THE INTERIOR AND EXTERIOR CALIBRATION FOR ULTRACAM D

K. S. Qtaishat, M. J. Smith , D. W. G. Park

Civil and Environment Engineering Department, Mu'ta, University, Mu'ta, Karak, Jordan, 61710 khaldoun_q@hotamil.com
Telephone +962777265002

Commission, WG VI/4

KEY WORDS: UltraCam D, Interior calibration, Exterior calibration, *Misalignment*, Direct georeferencing.

ABSTRACT

There are now many different digital sensor systems available for photogrammetry, remote sensing and digital image analysis. Cramer (2005) provides a summary of the systems available in 2005 and these include; single and multi-cone/lens systems as well as high resolution push broom scanners. Before any imagery can be used for high precision measurement purposes in photogrammetry there is a need to determine the geometric model of the sensing system. In the case of frame cameras there is a need to establish the sensor model and determine the relationship of this model in comparison to the standard normally (and traditionally) used in photogrammetry which is perspective geometry. The process of measuring the relationship of a 'real' frame camera geometry in comparison to perspective geometry is known as camera calibration. Camera calibration is normally undertaken by the manufacturer before supplying a camera for photogrammetry then periodically, and when necessary, during the life of the camera.

The technology of GPS and an inertial measurement unit (IMU) integrated with an aerial camera, either analogue or digital, is regularly being used for production purposes. The importance of GPS and IMU measurements is increasing as there is greater and greater interest to work without ground control and strive towards direct georeferencing of imagery. Arguably, direct georeferencing can be considered with and without aerial triangulation as the use of automatically measured minor control points (tie and pass points) can be easily and efficiently undertaken by modern aerial triangulation software. Critical to the success of direct georeferencing, particularly without aerial triangulation, are the IMU measurements and therefore the determination of the geometric relationship between the IMU and the camera geometry. As experience is gained from undertaking misalignment (boresight) calibrations a number of interesting results are being produced.

1. INTRODUCTION

The 'new' multi cone digital camera systems are geometrically complex systems. The image used for photogrammetric analysis is made up of a number of images produced by a cluster of camera cones and possibly various groups of CCD arrays. This produces a resultant image which is not just based on traditional single lens/focal plane camera geometries but is dependant on the joining of images from multiple lens (different perspectives), handling groups of focal planes and the matching of overlapping image areas. For optimal use of this imagery there is a need to:

1. understand this complex geometric model;
2. undertake a calibration of the 'real' camera;
3. analyse the relationship between the calibrated camera geometry and perspective geometry;
4. establish whether existing calibration procedures are adequate;
5. possibly establish new procedures;
6. establish how long a camera calibration lasts before periodic recalibration is required.

Some of these requirements can only be determined through long-term experience/research and some can be determined through investigation and short-term research. This report provides an investigation into the camera calibration of a Vexcel UltraCam D aerial camera based on results achieved from two flights flown over a test site over Fredrikstad-Germany as part of the EuroSDR Digital Camera Calibration project.

Critical to the success of direct georeferencing, where aerial triangulation is not used, are the IMU measurements and therefore the determination of the geometric relationship between the IMU and the camera geometry (Smith et al., 2006). So the other main objective of this paper is to investigate the determination of the relationship between the camera and IMU (boresight calibration) for the Vexcel UltraCam D digital camera and for the ZEISS RMK TOP 15 film camera. As experience is gained from undertaking misalignment (boresight) calibrations a number of interesting results are being produced.

The theory behind this relationship is well documented by a number of researchers (for example, Jacobson, 2003) and commercial system providers (for example, Mostafa, 2002). As the availability of suitable inertial systems has become more widespread the theory has been put into practice. The integration of inertial sensors with analogue cameras produced a number of challenges particularly in terms of the stability of the mounting which led to considerable interest in the calibration (boresight calibration) between the IMU and the camera (Smith et al., 2006). This naturally leads to some discussion on how frequently the boresight calibration needs to be performed.

As there is limited experience of undertaking boresight calibrations with the UltraCam D camera some analysis is presented on the impact of changing the main variables in the calibration procedure. Investigations to asses the effect of different parameters on the boresight determination accuracy have included in this paper. These parameters are the number images, the number of ground control points and the number of tie points used in the aerial triangulation. The computation process to compute the misalignment matrix has been undertaken through an aerial triangulation program 3DB.

