DIGITAL CAMERA CALIBRATION USING IMAGES TAKEN FROM AN UNMANNED AERIAL VEHICLE

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ABSTRACT:

For calibrating the camera, an accurate determination of the interior orientation parameters is needed. For more accurate results, the calibration images should be taken under conditions that are similar to the field samples.
The aim of this work is the establishment of an efficient and accurate digital camera calibration method to be used in particular working conditions, as it can be found with our UAV (Unmanned Aerial Vehicle) photogrammetric projects.
The UAV used in this work was md4-200 modelled by Microdrones. The microdrone is also equipped with a standard digital non-metric camera, the Pentax Optio A40 camera. To find out the interior orientation parameters of the digital camera, two calibration methods were done. A lab calibration based on a flat pattern and a field calibration were fulfilled. To carry out the calibration, Photomodeler Scanner software was used in both cases. The lab calibration process was completely automatic using a calibration grid. The focal length was fixed at widest angle and the network included a total of twelve images with ± 90º roll angles. In order to develop the field calibration, a flight plan was programmed including a total of twelve images. In the same way as in the lab calibration, the focal length was fixed at widest angle. The field test used in the study was a flat surface located on the University of Almería campus and a set of 67 target points were placed. The calibration field area was 25 x 25 m approximately and the altitude flight over ground was 50 m. After the software processing, the camera calibration parameter values were obtained. The paper presents the process, the results and the accuracy of these calibration methods. The field calibration method reduced the final total error obtained in the previous lab calibration. Furthermore the overall RMSs obtained from both methods are similar. Therefore we will apply the field calibration results to all our photogrammetric projects in which the flight high will be close to 50 m.

KURZFASSUNG:

Kamerakalibrierung bezeichnet ein Verfahren, welche die Parameter einer Kamera bestimmen. Die Bilder müssen unter den gleichen Bedingungen wie auf den Feldproben gemacht werden.
Das Ziel des Beitrags ist es, eine benötigte Methodologie für Kamerakalibrierung mit UAV Photogrammetrie zu erreichen.
Das UAV-System für die Untersuchungen wurde md4-200 bei Microdrones erfunden. Die md4-200 ist mit einer Kompaktkamera, einer Pentax Optio A40 Digitalkamera, ausgestattet. Zwei Kamerakalibrierungsmethoden sind gemacht worden, um die inneren Kamera Parameter kennen zu können. Eine Laborkalibrierung mit einem Testfeld und eine Testfeldkalibrierung sind ausgerichtet worden. Photomodeler Scanner software ist für die Kamerakalibrierungsprozesse in beiden Test ausgewählt worden. Der Laborkalibrierungsprozess war vollautomatish. Die Bilder sind mit längerer Brennweite gemacht worden. Die Bilder des Testfeldes werden von vier Standpunkten aus aufgenommen, einmal als Querformat und jeweils einmal als Hochformat um 90° und um 270° gekantet. Zwölf Bilder sind gemacht worden. Um eine Testfeldkalibrierung zu entwickeln, mussten wir einen UAV-Flug mit zwölf Bildern planen. Ebenso wie mit der Laborkalibrierung, sind die Bilder mit längerer Brennweite gemacht worden. Für diese Analysen wurde ein Testfeld mit 67 Targets am Campus der Universität Almeria angelegt. Das Feldareal war etwa 25 x 25 m und die Flughöhe über dem Erdboden war 50 m. Die Parameter von der Kamera sind durch Photomodeler Scanner Sottware erreich worden. Der Beitrag stellt den Prozess, die Ergebnisse und die Genauigkeit von den Kalibrierungsmethoden vor. Nach der Durchführung der Erfassung der Kamerakalibrierung und der Auswertung der Ergebnisse kann man sagen, dass die Testfeldkalibrierung für die Aufgabe der Kamerakalibrierung geeignet ist und die Genauigkeit ist gut für UAV Photogrammetrie.

