ASSESSING THE DIRECT GEOREFERENCING PERFORMANCE OF THE ULTRACAM XP FOR PHOTOGRAMMETRIC APPLICATIONS

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ABSTRACT:

Integrated orientation systems for measuring position and attitude using GPS and inertial measurement units (IMU's) are widely used in airborne surveys. The photogrammetric and remote sensing community have enthusiastically welcomed this technology as it brings about enhanced solutions and significant increases in efficiency. The traditional advantage of using in-flight GPS/IMU in photogrammetric applications is to enable a reduction in the number of ground control points (GCP) required during the aerial triangulation stage. However, with photogrammetric technology being used for a variety of applications, which have a variety of accuracy requirements, there becomes a need to assess the performance of the direct georeferencing and the GCP requirements for modern aerial survey.

The overall aim of the research undertaken at The University of Nottingham is to investigate the geometric potential of using the in-flight GPS/IMU information available with the UltraCamXp. This paper presents results from a block of 36 UltraCamXp images taken over the University Park Campus at Nottingham.

In order to assess the quality and accuracy for various outputs, a benchmark solution is determined with all the available ground control and check points. Using the benchmark aerial triangulation solution as a reference a DSM and ortho-image are produced. The reference triangulation and output products form the basic data sets for comparison against similar derived products using direct georeferencing (using aerial triangulation without ground control).

An analysis of the results and comparisons is carried out that indicate the potential and limitations of in-flight GPS/IMU in photogrammetric applications. The results show that high quality products can be produced without the need for ground control.

1. INTRODUCTION

1.1 Background

Integrated orientation systems for measuring position and attitude using GPS and IMU are widely used in airborne surveys. The photogrammetric and remote sensing community have enthusiastically welcomed this technology as it brings about enhanced solutions and significant increases in efficiency. A traditional advantage of using in-flight GPS/IMU in photogrammetric applications is the reduction in the number of ground control points required during the aerial triangulation stage. However, with the technology being used for a variety of applications, which have a variety of accuracy requirements, there, becomes a need to assess the performance of the direct georeferencing and the GCP requirements for modern aerial survey.

Although many studies have been undertaken in the past to investigate this issue and related issues (Cramer, 2009; Cramer and Haala, 2010) wider experiences are always valuable particularly as the results soon become out of date as new sensors and technologies become available.

The UltraCamXp is one of the very latest range of airborne cameras providing a very high resolution image on a large format. The UltraCam range of cameras (UltraCam, 2011a) is now well established and is widely used in industry.

With a variety of applications, there comes a need for a variety of solutions, balancing quality and efficiency. At both extremes, for example, high accuracy engineering applications and lower accuracy environmental geographical studies, challenges are presented to the technology. Even at the lower accuracy requirements, there is a demand for achieving the solution in a cost effective way. Minimising the need to use control points is one way of reducing cost and this paper is focusing on assessing the direct georeferencing capabilities of the UltraCamXp sensor.

Application areas in forestry, infrastructure/asset management, agricultural and environmental monitoring demand the

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production of image based products typically ortho-images. The products for this type of application require fast, simple and therefore efficient procedures, thus keeping the technical photogrammetric aspects to a minimum. As often, the accuracy requirements are not extremely demanding and therefore direct georeferencing (using aerial triangulation without ground control) has great potential.

Although the use of an integrated solution of GNSS positioning and inertial measurements theoretically enables the aerial triangulation to be removed from the workflow to produce photogrammetrically derived products, there are some clear benefits in running an aerial triangulation, which is an extremely easy and fast process in modern photogrammetric software. The advantages include error analysis, the creation of a consistent and reliable block of images and minimises y – parallax in stereo-pairs of images.

1.2 Aims and objectives

The overall aim of the research undertaken at The University of Nottingham is to investigate the potential of the UltraCamXP. The aim of this paper is to present results from the initial stage of this research, which is investigating the direct and indirect georeferencing of the images. This amounts to primarily the use of aerial triangulation, a much-automated process today, with and without ground control. More specifically the following objectives have been investigated:

1. An assessment of aerial triangulation results;
2. An assessment of the performance of the in-flight GPS and IMU through the comparison of digital surface models and ortho-images.

1.3 Methodology

The methodology is based on the use of the Leica Photogrammetric Suite (LPS) and the following stages:

1. Understanding the camera system
2. Creation of a test site with available:
    a. images;
    b. ground control and check points.
3. A comparison of aerial triangulation (AT) using varying amounts of ground control and in-flight position and attitude measurement. A bench-mark result is produced initially with maximum ground control.
4. An assessment of DSM's produced from direct and indirect georeferenced images. This provides an assessment of heighting quality.
5. An assessment of ortho-images produced from direct and indirect georeferenced images. This provides an assessment of planimetric quality.

The method of analysis is based on image, control and check point residuals.

2. TECHNOLOGY

2.1 System hardware

As mentioned above the UltraCamXp is one of the latest range of digital airborne large format cameras.