2. ASSESSMENTS OF RESULTS

The results were assessed from a posteriori statistical analysis from the computation or the assessment the quality of the resulting photogrammetric product. The first method is an internal assessment while the second is often an external assessment. The results presented here show internal analysis through the parameter standard errors and the image residuals and the external assessment is through the RMSE of check point residuals.

3. THE TEST SITE

Three UltraCam D boresight calibration flights are analysed over the established Milton Keynes site used by Simmons Aerofilms Ltd. A traditional flight plan was used with a flying height of 880m, a nominal forward overlap of 60% and a nominal side overlap of 20% for all flights. These were undertaken due to the camera being moved between two aircraft. Figure 1 shows a typical flight plan of the block flown

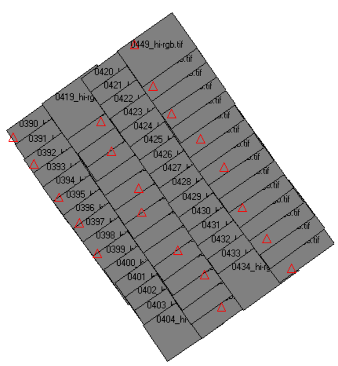

Figure 1. Block of 60 images taken at 880m flying height – using the UltraCam D

To enable some comparison to take place with a frame camera, results from a 24 photograph metric ZEISS RMK TOP 15 block are assessed. The images are taken at 880m flying height and an imagery scale of 1:6000 over the same test area, see Figure 2. The data from the frame camera taken at scale 1:6000 was specially chosen as it has the same swath width as the UltraCam D digital camera.

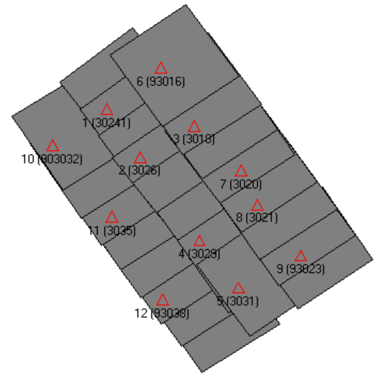

Figure 2. Block of 24 photographs taken at 880m flying height – using the metric ZEISS RMK TOP 15

4. AIMS

The aims of this paper were to investigate the interior and exterior calibration of a Vexcel UltraCam D digital aerial camera. This will involve investigating the following objectives:

1. understanding the geometry of the UltraCam D.
2. establishing whether existing camera calibration techniques are suitable.
3. possibly proposing an alternative camera calibration approach.
4. The effect of the number of images and number of ground control points on the determination of misalignment matrix.
5. The effect of number of tie points on the determination of misalignment matrix.

5. METHODOLOGY

As the geometry of the UltraCam D is different from the traditional single cone/CCD camera an analysis will be undertaken to try to identify any systematic patterns in the image residual. This will enable alternative calibration procedures to be considered. Two methods can be identified to apply a new calibration model to the image coordinates:

1. self-calibration during the bundle adjustment.
2. by identification and quantification of systematic residuals followed by application to image coordinates and re-computation of the bundle adjustment.

6. THE RESULT FROM EXISTINGINTERIOR SELF-CALIBRATION MODELS

A number of self calibration models where tested from Leica LPS and ORIMA software to assess the most suitable for this type of imagery. The results presented here come from ORIMA and are considered the 'best' result from existing self-calibration models based on the smallest image residuals and RMSE of ground and check points.

Self Calibration method	Ground control points RMSE (m) of residuals			Ground check points RMSE (m) of residuals			Image coordinates RMSE (μm)of residualsa	
	X	Y	Z	X	Y	Z	x	y
Self Calibration	0.036	0.032	0.051	0.092	0.135	0.201	1.71	1.75

Table 1. *Results AT with self-calibration model*

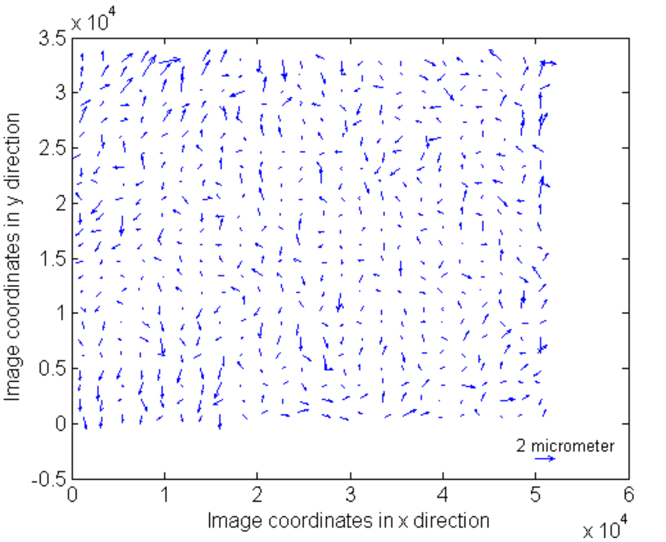

Figure 2. *Mean image residuals in 24x24 sub-areas, results of AT with self-calibration model (coordinates in μm, partitioning shows approximate boundaries of the CCD arrays)*

