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Calibration of high resolution digital camera based on different photogrammetric methods

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Abstract. This paper presents method of calibrating high-resolution digital camera based on different configuration which comprised of stereo and convergent. Both methods are performed in the laboratory and in the field calibration. Laboratory calibration is based on a 3D test field where a calibration plate of dimension 0.4m x 0.4m with grid of targets at different height is used. For field calibration, it uses the same concept of 3D test field which comprised of 81 target points located on a flat ground and the dimension is 9m x 9m. In this study, a non-metric high resolution digital camera called Canon Power Shot SX230 HS was calibrated in the laboratory and in the field using different configuration for data acquisition. The aim of the calibration is to investigate the behavior of the internal digital camera whether all the digital camera parameters such as focal length, principal point and other parameters remain the same or vice-versa. In the laboratory, a scale bar is placed in the test field for scaling the image and approximate coordinates were used for calibration process. Similar method is utilized in the field calibration. For both test fields, the digital images were acquired within short period using stereo and convergent configuration. For field calibration, aerial digital images were acquired using unmanned aerial vehicle (UAV) system. All the images were processed using photogrammetric calibration software. Different calibration results were obtained for both laboratory and field calibrations. The accuracy of the results is evaluated based on standard deviation. In general, for photogrammetric applications and other applications the digital camera must be calibrated for obtaining accurate measurement or results. The best method of calibration depends on the type of applications. Finally, for most applications the digital camera is calibrated on site, hence, field calibration is the best method of calibration and could be employed for obtaining accurate measurement.

Introduction

Digital camera calibration becomes essential to achieve the precision of the measurement task. However, when talk about non-metric digital camera, there are consideration must be aware the internal especially geometry camera instability. Camera parameters usually could be recovered through camera calibration process which comprised of focal length (c), principal point offset (x_p, y_p) which represent the coordinates of the center of the image, radial lens distortion (k_1, k_2, k_3) and tangential lens distortion (p_1, p_2). Nowadays, various techniques of camera calibration were introduced several years ago as new flexible technique [1], targetless [2], multi-camera [3-4], automatic approach [5], simple calibration [6], on-the-job calibration [7-8], self-calibration [8-11] and so on but there are not many calibration techniques in which the images taken using UAV system.

The technology development of UAV has increased and improved from year to year. Nowadays, there are hundreds of UAV operate by military and civil applications. The operation of UAVs are combined with the development of high hardware technology has opened the opportunities of UAV to explore many activities across different fields such as military operation, surveillance, environmental monitoring, agriculture operation, aerial photography, mapping, scientific research and so on.

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Practically, these UAVs are equipped with devices such as camera, sensors, communication tools and other payloads to perform certain activity. The UAVs have several advantages such as low cost operation, simple manipulation, high resolution, flexibility and others. According to [13], the advantages in developing the technology of UAV for low altitude photogrammetric mapping are to perform aerial photography at cloudy day, to get full image of object from the top, and to supply a low cost and easy system for high frequency needs of aerial photogrammetric survey. UAV system is not limited by human on aircraft for data collection in dangerous or hazardous environment without risk of pilot. Therefore, the aim of this study is the establishment of an efficient and accurate digital camera calibration method using Hexacopter UAV (rotary wing) to be used in our future photogrammetric application or other application.

Materials and Procedures

1.1. High Resolution Digital Camera

The high resolution digital camera used in this study is Canon Power Shot SX230HS (see Figure 1). The specification of Canon Power Shot 230HS digital camera such as image dimension – 4000 x 2248, focal length – approx. 5mm, pixel resolution – approx.. 12.8 megapixels, shutter speed – 15-1/3200 sec (total shutter speed range) and weight 223g (including the battery and memory card). This type of digital camera suitable for low cost photogrammetric methods.

