration, unmanned aerial vehicle

INTRODUCTION

Currently mapping technique requirements have increased due to the introduction of camera technology for civilians (Tahar & Ahmad, 2012). It is a low-cost camera technology which is affordable by most people (Seul et al., 2015; Vega et al., 2017). The camera is independent and efficient in producing very high resolution of orthogonal-corrected images and 3-dimensional (3D) terrain data (Grenzdörffer et al., 2008). Subsequently, camera technology has grown rapidly from year to year and is widely used for military applications, surveillance, environmental, and agricultural monitoring, as well as urban mapping and others (Hamid & Ahmad, 2014). Camera calibration is an important process due to the accuracy and reliability requirements for 3D information extraction from images (Yusoff et al., 2017). To produce quality images, camera calibration is an important issue that requires consideration to achieve accuracy and precision in measurement (Hamid & Ahmad, 2014).

However, the instability of geometric cameras needs to be considered to ensure image quality during data acquisition. Several parameters, such as focal length, offset main point, radial lens distortion and distortion of tangent lenses require consideration during the camera calibration (Perez et al., 2011). Several techniques for camera calibration are available, but only a small fraction is used for non-metric images (Hamid & Ahmad, 2014). In the last two decades, it has become a major topic for research (Fryskowska et al., 2016), especially on the parameter assessment of high quality internal orientation. Most users simply utilise any camera for mapping without knowing the effect of instability of camera parameters during image acquisition. The main problem with camera calibration process is the internal geometry that exposes many distortions to wide-angle lens (Fryskowska et al., 2016). Users should assess the camera performance to achieve the specific accuracy requirements.

Camera calibration in 3D context is a process determination of internal geometric and optical features of a camera relative to a particular coordinate system (Heikkila et al., 1997). Usually, calibration is implemented by observing the 3D geometry of calibration objects known at high accuracy (Zhang, 1999). Most photogrammetry applications require stable camera parameters for image acquisition. A simple camera calibration is typically used in most studies to obtain a camera parameter value. However, change in internal calibration parameter values used should be considered at different mapping altitudes (Yusoff et al., 2015). Some calibration methods for geometric cameras were presented in previous studies, for example, Heikkila et al. (1997) reviewed a four-step calibration procedure. Weng, (1992) studied on a proposed calibration procedure for major sources of camera distortion. Hamid and Ahmad (2014) presented a method to calibrate high resolution digital cameras based on different configurations, and (Yusoff et al., 2017) calibrated the camera at different camera distances. In the past, cameras used for photogrammetry work were very expensive and only a few were available. At present, many cheaper cameras are used in photogrammetry purposes, especially for close-range photogrammetry. The 3D and 2D measurements require precise camera calibration to correct image distortion in the camera. Typically, geometric errors occur systematically due to non-metric lens quality. Non-metric cameras that are used in mapping need to be preceded by camera calibration because of their instability and unknown internal orientation (Fryskowska et al., 2016).

Therefore, camera calibration needs to be implemented to reduce distortion and avoid the 3D model from being curved. High-precision mappings with low-cost digital cameras require camera calibration (Weng et al., 1992; Yusoff et al., 2015). Camera image and lens parameters are geometric camera calibration features that can be used to correct lens shading, measure the size of object and determine the camera location. Previous studies, such as by Anshari and Cahyono (2011), Tahar and Ahmad (2012) and Yusoff (2015) had mentioned that the calibration process must be completed to improve the camera focus and orientation parameters. Camera calibration and image orientation are the basic requirements for all image metric reconstruction (Remondino et al., 2011). The lens distortion of small consumer grade digital cameras is still an issue (Weng et al., 1992) in terms of accuracy although there have been numerous studies on camera calibration (Yanagi & Chikatsu, 2015). However, camera calibration is important to obtain high accuracy mapping, especially by using low cost cameras (Yusoff et al., 2017).

Most photogrammetric requirements need centimetre Ground Sample Distance (GSD) especially for small areas. Therefore, the quality of camera is very important to achieve accuracy. Non-metric cameras usually use wide-angle lens to provide large scale mapping. Therefore, this study assesses the performance of different non-metric cameras with the potential to be used for image acquisition in photogrammetry purposes, such as DJI 4 pro, Nikon SLR D60 and iPad mini 4 cameras. The aim of this research is to assess the internal non-metric camera parameters. This study will provide a good understanding of the camera calibration procedure.