On visual inspection of figure 2. there is no overall identifiable systematic patterns in the whole image. There are small areas where systematic patterns can be identified, some showing a relationship to the CCDs (for example see bottom left corner) but it should be noted that in general the image residuals over the whole image are very small. As these residuals could come from a variety of sources and this is only results from one block, these patterns may not be due to uncorrected systematic characteristics of camera/image geometry. This raises the question 'is this pattern of residuals repeatable between blocks of images?

7. ANALYSIS OF AERIAL TRIANGULATION IMAGE RESIDUALS – IESSG APPROACH

As the geometry of the UltraCam D is different from the traditional single cone/CCD camera an analysis will be undertaken to try to identify any systematic patterns in the image residuals. This will enable alternative calibration procedures to be considered. The potential camera features which may cause variations from the traditional self-calibration models will be investigating through analysis of triangulation image residuals.

Self Calibration method	Ground control points RMSE (m) of residuals			Ground check points RMSE (m) of residuals			Image coordinates RMSE (μm)of residuals	
	X	Y	Z	X	Y	Z	x	y
IESSG Approach	0.051	0.034	0.025	0.151	0.088	0.158	1.548	1.59

Table 2. *Results AT with IESSG approach*

The following figure 3 shows the mean image residuals of the observations for the sub- areas in the image.

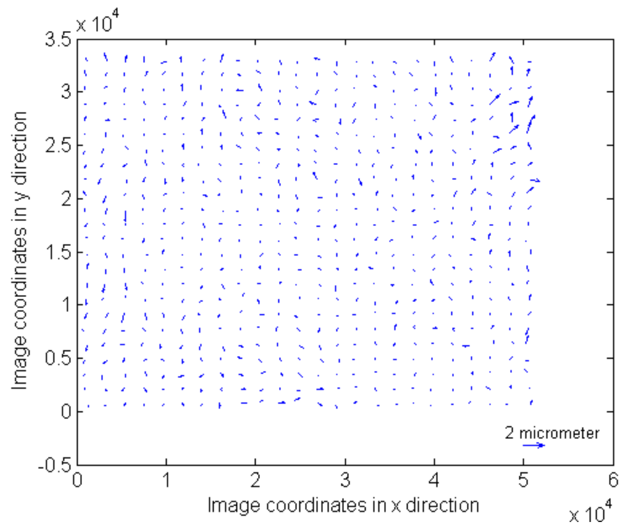

Figure 3. Mean image residuals, results of AT with IESSG approach (coordinates in μm, partitioning shows approximate boundaries of the CCD arrays)

Table 2. shows again small RMSE values for the ground control points as identified in the high flown trials. It also shows a small improvement in applying a traditional single lens self-calibration model technique. The really interesting improvement comes from applying the IESSG approach which has reduced relatively significantly the x and y image residuals and the Z RMSE values for the check points.

8. THE EFFECT OF THE NUMBER OF IMAGES AND NUMBER OF GROUND CONTROL POINTS ON THE DETERMINATION OF MISALIGNMENT MATRIX *EXTERIOR CALIBRATION)

To evaluate the boresight calibration using a different number of strips and ground control points, the calibration flights on 06/05/2005 for UltraCam D and on 09/09/2003 for RMK TOP 15 were selected. Table 3 and Table 4 show the results for what might be considered the extreme scenarios for UltraCam D digital camera and RMK TOP 15 film camera. Changes of misalignment angles from reference solutions have been shown in Table 3 and Table 4. The reference boresight angles in Table 3 are those determined using the block configuration of 4 strips and 11 ground control points, and in Table 4 are those determined using the block configuration of 3 strips and 9 ground control points