1. INTRODUCTION

Recent increase in the using of digital cameras for photogrammetric purposes is encouraged to calibrate it. An accurate determination of the camera's interior and exterior orientation parameters is needed for calibrating a camera. Many calibrating techniques have been developed in the last few years: Mason et al. (1997), Karras and Mavrommati (2001), Honkavaara et al. (2006), Remondino and Fraser, (2006), Douskos et al. (2007), Grammatikopoulos et al. (2007), Wang et al. (2008), Zhang et al. (2010) and others, but there are not many calibration techniques in which the images are taken from UAVs. Also in Clarke and Fryer (1998) can be found a review of some calibration methods.
Camera parameters commonly discovered through calibration procedures include the computed principal distance or focal length *(f)* of the lens, parameters $(x_p, y_p,)$ which denote the coordinates of the center of projection of the image (principal point), and lens distortion coefficients *(k1, k2, k3, p1, p2)* where the terms *ki* represent coefficients of radial lens distortion and *pi*

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terms represent coefficients of decentering distortion caused by a lack of centering of lens elements (William, 2004). Radial and decentring distorsions comprise the aberrations which affect the location of images (Fryer, 1996).

A common criticism with small format aerial photography is the camera’s geometric instability and limited precision and accuracy (Warner and Carson 1991). This criticism becomes even more significant with digital cameras and their low-cost lenses. Often, it is impossible to obtain data about the interior orientation of the camera; thus, alternative camera calibration methods have been suggested (Zhang 2000). The success of digital camera calibration establishes the prerequisite and foundation for digital close-range photogrammetry and 3D modelling (Zhang et al. 2010).

The main advantage of an Unmanned Aerial Vehicle (UAV) system acting as a photogrammetric sensor platform over more traditional manned airborne or terrestrial surveys is the high flexibility that allows image acquisition from unconventional viewpoints (Irschara et al. 2010).

The aim of this work is the establishment of an efficient and accurate digital camera calibration method to be used in particular working conditions, as it can be found with our UAV photogrammetric projects.

2. MATERIALS AND METHODS

2.1 The Unmanned Aerial Vehicle

The UAV used in this work was the md4-200 (Microdrones) (www.microdrones.com) (see Fig. 1). It has the ability for vertical take off and landing with autonomous and semiautonomous control capacities, provides position hold and autonomous way-point navigation, with GPS antenna, altimeter and magnetometer to calculate the position coordinates during the flight.

Figure 1. The md4-200 with the digital camera Pentax Optio A40

The drone is also equipped with a CCD standard digital non-metric camera, the Pentax Optio A40 camera, that can be tilted (up to 90º) to capture images from different angles. This camera has 12.0 mega pixels resolution, picture stabilization, trigger and zoom function (www.microdrones.com).

The drone can be operated fully autonomous including auto start and auto landing thanks to the waypoint navigation guidance. In our work the take off and the landing were manual and the rest of the flight was autonomous.

2.2 Flight Planning

The flight planning was programmed using the MdCockpit V2.6.2.6 compatible software with the drone. Using the module Waypoint Editor, the flight path was designed. It is a graphical interface based on Google Earth information, and the actions to do in each waypoint were defined, including holding position, picture orientation and trigger activation. Google Earth is linked to the Waypoint Editor module integrated in the MdCockpit software. The obtained information from Google Earth was planimetric and this software can be used for mountain terrains but it must take into account the difference between altitudes in the flight plan.

For field calibration an orbital route was defined including a total of 12 waypoints (see Fig. 2). In figure 2 cannot be seen the current surface of the test field calibration because in the past there were greenhouses in the same area. Figure 4 shows the current surface of the test field calibration. Each waypoint had assigned the action of taking a photo.