MATERIALS AND METHODS

The quantitative method was used in this study, to conduct data acquisition and assess the internal parameters of the chosen cameras. The study consisted of four phases. Phase 1 deals with the planning for digital camera selection. Phase 2 addresses the data acquisition by using the DJI 4 Pro, iPad mini 4 and Nikon SLR D60 cameras. Phase 3, which is the most important part, deals with data processing. Finally, phase 4 presents the results and data interpretations (Figure 1). The research on camera calibration was conducted on DJI 4 Pro camera, iPad mini 4 and SLR digital cameras by using the self-calibration method. The process was performed in a laboratory that was equipped with sufficient lighting. Grid calibration paper was used to capture images as objects and the camera calibration was performed by using the PhotoModeler software.

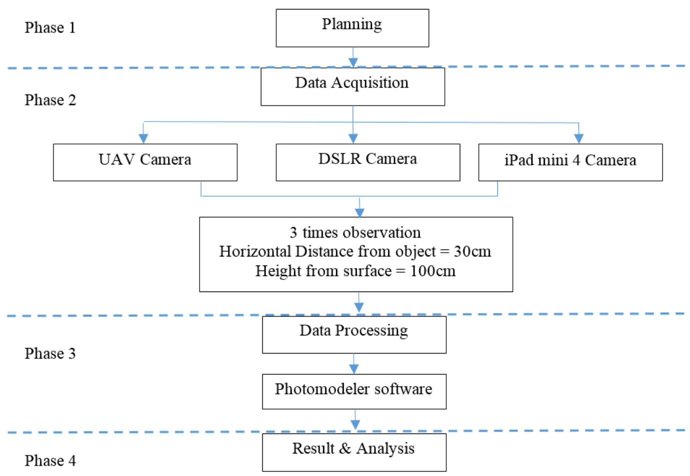

Figure 1. Methodology process

Planning: Digital Camera Specification

Phase 1 is the planning process that defines the types of camera and calibration used. This study is aimed at assessing the internal geometries of DSLR and digital UAV digital cameras. The UAV camera uses a 1" CMOS (complementary metal-oxide semiconductor) sensor with effective 20-megapixel resolution and a 13.2mm x 8.8mm sensor size, while the DSLR digital camera has a 10-megapixel resolution with the CCD (charge-coupled device) format and 23.60mm x 15.80mm of sensor size. The iPad mini 4's digital camera has 64 GB storage with a LED multi-touch display and the screen resolution is 326ppi. Figure 2 presents the digital cameras that were used for camera calibration.

(a) (b) (c)

Figure 2. Digital camera (a) UAV camera (b) Nikon SLR D60 camera (c) iPad mini 4

Data Acquisition

Self-calibration was used to perform the camera calibration to determine the internal camera parameters. This study used printed calibration grid from the PhotoModeler software which was adjusted with the calibration point. The calibration point is a standard form that can be printed on a piece of paper by using a certain size. The calibration grid was used to perform the camera calibration process by placing it on the floor. Three sets of image acquisition were applied in this study. The camera distance and altitude were also set based on the size of the calibration grid paper. The studied digital camera was mounted on a tripod to avoid shaking and imbalance during image capture. In this calibration, eight (8) photographs of the calibration grid were acquired from four (4) camera positions as shown in Figure 3.

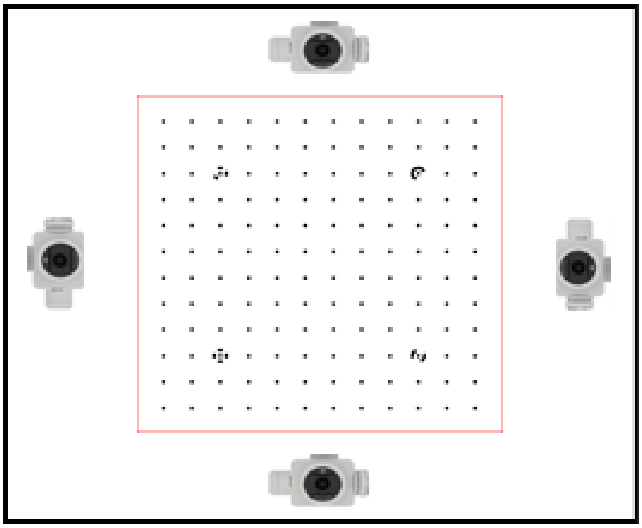

Figure 3. Camera position during image acquisition.