Number of strips/GCP/ CP	Changes in misalignment angles (arc-min)			Standard error (arc-min)			RMSE of image coordinate (μm)		RMSE on check ground control points (m)		
	roll	pitch	yaw	roll	pitch	yaw	x	y	X	Y	Z
Four/11/6	0	0	0	0.072	0.059	0.067	1.90	1.77	0.105	0.138	0.109
Four/8/9	0.017	-0.047	-0.127	0.059	0.048	0.058	1.93	1.74	0.127	0.084	0.128
Four/5/12	0.017	-0.043	-0.159	0.059	0.048	0.059	1.93	1.74	0.133	0.076	0.154
Four/3/14	0.022	-0.037	-0.220	0.059	0.047	0.061	1.92	1.74	0.141	0.079	0.154
Four/1/16	0.021	-0.007	-0.200	0.059	0.047	0.061	1.92	1.74	0.147	0.113	0.173
Four/0/17	0.019	-0.011	-0.195	0.059	0.047	0.061	1.97	1.67	0.110	0.162	0.147
Three/11/6	-0.032	-0.071	0.159	0.074	0.061	0.069	1.84	1.65	0.161	0.072	0.142
Three/8/9	-0.038	-0.133	0.015	0.069	0.055	0.067	1.86	1.65	0.148	0.168	0.152
Three/5/12	-0.020	-0.111	0.028	0.069	0.055	0.067	1.86	4.64	0.164	0.172	0.169
Three/3/14	0.002	-0.070	0.063	0.069	0.055	0.073	1.84	1.54	0.132	0.131	0.169
Three/1/16	0.013	-0.123	0.083	0.070	0.055	0.070	1.83	1.54	0.148	0.110	0.153
Three/0/17	0.014	-0.099	0.028	0.070	0.055	0.074	1.80	1.52	0.155	0.143	0.144
Two/8/3	0.010	0.075	-0.147	0.084	0.067	0.083	1.84	1.33	0.157	0.117	0.096
Two/7/4	0.012	0.045	-0.100	0.083	0.066	0.083	1.84	1.34	0.140	0.097	0.126
Two/5/6	0.005	0.043	-0.228	0.082	0.066	0.087	1.84	1.33	0.175	0.067	0.097
Two/3/8	0.009	0.086	-0.271	0.083	0.065	0.093	1.83	1.32	0.181	0.104	0.147
Two/1/10	0.001	0.093	-0.411	0.084	0.065	0.093	1.83	1.32	0.151	0.110	0.149
Two/0/11	0.003	0.105	-0.325	0.083	0.065	0.094	1.83	1.32	0.158	0.113	0.153
One/4/2	-0.267	-0.166	-0.003	0.144	0.120	0.136	1.95	1.04	0.162	0.080	0.075
One/3/3	-0.218	-0.040	-0.086	0.160	0.122	0.143	1.95	1.03	0.158	0.073	0.134
One/2/4	-0.214	0.025	-0.113	0.142	0.119	0.134	1.95	1.03	0.138	0.073	0.130
One/1/5	-0.068	0.393	-0.059	0.217	0.127	0.155	1.93	1.03	0.259	0.03	0.122
One/0/6	-0.173	16.537	0.343	10.947	0.130	0.206	1.91	1.01	3.082	2.633	1.586

Table 3. The changes in misalignment angles for the UltraCam D using different number of strips and ground control points

Number of strips/GCP/CP	Changes in misalignment angles (arc-min)			Standard error (arc-min)			RMSE of image coordinate (µm)		RMSE on check ground control points (m)		
	roll	pitch	yaw	roll	pitch	yaw	x	y	X	Y	Z
Three/9/3	0.000	0.000	0.000	0.122	0.104	0.122	3.88	4.04	0.249	0.057	0.155
Three/6/6	-0.045	0.030	0.039	0.120	0.102	0.121	3.86	4.05	0.255	0.054	0.179
Three/4/8	0.076	-0.042	0.007	0.115	0.098	0.117	3.88	4.06	0.452	0.090	0.165
Three/2/10	0.091	-0.049	0.166	0.110	0.094	0.114	3.86	4.05	0.520	0.109	0.218
Three/1/11	0.098	-0.086	0.003	0.108	0.091	0.113	3.77	4.03	0.599	0.127	0.277
Three/0/12	0.141	-0.083	0.026	0.107	0.089	0.114	3.70	3.96	0.676	0.163	0.365
Two/8/4	0.392	-0.064	0.133	0.154	0.128	0.149	3.54	3.94	0.292	0.079	0.133
Two/6/6	0.302	-0.061	0.273	0.151	0.124	0.148	3.41	3.91	0.314	0.113	0.245
Two/4/8	0.475	-0.051	0.116	0.149	0.120	0.149	3.39	3.86	0.344	0.190	0.289
Two/2/10	0.379	-0.045	0.062	0.142	0.114	0.150	3.36	3.88	0.409	0.192	0.366
Two/1/11	0.300	-0.050	0.088	0.140	0.112	0.149	3.34	3.88	0.490	0.165	0.365
Two/0/12	0.377	-0.037	0.055	0.136	0.106	0.143	3.34	3.85	0.642	0.168	0.396
One/5/2	-1.074	0.047	0.064	0.232	0.189	0.205	2.79	3.82	0.106	0.109	0.096
One/4/3	-0.960	0.008	0.141	0.229	0.186	0.201	2.75	3.80	0.268	0.144	0.135
One/2/5	-0.637	-0.371	0.419	0.274	0.168	0.199	2.39	3.81	0.541	0.188	0.281
One/1/6	-0.494	-0.359	0.245	0.354	0.174	0.204	2.43	3.79	0.528	0.184	0.282
One/0/7	-20.741	0.547	0.266	10.867	0.417	0.229	2.07	3.67	5.066	3.059	3.038