1.2. The Unmanned Aerial Vehicle

The UAV used in this study is Hexacopter UAV as shown in Figure 1. It has the ability for automatic height control, take-off and landing with autonomous and manual control, provide automatic stabilizer and autonomous way point navigation using MikroKopter Tool, with GPS antenna, altimeter and magnetometer to calculate the position coordinates during flight.

Figure 1. Hexacopter UAV attached with digital camera Canon PowerShot SX230 HS.

1.3. Digital Camera Calibration Method

In this study, two camera calibration methods are used. The first method is a lab calibration which comprise of 3D calibration plate with a dimension of 0.4 x 0.4 meter (Fig. 2). A bar scale of length 553 mm is used too. A second camera calibration is performed on the field where the 3D test field was used with a dimension of 9 x 9 meter (Fig. 3). This test field comprised of 81 wooden pegs located into the ground. The size of each wooden peg is 2 x 3 inches. All the wooden pegs are at different height and the 3D coordinates of these wooden pegs were determined using close traverse. Three (3) scale bars were used where the length of 332 mm, 582 mm, and 1178 mm. Calibration site was built near the Faculty Geoinformation and Real Estate (FGRE), Universiti Teknologi Malaysia. An image processing was used for both laboratory and field calibration.

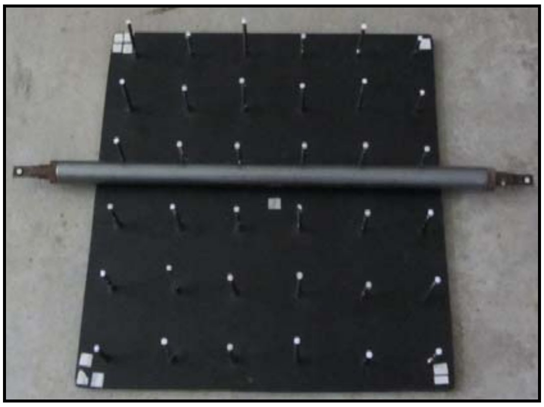

Figure 2. 3D calibration plate of 0.4 x 0.4 meter.

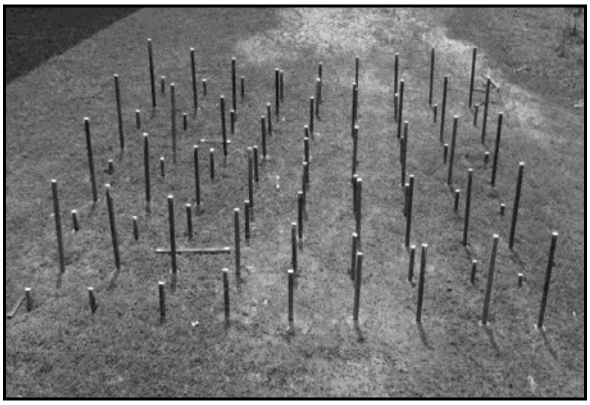

Figure 3. 3D test field with dimension of 9 x 9 meter.

1.3.1. Laboratory Calibration

A digital camera was setup at different configurations (convergent, generic network and stereo) and different heights at 80cm, 100cm and 120cm. All camera configurations, images of calibration plate were taken at each position in landscape position of 0 degree and in portrait position of 90 degrees. The light rays from the camera station are pointing towards center of calibration plate. For convergent and stereo configuration, eight (8) images were taken from four (4) stations around the calibration plate while for generic network configuration sixteen (16) images were taken from eight (8) stations around the calibration plate at different height per dataset. After images of the calibration plate were acquired, these images were downloaded into a computer for data processing and analyzed using photogrammetric calibration software. As standard procedure of camera calibration, the results comprised of eight (8) camera calibration parameters which include focal length (c), principal point (x_p, y_p), radial distortions (k_1, k_2, k_3) and tangential distortions (p_1, p_2).

