IMU AND DIGITAL AERIAL CAMERA MISALIGNMENT CALIBRATION

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ABSTRACT

The use of in-flight control systems for controlling blocks of aerial photography is now an established procedure. 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.

To study the calibration of the integration of the sensors the IESSG has adapted its aerial triangulation software 3DB. This paper will present the results from trials using a Vexcel UltraCam D digital camera fitted with an Applanix POS AV 510, GPS/IMU integrated system. Various image configurations have been considered in the analysis.

1 INTRODUCTION

The correct determination of the misalignment matrix is very important because any errors in the misalignment between the IMU body frame and the image coordinate system will cause errors in object point coordinate determination using GPS/IMU for direct sensor orientation.

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. This naturally leads to some discussion on how frequently the boresight calibration needs to be performed.

Digital cameras brought further challenges when combined with GPS and IMU sensors. The early digital cameras were small format and what might be termed 'non-metric', not specifically designed for photogrammetry. This meant the cameras were not designed with the type of optical geometry and level of stability traditionally expected by photogrammetrists. This raised questions regarding the calibration and stability of both the internal camera geometry and the integration with the IMU and GPS sensors. The camera geometry associated with small format cameras and their calibration both for film and digital images has been well researched in the past particularly, by the close range/terrestrial photogrammetry community (Atkinson, 1996). This has more recently led to some interesting research in investigating the interaction and methods for combining both the calibration of the internal camera geometry and the boresight (Mostafa, 2002).

More recently, there has been the emergence of aerial digital cameras specifically designed and built for photogrammetry. The camera forms part of an integrated system with GPS and IMU sensors. Examples of these can be found in Smith et al. (2005) and Cramer (2005). These cameras are rigorously calibrated for their internal optical geometry and the stability of the camera geometry. Having been designed to accommodate an

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IMU and GPS as an integral part of the sensor system the relationship should be inherently stable and well known. The existing procedures produced from experiences undertaking boresight calibrations with analogue and non-metric digital cameras are expected to be suitable for applying to this new range of digital cameras. Boresight calibration experience with these cameras is now being gained from practical observation. The questions still remain partially unanswered with regard to frequency of calibration and optimum procedures for quality and efficiency.

During the period May to September 2005 Simmons Aerofilms Ltd moved their Vexcel UltraCam D digital aerial camera between two aircraft. As might be expected, after each move of the camera a boresight calibration was undertaken over their established calibration test field at Milton Keynes. This appeared a good opportunity to compare how the misalignment of the IMU to the camera was affected by these moves. The UltraCam D is fitted with an Applanix POS AV 510 integrated GPS/IMU. Details of the camera and system can be found in Smith et al. (2005).

Results are presented here from the three boresight calibrations to assess the changes that have occurred after each move. As there is limited experience of undertaking boresight calibrations with the camera some analysis is presented on the impact of changing the main variables in the calibration procedure. Investigations in the past by various researchers have included; the number of images, the number of ground control points and the number of tie points used in the triangulation.

1.1 Assessment of results

One of the most difficult issues that requires addressing is how to assess the quality of the boresight calibration. In general, a way to check the quality of any measurement is by comparing results with a measurement from significantly higher quality equipment or measurement system. This would then provide a benchmark or reference measurement to compare against. In the past this has been very difficult to achieve as far as IMU measurements are concerned as there has been little equipment available to compare against the high quality geodetic grade IMU often used. It has also not necessarily been a trivial task to integrate a second IMU into what is already a complex integration problem. This is slowly changing as certainly the IESSG has purchased a high quality IMU the Honeywell CIMU with a gyro bias specification of 0.0035° per hour integrated with GPS in an Applanix POS environment to allow assessment of 'lower-cost' IMUs (see Figure 1.).

The alternative is to assess the results from a posteriori statistical analysis from the computation or the assessment of 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.

Figure 1. The Honeywell CIMU navigation grade IMU

2 THE COMPUTATION PROCESSS - 3DB AERIAL TRIANGULATION

The computation process has been undertaken through an aerial triangulation program called 3DB which has been developed over many years at the IESSG. It was first developed as a conventional bundle adjustment and further developed to include GPS and IMU measurements as they have become more readily available. It has been tested against a number of data sets, and compared against commercial software over the years. More recently, appropriate validation has been undertaken by comparing against Leica Photogrammetry Suite (LPS) and ORIMA as well as the Applanix POSCAL™ software. The program has been written as a research tool to provide great flexibility in the development and testing of new algorithms, having been created specifically for convenience and ease of programming.

2.1 Misalignment matrix computation

As far as the misalignment matrix is concerned, the approach could be referred to as a '1-step procedure (Skaloud et al., 2003). It can be summarized as follows:-

1. Input values: IMU orientations (roll, pitch, and heading), and estimated misalignment matrix parameters all with appropriate standard errors..
2. The misalignment matrix can be determined in the bundle adjustment as a single misalignment matrix for all the projection centers or as a single matrix for each projection centre.