Table 4 The changes in misalignment angles for the RMK TOP 15 using different number of strips and ground control points

The results in Table3 and Table 4 show that calibrating the boresight using one strip without ground control points yields significantly poorer precision in the boresight pitch component for UltraCam D digital camera and poorer precision in the boresight roll component for RMK TOP 15 film camera. The heading component of the boresight for both cameras does not seem to be effected by the ground control points at all because in-flight GPS fixing it. Furthermore, there is no difference between only two ground control points or using all of them as far as the boresight precision is concerned.

Also Table 3 and table 4 show that the average roll and pitch standard error for UltraCam D is 0.079 arc-min which is equivalent to about 2.4µm on the image or about 2cm on the ground. For RMK TOP 15, the average roll and pitch standard error is 0.145 arc-min which is equivalent to about 6.5µm on the image or about 3.7cm on the ground. Interestingly the image residuals for UltraCam D are significantly smaller; the average RMSE image coordinate is 1.88µm in x and 1.59µm in y. Also the check points residuals for UltraCam D are smaller. The average RMSE check pints is 0.152m, 0.105m, and 0.137m in X, Y, and Z respectively. With RMK TOP 15 film camera, the average RMSE image coordinate is 3.35µm in x and 3.92µm in y, and average RMSE check pints is 0.418m, 0.133m, and 0.247m in X,Y, and Z respectively

The results in Table 3 and Table 4 show that the changes in the roll angle with the RMK TOP 15 are almost close to one arc-min when a single strip configuration is used. This is almost four times greater than the changes in the roll angle of with UltraCam D when the same configuration is used.

In general, the results for UltraCam D digital camera show that there are not significant differences in the misalignment components, between using different strips and ground control points configurations, except the results from one strip without ground control points configuration. The maximum difference for misalignment with UltraCam D between 4 strips and one strip block configuration is 0.006 deg in pitch, but the maximum for misalignment with film camera between 3 strips and one strip block configuration is

0.018 deg. The four strip computations with UltraCam D show an improvement in the standard errors of the misalignment angles over the other strip configurations. However, there is little change in the check point RMSE.

9. THE EFFECT OF NUMBER OF TIE POINTS ON THE DETERMINATION OF MISALIGNMENT MATRIX

Table 5 and Table 6 show the changes of misalignment angles from reference solutions. The reference boresight angles in Table 5 are those determined using the block configuration with 1172 tie points, and in Table 6 are those

In summary, the misalignment matrix for UltraCam D digital camera and RMK TOP 15 film camera can be determined using different imaging configurations without the need for ground control points, except the single strip without the any ground control results determined using the block configuration with 368 tie points. The maximum change in misalignment angles is in the roll with a change of 0.173arc-min with the UltraCam D. The results do not show much difference, the largest being the UltraCam D results in roll, identifying a consistent and sufficient set of tie point observations. Also the results show that the effect of number of tie points is not limiting factor for boresight quality.