1.3.2. Field Calibration

Field camera calibration site is located near the Faculty of Geoinformation and Real Estate (FGRE), Universiti Teknologi Malaysia (UTM). To develop the field calibration, as mentioned in Section 2.3, the test field area has dimension of 9 x 9 m and 81 target points. Each target is determined based on close traverse around the test field using a total station for determination of 3D coordinates. Image acquisition is divided into two parts based on convergent and stereo configuration. For the convergent case, the UAV was flown at the height of approximately 5 m while for the flying height is stereo 20 m. The UAV was flown manually, due to the test field is near to the building. A total of 32 images for camera configuration in convergent and 28 images of the stereo camera configuration were acquired. Eight (8) images per camera configuration were chosen for image processing. The field calibration process was performed similar to laboratory calibration. For future photogrammetric application, the field calibration should be employed so that accurate results could be achieved.

Results and Discussion

In this section, the results of measurement for different camera configuration setup, camera elevation and different calibration methods which are laboratory calibration and field calibration are briefly discussed. After the image processing, camera calibration parameters were obtained from the camera calibration software which utilizes self-calibration bundle adjustment. The results for the different camera setup, different camera elevation and different methods are tabulated in the following sections.

1.4. Camera Configuration Setup versus Camera Elevation

Table 1, 2 and 3 show the mean and standard deviation for the camera calibration parameters for the three (3) camera configurations and three (3) camera elevations respectively. The results of camera calibration which utilized camera configuration setup at the position of 80 cm height (table 1) showed that the lowest standard deviation for focal length is ±0.00567mm achieved by the generic network configuration. While the lowest and best standard deviation of x_p and y_p, is ±0.005612mm and ±0.005497mm respectively for generic network configuration. For the rest of camera calibration parameters, the standard deviations are very small and close to one another. For the case of stereo camera configuration for every camera elevation, the photogrammetric calibration software failed to process the image due to weak geometry which means the results depend on the configuration position of the camera and the angle between the cameras. The smaller the angle, the less will be the accuracy of the result. On the other hand, for aerial photogrammetry normally height-base ratio A/B, is employed. Based on this configuration, the higher accuracy could be achieved when the intersection angle is near 90˚ and also other constraints must be considered.

Table 1. Camera calibration parameters for camera configuration setup at 80 cm height.

Camera Calibration Parameters	Camera Configuration Setup at 80cm Elevation					
	Convergent (Mean)	Std. Dev.	Generic Network (Mean)	Std. Dev.	Stereo (Mean)	Std. Dev.
c (mm)	5.104800	0.015185	5.099660	0.005668	Failed	Failed
x_p (mm)	-0.039780	0.008704	-0.040620	0.005612	Failed	Failed
y_p (mm)	-0.019120	0.011944	-0.023320	0.005497	Failed	Failed
k_1	0.001637	0.000310	0.001795	0.000264	Failed	Failed
k_2	-0.000109	0.000224	-0.000179	0.000390	Failed	Failed
k_3	0.000026	0.000031	0.000030	0.000248	Failed	Failed
p_1	0.000531	0.000115	0.000500	0.000041	Failed	Failed
p_2	0.000559	0.000151	0.000615	0.000065	Failed	Failed

Table 2. Camera calibration parameters for camera configuration setup at 100 cm height.

Camera Calibration Parameters	Camera Configuration Setup at 80cm Elevation					
	Convergent (Mean)	Std. Dev.	Generic Network (Mean)	Std. Dev.	Stereo (Mean)	Std. Dev.
c (mm)	5.095780	0.006751	5.098560	0.006838	Failed	Failed
xp (mm)	-0.055080	0.005864	-0.044420	0.003905	Failed	Failed
yp (mm)	-0.026080	0.006116	-0.022220	0.004072	Failed	Failed
k_1	0.001981	0.001103	0.002251	0.000264	Failed	Failed
k_2	-0.000429	0.001157	-0.000450	0.000175	Failed	Failed
k_3	0.000119	0.000350	0.000074	0.000029	Failed	Failed
p_1	0.000680	0.000065	0.000546	0.000052	Failed	Failed
p_2	0.000602	0.000095	0.000554	0.000041	Failed	Failed

The results of camera calibration which utilizes camera configuration setup at the position of 100cm height are shown in table 2. In this table, the lowest standard deviation for focal length is ±0.006751mm achieved by the convergent configuration. While for the principal point offset coordinates x_p and y_p, is ±0.003905mm and ±0.004072mm respectively for generic network configuration. For the remaining results of camera calibration, the differences in standard deviation are small.