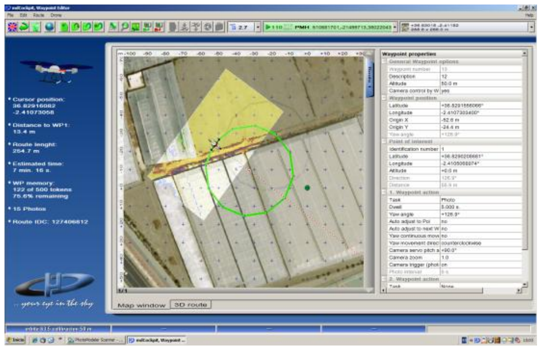

Figure 2. Flight planning with MdCockpit V2.6.2.6

2.3 Digital camera calibration methods

In this study two camera calibration methods were done. The first one consists in a lab calibration with a grid pattern and the second one, a field calibration, were the targets were draw in a flat surface. Photomodeler Scanner software was used for both calibration methods. This software is based on the bundle adjustment principle. For good calibration results, images should cover the whole imaging area and should be of very good sharpness and contrast. Also a minimum of eight images in good convergent positions are required. (www.photomodeler.com).

2.3.1 Lab camera calibration. In June 2010 a set of 12 convergent images were taken. The images covered the calibration grid pattern included in the installation package of Photomodeler. The grid pattern was placed on the floor and three images were collected from each of the pattern´s four sides. Figure 3 shows an image of the camera calibration pattern fixed on the floor. A tripod was used to ensure image stability.

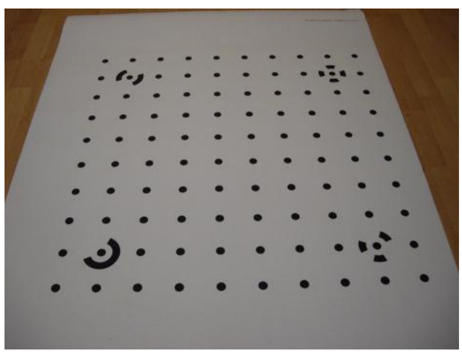

Figure 3. Lab camera calibration pattern

The focal length was fixed at minimum zoom (widest angle), with the focus fixed to infinite and the network included images with ± 90º roll angles. The camera positions were close to 45 degrees from the horizontal and vertical.
Interior orientation parameters (IOP) of the digital camera were estimated using the module Camera Calibrator of Photomodeler Scanner software in which the bundle block adjustment method is used. The calibration process was completely automatic and the calibration results were stored.

2.3.2 Field camera calibration. The calibration images should be taken under similar conditions to the field samples for most accurate results. In order to get this goal, we proposed a camera field calibration using an UAV to take the images in similar conditions as our future photogrammetric projects.
To develop the field calibration, as it is mentioned above, a flight planning was programmed defining an orbital route including a total of 12 convergent images. We chose eight of the twelve images, due to the similarity of some images. In the same way as in the lab calibration, the focal length was fixed at widest angle and recorded as a 3648 pixels by 2736 pixels image. The field test used in the study was a flat surface located on the University of Almería Campus (Spain) and a set of 67 target points covering the calibration field pattern were draw (Fig. 4). The calibration field area was 25 x 25 m approximately.

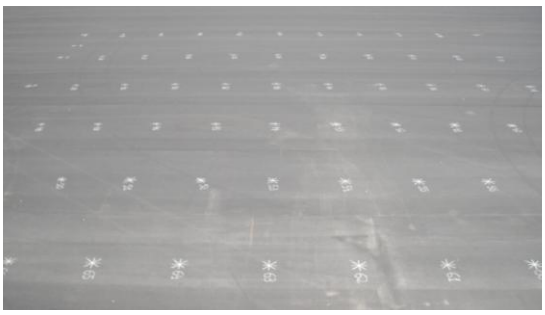

Figure 4. Field calibration surface with the targets points

The altitude flight over ground was 50 m to ensure, as possible, the same conditions as it could be used for future photogrammetric projects. In this case, the calibration process was not fully automatic. We set up a point-based PhotoModeler project using the lab calibration parameters. Then we marked and referenced as many targets as we recognised on the images and when the project began to be processed, the option full field calibration was chosen and the IOP were stored. To estimate the accuracy of the method proposed, horizontal and vertical coordinates of the targets were determined in the ED-50 reference frame with the Ibergeo geoidal model, using a Trimble R6 GPS receiver and applying a post-processing method with Trimble Geomatic Office software. We used the time data correction from the Almeria station, belonging to the Positioning Andalusian Network (RAP) (http://www.juntadeandalucia.es/obraspublicasytransportes/redandaluzadeposicionamiento/rap).