No of GCP/ CP	No of Tie points	Changes in misalignment angles (arc-min)			Standard error (arc-min)			RMSE of image coordinate (µm)		RMSE on check ground control points (m)		
		roll	pitch	yaw	roll	pitch	yaw	x	y	X	Y	Z
11/6	1172	0	0	0	0.069	0.058	0.067	1.90	1.77	0.105	0.138	0.109
11/6	434	0.145	-0.019	0.026	0.077	0.066	0.077	1.84	1.86	0.122	0.108	0.099
11/6	368	0.165	-0.008	-0.014	0.072	0.059	0.067	1.86	1.76	0.110	0.135	0.113
11/6	268	0.173	0.004	-0.095	0.080	0.069	0.084	1.79	1.845	0.108	0.157	0.117

Table 5. The changes in misalignment angles for the UltraCam D using different number of tie points

No of GCP/ CP	No of Tie points	Changes in misalignment angles (arc-min)			Standard error (arc-min)			RMSE of image coordinate (µm)		RMSE on check ground control points (m)		
		roll	pitch	yaw	roll	pitch	yaw	x	y	X	Y	Z
8/4	582	0	0	0	0.122	0.104	0.122	3.88	4.04	0.249	0.057	0.155
8/4	168	0.090	0.080	0.050	0.124	0.110	0.129	4.20	4.04	0.248	0.056	0.153
8/4	135	-0.028	0.015	-0.023	0.128	0.113	0.131	4.72	4.06	0.236	0.068	0.129

Table 6. The changes in misalignment angles for the RMK TOP 15 using different number of tie points

10. CONCLUSIONS

3DB software has been used successfully for computing the boresight misalignment for the UltraCam D digital camera and RMK TOP 15 film camera. The results show that significant changes can occur in the misalignment angles between the IMU and the camera if the camera is moved between aircraft, as might be expected. Results show that the boresight calibration can be determined for UltraCam D digital camera using different imaging configurations without the need for ground control points, except the single strip without any ground control results. The maximum difference for misalignment with UltraCam D between 4 strips and one strip block configuration is 0.006 deg in pitch, but the maximum for misalignment with film camera between 3 strips and one strip block configuration is 0.018 deg. Again as expected, the results show that using four strips rather than one has produced higher standard errors for the misalignment angles although little difference is shown by the check points.

On the other hand, the effect of number of tie points per block to compute the misalignment matrix is very minimal for both cameras. Also the results show that the effect of number of tie points is not limiting factor for boresight quality for both cameras.

So, the misalignment components are far easier to be determinined using UltraCam D data as any mix of strip and/or ground control points and/or tie point configurations may be used without noticeable change in the result (except single strip without ground control points).

11. REFERENCES

Cramer, M. (2005). Digital Airborne Cameras-Status and Future. ISPRS Hannover Workshop on High resolution Earth imaging for geospatial information Proceedings, Volume XXXVI Commission I WGI/1, ISPRS Hanover workshop, Hanover 17-20 May, ISSN No. 1682-1777.

Jacobsen, K. (2003). System calibration for direct and integrated sensor orientation. Proceedings of the ISPRS Workshop. Working Group 1/5. Castelldefels, Spain, 22-23 May 2003.

Mostafa, M R. (2001). Airborne image georeferencing by GPS-Aided Inertial Systems: Concepts and performance analysis. 22nd Asian Conference on Remote Sensing, Asian Association on Remote Sensing (AARS). Singapore.

Mostafa, M R. (2001). Digital Multi-Sensor Systems-Calibration and Performance Analysis. OEEPE Workshop Integrated Sensor Orientation, Hannover, Germany, Sep 17-18, 2001.

Mostafa, M R. (2002). Camera/IMU boresight calibration: New advance and performance analysis. Proceedings of the American Society for Photogrammetry and Remote Sensing, Annual Meeting, Washington, DC, April 21-26, 2002.

Smith, M. J. (2004). Personal notes on Integration of GPS and IMU in aerial triangulation and 3DB. IESSG, the University of Nottingham. Internal Document.

Smith, M. J., Qtaishat, K., Park, D. W. G., and Jamieson, A. (2005). Initial Results from the Vexcel UltraCam D Digital Aerial Camera. ISPRS Hannover Workshop on High resolution Earth imaging for geospatial information Proceedings, Volume XXXVI Part I/W3 ISSN No. 1682-1777.

Smith, M. J., Qtaishat, K., Park, D. W. G., and Jamieson, A. (2006). IMU and Digital aerial camera misalignment calibration. The Calibration and Orientation Workshop. A Workshop of the EuroSDR Commission 1 and the ISPRS working Group 1/3. Spain.

Smith, M. J., Kokkas, N., and Qatishat, K. (2006). EuroSDR Digital Camera Calibration. Report on: UltraCam D Digital Aerial Camera Calibration. EuroSDR Camera Calibration Project 2. Report from the University of Nottingham, May 2006.

12. ACKNOWLEDGMENT

The authors would like to thank the support of Simmons Aerofilms Ltd and the Jordanian Government.