In all camera positions, the calibration grid image was taken at a landscape position of 0º and at a portrait position of 90º. Eight (8) images of the calibration grid were captured, where four (4) images were in landscape position and another four (4) images were in portrait position. All images captured on the UAV, iPad mini 4 and DSLR cameras used the calibration grid for both the landscape and portrait positions. Figure 4 shows the camera position during the image capture for the camera calibration.

Data Processing

The PhotoModeler software was used to process images for camera calibration. This software includes a camera calibration function which helps to specify information on the camera, such as focal length, lens distortion and principal point (PhotoModeler software).

(a) (b) (c)

Figure 4. Camera calibration (a) DSLR digital camera (b) UAV camera (c) iPad camera

All captured images were imported into the PhotoModeler software by using the *'Add Photo'* function. The images were automatically transferred to the software. The next process was to run the images since all the images were taken under sufficient coverage, as required by the PhotoModeler software for the calibration. All internal camera parameters appeared when the camera calibration was successfully completed.

RESULTS AND DISCUSSION

Measurements were taken by using different non-metric cameras (Nikon SLR D60, iPad mini 4 and DJI 4 Pro) with different resolutions. After image processing, the internal camera parameters, such as focal length, radial lens distortion, decentering lens distortion and principal point were obtained from the software. The total final error was also checked to identify the camera calibration accuracy. According to the general guidelines for PhotoModeler, a good calibration should have a total error of below 1.0, and a normal high quality task would have a maximum residual of below 1.0 pixel (www.photomodeler.com). The parameter values were obtained from the camera calibration process and three observations were set up for each camera, as tabulated in Table 1 for DJI 4 Pro, Table 2 for Nikon SLR D60 camera and Table 3 for iPad camera.

All cameras were given different focal lengths and perspective views. Focal length describes the angle of view of a scene which will be captured. Data for the internal parameter values were obtained three times based on the camera positions at a height of 100cm and 30cm distance from the object. The results for different types of camera showed a slight difference in the three observations.

Based on the results, the iPad camera had a wider view angle, followed by DJI 4 Pro and Nikon SLR cameras. This indicated that the iPad camera was appropriate to capture short distance images at low altitudes.

Table 1

Internal Parameter Values (mm) for DJI 4 Pro Camera

Items	Parameter values (1)	Parameter values (2)	Parameter values (3)
f	10.0387	10.0191	10.0171
X	6.6768	6.6841	6.6671
Y	4.9694	4.9692	4.9697
K_1	-1.305e-004	-1.122e-004	-1.528e-004
K_2	8.720e-007	8.965e-007	8.656e-006
K_3	0.000e+000	0.000e+000	0.000e+000
P_1	-2.721e-004	-3.024e-004	-2.992e-004
P_2	0.000e+000	0.000e+000	0.000e+000

Table 2

Internal Parameter Values (mm) for Nikon SLR Camera

Items	Parameter values (1)	Parameter values (2)	Parameter values (3)
f	43.2456	43.1236	43.1742
X	11.8961	11.8607	11.8255
Y	8.0290	8.0252	8.0738
K_1	-1.175005	-9.571e-006	-7.948e-006
K_2	3.425e-008	2.711e-008	2.460e-008
K_3	0.000e+000	0.000e+000	0.000e+000
P_1	1.026e-005	1.511e-005	2.142e-005
P_2	1.325e-005	1.401e-005	2.089e-005

Table 3

Internal Parameter Values (mm) iPad mini 4 Camera

Items	Parameter values (1)	Parameter values (2)	Parameter values (3)
f	3.4607	3.4748	3.4805
X	1.9390	1.9360	1.9321
Y	1.4497	1.4508	1.4489
K_1	-1.031e-002	-1.115e-002	-1.029e-002
K_2	1.462e-003	2.071e-003	2.020e-003
K_3	0.000e+000	0.000e+000	0.000e+000
P_1	-1.875e-004	-1.446e-004	-1.754e-004
P_2	1.335e-004	7.980e-005	1.200e-004

The average root-mean-square-error (RMSE) values in the three observations were quite different, as shown in Figure 5. From the results, it was found that the overall root mean square (RMS) result was significantly different between the three types of cameras. DJI 4 Pro camera recorded the largest reading for overall average RMSE as compared to the SLR and iPad cameras. However, the overall RMSE met the requirements for camera calibration by using the PhotoModeler software. Errors are usually caused by the image matching algorithm used in the software during image capturing and processing. The results showed that DJI 4 pro and iPad cameras recorded an RMS of between 0.15 and 0.25 while Nikon SLR D60 camera recorded an RMS of between 0.05 and 0.1. In fact, the results also had slight differences among these three calibration sets.