3. RESULTS

The paper presents the process, the results and the accuracy of two calibrations methods. After the software processing, the camera calibration parameter values were obtained.
The calibrated parameters obtained were: focal length, format size of the CCD sensor, location of the principal point sensor, two radial distortion function coefficients and two decentring distortion function coefficients (see Table 1 and Table 2).

	Lab calibration	
Focal length (mm)	8.184 ± 7.8e-004	
Format size (mm)	7.485 ± 2.7e-004 x 5.613	
Principal point (mm)	3.722 ± 8.4e-004 x2.677 ± 0.001	
Radial distortion function parameters	K1	2.821e-003 ± 1.3e-005
	K2	-1.538e-005 ± 8.6e-007
Decentring distortion function parameters	P1	5.026e-005 ± 3.2e-006
	P2	-4.478e-004 ± 3.9e-006

Table 1. Camera lab calibration parameter values

	Field calibration (50m flight high)	
Focal length (mm)	8.221 ± 0.033	
Format size (mm)	7.452 ± 0.016 x 5.613	
Principal point (mm)	3.714 ± 0.009 x 2.553 ± 0.061	
Radial distortion function parameters	K1	2.728 e-003 ± 4.9e-005
	K2	-3.077 e-006 ± 1.9e-006
Decentring distortion function parameters	P1	5.155 e-005 ± 1.2e-005
	P2	-2.145 e-004 ± 1.6e-004

Table 2. Camera field calibration parameter values

In figure 5 the mosaic of field calibration project can be seen.

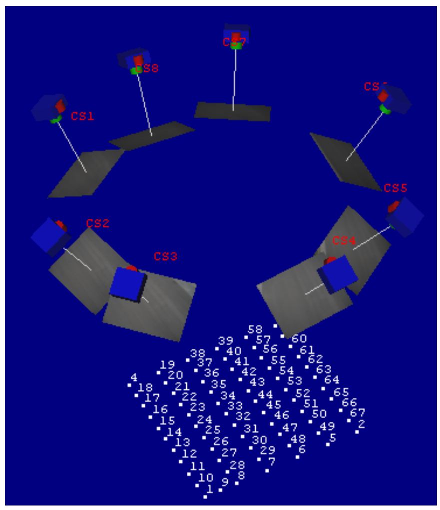

Figure 5. Mosaic of the images and points where the photos were taken from

To check the accuracy of the camera calibration results the total final error must be checked. In both methods the data sets are not the same. For lab calibration the data set is the grid of the pattern (Fig. 3) and for filed calibration are the 67 targets points (Fig. 4). According to Photomodeler tutorial a value less than 1.0 pixel indicates a good calibration and very good calibrations can have a final total error smaller than 0.4 pixels (www.photomodeler.com). In our case, the lab calibration has a final total error of 1.940 pixels (see table 3). It is a total error a bit higher than the recommended. The field calibration has a total error of 0.282 pixels, which is assumed to be a very good calibration project.

	Lab calibration	**Field calibration (50m flight high)**
Final total error (pixel)	1.940	0.282
Largest marking residual (pixel)	0.723	0.700
Overall RMS (pixel)	0.245	0.341

Table 3. Total final error and residuals of the camera calibration projects

If the bars in the error chart (see Fig. 6) get smaller, the final total error decreases. Also checking the marking residuals is a good way to test the calibration quality. Photomodeler tutorial recommended having a largest marking residual less than 1.0 pixel (www.photomodeler.com). In both cases the largest marking residuals are less than 1.0 pixel. The lab calibration has 0.723 pixels and the field calibration 0.700 pixels (see table 3).