In table 3 shows the results of camera calibration which utilizes camera configuration setup at the position of 120cm height. The performance of generic network configuration is still better than other camera configuration where the standard deviation for focal length is ±0.006694mm. While, for the principal point offset coordinates x_p and y_p is ±0.011368mm and ±0.004021mm respectively which are better than convergent configuration. Once again the camera calibration results indicate that generic network configuration is the most efficient camera configuration for camera calibration.

Table 3. Camera calibration parameters for camera configuration setup at 120 cm height.

Camera Calibration Parameters	Camera Configuration Setup at 120 cm Elevation					
	Convergent (Mean)	Std. Dev.	Generic Network (Mean)	Std. Dev.	Stereo (Mean)	Std. Dev.
c (mm)	5.107440	0.011803	5.104560	0.006694	Failed	Failed
xp (mm)	-0.045920	0.016438	-0.046020	0.011368	Failed	Failed
yp (mm)	-0.008180	0.007599	-0.008960	0.004021	Failed	Failed
k_1	0.002212	0.000430	0.002203	0.000180	Failed	Failed
k_2	-0.000441	0.000280	-0.000581	0.000182	Failed	Failed
k_3	0.000037	0.000113	0.000117	0.000051	Failed	Failed
p_1	0.000580	0.000141	0.000614	0.000111	Failed	Failed
p_2	0.000395	0.000112	0.000404	0.000051	Failed	Failed

1.5. Laboratory Calibration versus Field Calibration

Table 4 shows the camera calibration parameters and final standard error for laboratory calibration and field calibration. The results of the laboratory calibration and field calibration showed slight different of total standard error for both methods. Similarly, for radial lens distortion and tangential lens distortion the standard error for both methods showed slight different. Based on the results of both methods, the field camera calibration method is reliable and useful calibrating non-metric digital camera.

Table 4. Camera calibration parameters for laboratory calibration and field calibration.

Camera Calibration Parameter	Two Camera Calibration Methods			
	Lab Calibration	Final Standard Error	Field Calibration	Final Standard Error
c (mm)	5.094700	6.894e-003	5.115900	1.066e-002
xp (mm)	-0.034600	5.997e-003	-0.028200	9.176e-003
yp (mm)	-0.020000	5.470e-003	-0.026200	1.317e-002
k_1	0.001902	4.666e-004	0.001392	9.189e-005
k_2	-0.000510	4.164e-004	0.000016	1.850e-005
k_3	0.000137	1.040e-004	-0.000003	1.145e-006
p_1	0.000464	9.747e-005	0.000550	9.641e-005
p_2	0.000566	1.295e-004	0.000512	8.528e-005

Conclusion

In photogrammetric application especially for close range photogrammetry, both convergent and generic network configurations are widely used. In general, it is found that the standard deviation of focal length improve well as the height increases. For the other camera calibration parameters, the standard deviations are very small, minimum and close to zero value. For generic network configuration, it produces better result compared to convergent configuration with reference to the standard deviation of focal length as shown in Table 3. The results also showed that as the height of the camera increases the standard deviation decreases as shown in Table 1, 2 and 3. For stereo configuration, the result showed that this configuration are not suitable for camera calibration.

In this study, it is clearly shown that the field calibration has the advantage that the images were taken under similar conditions to the images taken using UAV. The field calibration has proved be very efficient and provides accurate results for the purpose of camera calibration. Finally, the field calibration must be employed for obtaining good measurement and results. This method could be employed for diversified application such as engineering, archaeology, architecture, medical, environmental, cultural heritage and exacta.

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