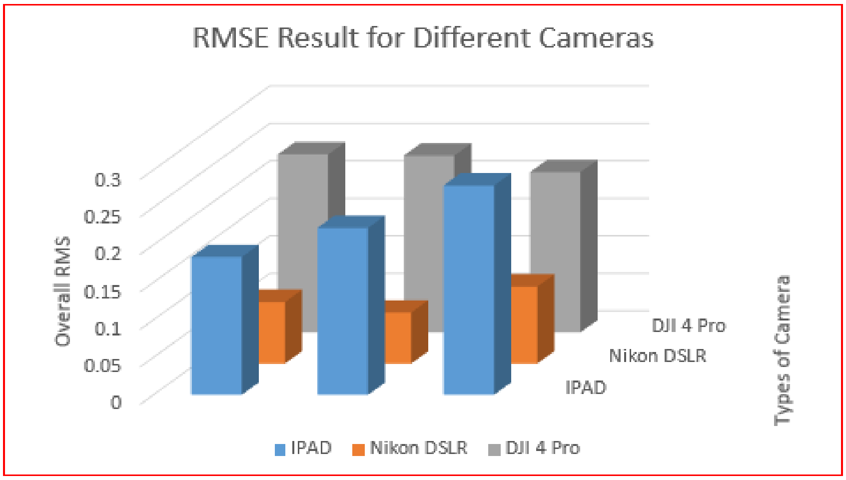

Figure 5. Overall RMSE result for different cameras with three times observation

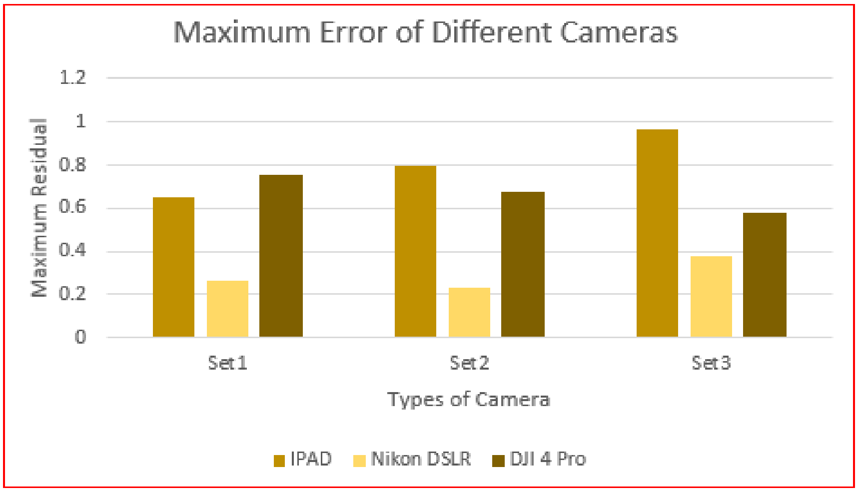

Figure 6. Result of maximum residual for both cameras

The camera calibration results were based on the total final error. Figure 6 presents the differences in the types of camera used. Nikon SLR D60 provided better residual standard error as compared to the DJI 4 Pro and iPad cameras. The maximum residual result for Nikon SLR D60 was 0.2887, while DJI 4 Pro and iPad were 0.6687 and 0.8064, respectively. The maximum residual values of three digital cameras were verified following the standard requirements for camera calibration.

CONCLUSION AND RECOMMENDATIONS

Based on this research, all types of digital camera used met the PhotoModeler software requirements for camera calibration purposes since the results showed that all of the digital cameras obtained a maximum residual of below 1.0 pixel. However, the residual of Nikon SLR D60 was very small as compared to the residuals of the DJI 4 Pro and iPad cameras. Various camera distances should be applied to achieve good mapping accuracy. This study proved that the tested non-metric cameras were acceptable for photogrammetric purposes provided that it must be calibrated before image acquisition. It is recommended that for future study the camera calibration can also be performed by using field calibration to determine the ideal internal camera parameters.

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