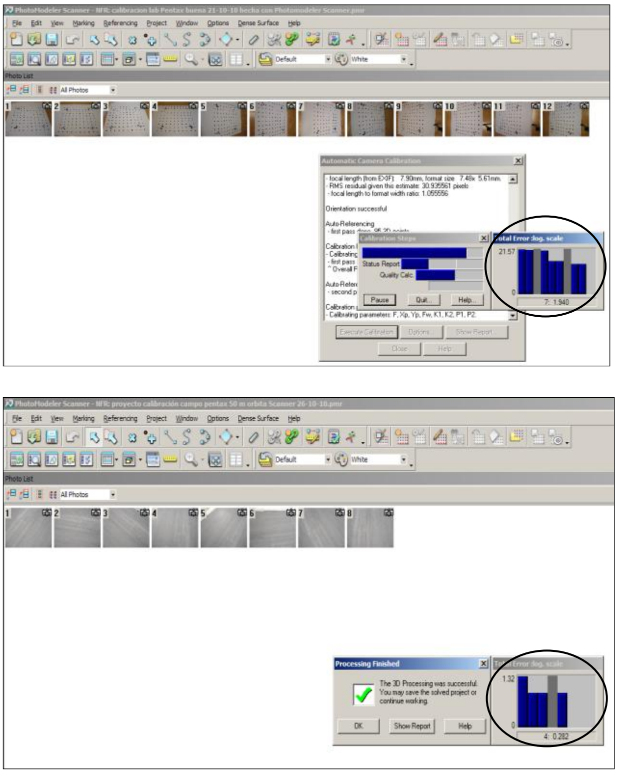

Figure 6. Upper figure shows the processing of the lab calibration and the lower figure shows the field calibration processing. The accumulated error of both processes can be seen representing by the error chart

Accuracy of field calibration was also checked comparing the GPS coordinates of the targets with the coordinates obtained with Photomodeler. This software only needs three control points to change from relative to absolute coordinates. For this process the targets number one, two and four were used. The planimetric and the altimetric RMS were calculated. The planimetric RMS was 0.028 m and the altimetric 0.026 m. These small errors point out the accuracy of the project.

4. DISCUSSION

In our study the results show that Photomodeler software is a flexible and a powerful tool for camera calibration using the bundle block adjustment method. Wiggenhagen (2002), Remondino and Fraser (2006), Wotjas (2010) and Zhang et al. (2010) also used Photomodeler software to calibrate CCD cameras with good results.

The management of Photomodeler for applying an automatic calibration (lab calibration) or a field calibration is very straightforward and its relative low cost in comparison with other photogrammetric software make it appropriate software for digital camera calibration.

Field camera calibration has the advantage that the images were taken under similar conditions to the images could be taken with an UAV but it has the disadvantage of the necessity of an appropriate surface to put the targets and its accuracy measurements. Also it has a problem obtaining images with sufficient diversity of camera angles. Matsuoka et al. (2002) proposed a similar field calibration method of a non-metric digital camera. It was conducted at an open space paved with no special targets for an amateur application. They concluded that the calibration method proposed was useful for some non-professional fields.

The simplicity of the lab calibration with a flat grid pattern represents the highest advantage of this calibration method. Zhang (2000) also used a flat pattern to calibrate a camera with very good results. Besides the simplicity of this method, the necessary equipments are only the calibration pattern, the digital camera and a tripod to ensure stability.

The lower accuracy found in lab calibration might be due to the automatic process that generates more errors than with the manual process used in the field calibration.

The Pentax Optio A40 imagery collected with a flight high of 50 m with a md4-200 has demonstrated the potential of high resolution digital imagery for calibration purposes or photogrametric projects.

5. CONCLUSION AND FUTURE WORK

Field calibration method reduced the final total error obtained in the previous lab calibration. Furthermore the overall RMSs obtained from both methods are similar. Therefore we will apply the field calibration results to all our photogrammetric projects in which the flight high will be close to 50 m.

The obtained RMSs will be checked in future UAV photogrammetric projects in order to confirm whether the field calibration done is accurate.

6. REFERENCES

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