3 TRIALS

Three UltraCam D boresight calibration flights are analyzed 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 2 shows a typical flight plan of the block flown.

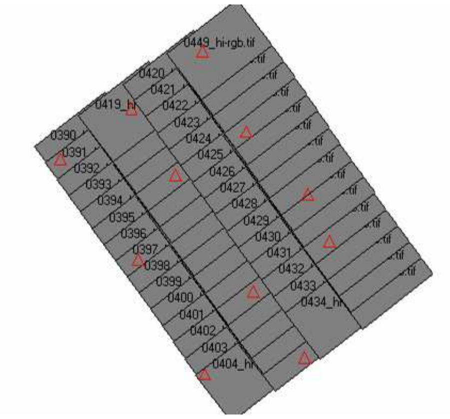

Figure 2. Typical block of about 60 images taken at approximately 880m flying height using the UltraCam D including some of the ground control points

4 MISALIGNMENT MATRIX RESULTS

In addition to the GPS/IMU position and attitude accuracy, the quality of direct orientation depends also on a good determination of the geometric relationship between the sensors being used, including the misalignment matrix (Jacobsen, 2003).

The frequency at which the misalignment calibration should be determined is debatable, although, it might be expected that a calibration is needed after the removal or installation of the camera in the aircraft.

Using the in-house IESSG 3DB software, the UltraCam D misalignment matrix was computed for each flight. To check the boresight calibration parameters the accuracy was assessed using the RMSE of the check ground control points.

Table 1 shows some of the statistics that resulted from the calibration of the three flights for UltraCam D digital camera. Changes of misalignment angles have been shown instead of the actual values as this is of greater interest in this particular analysis. The results show significant changes in the roll angle less in pitch and even less in the yaw angle.

The average roll and pitch standard error is 0.111 arc-min which is equivalent to about 1/3rd of a pixel (3µm) on the image or about 3cm on the ground. The image residuals and RMSE values of check points are comparable with previous experiences (Smith at al., 2005).

5 THE EFFECT OF THE NUMBER OF IMAGES AND NUMBER OF GROUND CONTROL POINTS ON THE DETERMINATION OF THE MISALIGNMENT MATRIX

In theory increasing the number of images results in an improvement in the quality of the result. However, there is a need to evaluate the effects of changing the number of images on the determination of the misalignment matrix.

To evaluate the boresight calibration using a different number of strips and ground control points, the calibration flight on 06/05/2005 for UltraCam D is selected. It would be expected that one strip would be sufficient in determining the misalignment as long as there was some ground control. So Table 2 shows the results for what might be considered the extreme scenarios.

The largest difference is 0.372 arc mins (22.3”) which is produced when moving from the one strip to four strip computation. Both the four strip computations show an improvement in the standard errors of the misalignment angles over the single strip. However, there is little change in the check point RMSE which suggests external consistency.

6 THE EFFECT OF THE NUMBER OF TIE POINTS ON MISALIGNMENT MATRIX

Very important in using a bundle triangulation is the measurement of the tie points. These points can now be measured automatically and therefore a large number of points can be observed in a block very efficiently. Again the 06/05/2005 block was chosen and two triangulations were performed with 368 an 1172 tie points per block, see Table 3. The maximum change in misalignment angles is in the roll with a change of -0.165 arc mins. The results do not show much difference in the statistics identifying a consistent and sufficient set of tie point observations.

No of strips/GCP/CP	Date of flight	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
3/19/6	09/09/2005	0	0	0	0.135	0.156	0.189	1.39	1.40	0.074	0.087	0.098
3/17/6	06/05/2005	-7.958	2.446	0.284	0.072	0.059	0.067	1.90	1.77	0.105	0138	0.109
2/4/2	09/03/2005	-0.776	-1.442	0.231	0.123	0.123	0.196	1.31	1.52	0.086	0.053	0.092

Table 1 Misalignment angle analysis for the UltraCam D on different dates

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
1/2/4	0	0	0	0.142	0.119	0.134	1.95	1.03	0.138	0.073	0.130
4/0/17	0.372	-0.298	-0.327	0.060	0.048	0.062	1.97	1.67	0.110	0.162	0.147
4/17/6	-0.148	-0.036	-0.303	0.072	0.059	0.067	1.90	1.77	0.105	0.138	0.109

Table 2 The misalignment angles for the UltraCam D using different number of strips and ground control 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
17/6	368	0	0	0	0.072	0.059	0.067	1.86	1.76	0.110	0.135	0.113
17/6	1172	-0.165	0.008	0.014	0.069	0.058	0.067	1.90	1.77	0.105	0138	0.109

Table 3 The misalignment angles for the UltraCam D using different number of tie points

7 CONCLUSIONS

The IESSG software 3DB has been used successfully for computing the boresight misalignment for the UltraCam D digital 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 using 4 strips rather than 1 has produced smaller standard errors for the misalignment angles although little difference is shown by the check points. Further investigation is being undertaken into the minimum requirement for number of images and control points. Changing the number of tie points has made little difference to the results although again the minimum number required could be investigated.

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