A summary of the key features are given here (UltraCamXP, 2011b):

1. Number of pixels 196mega pixels (17310 across track x 11310 along track pixels)
2. Pixel size 6μm
3. Focal length nominally 100.5mm
4. Geometrcially calibrated
5. Radiometrically calibrated
6. GPS/INS. Applanix POS-AV 510 system. This is part of the integrated Applanix 'POSTrack' GPS/INS and Flight Management System, which integrates the camera system including stabilised mount and pilot display.
7. GPS/INS data is processed using the Applanix POSPac MMS software suite – which uses a 'tightly coupled' post processing solution (Applanix, 2011)
8. GPS/INS systems calibrated with camera using high resolution Boresite flown to Applanix specification.

3. TRIALS, RESULTS AND ANALYSIS

3.1 Test site

The test site chosen is located at The University of Nottingham Campus. A conventional block of 36 images was captured with the UltraCamXp with a 70% forward overlap and a 20% side lap. The ground sample distance (GSD) is 6cm.

Twenty ground control points (GCPs) were coordinated in the field using a survey grade (dual-frequency) Leica GPS receiver and post-processed using Leica Geo-Office with an estimate quality of 10mm.

3.2 Aerial triangulation results

3.2.1 Observations and computations

In general, all 20 coordinated ground control points were measured on the images and 357 automatic tie points were extracted and measured. The in-flight GPS and IMU measurements were provided with a standard deviation of 0.03m, 0.03m and 0.6m in XYZ respectively and 0.03 degrees for the rotation elements. A number of aerial triangulation computations were performed and an interesting selection are presented here.

Aerial Triangulation Results – Trial 1 (Benchmark)

The benchmark AT solution is calculated using the in-flight GPS/IMU information as initial values with a standard deviation of 0.03m, 0.03m, and 0.06m for XYZ and 0.03 degrees for the rotation angles. Twenty ground control points are used, and no additional self-calibration model is used. The results are shown in Table 1 and Figure 1 indicates the residuals.

Total image unit weight RMSE = 2.6µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.045 (20)	0.000 (0)
Ground Y m	0.038 (20)	0.000 (0)
Ground Z m	0.033 (20)	0.000 (0)
Image x µm	2.0 (109)	0.0 (0)
Image y µm	2.1 (109)	0.0 (0)

Table 1. Benchmark AT results from trial 1

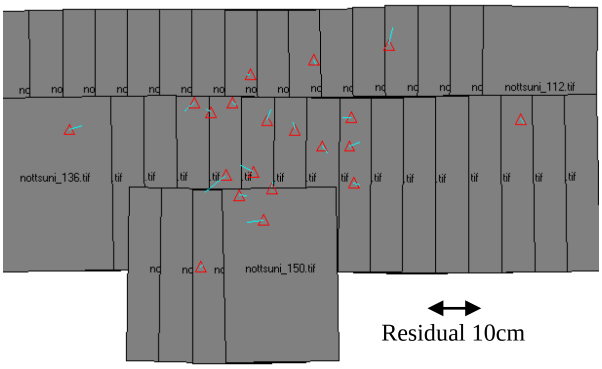

Figure 1. Trial 1 block showing residuals
(Δ = control points, O = check points)

Aerial Triangulation Results – Trial 2

The second trial solution is calculated using the in-flight GPS/IMU information as initial values with a standard deviation of 0.03m, 0.03m, and 0.06m for XYZ and 0.03 degrees for the rotation angles. This time only 1 ground control point is used in the centre of the block, and the remaining points set as check points. No additional self-calibration model is used. The results are shown in Table 2 and Figure 2 indicates the residuals.

Total image unit weight RMSE = 2.8µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.029 (1)	0.065 (19)
Ground Y m	0.042 (1)	0.053 (19)
Ground Z m	0.005 (1)	0.060 (19)
Image x µm	1.9 (8)	2.0 (0)
Image y µm	3.8 (8)	1.9 (0)

Table 2. AT results from trial 2

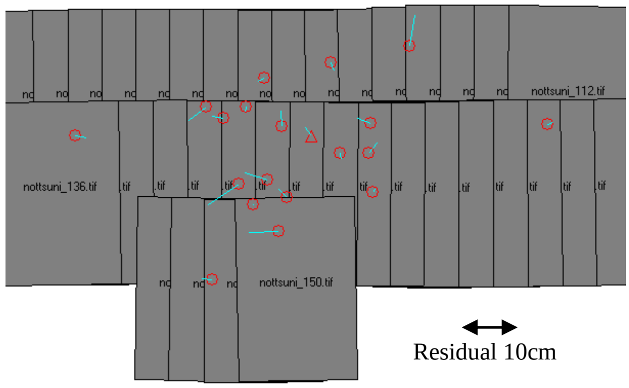

Figure 2. Trial 2 block showing residuals
(Δ = control points, O = check points)

Aerial Triangulation Results – Trial 3

The third solution is calculated using the in-flight GPS/IMU information as initial values with a standard deviation of 0.03m, 0.03m, and 0.06m for XYZ and 0.03 degrees for the rotation angles. No ground control points are used in the computation. No additional self-calibration model is used. The results are shown in Table 3 and Figure 3 indicates the residuals.

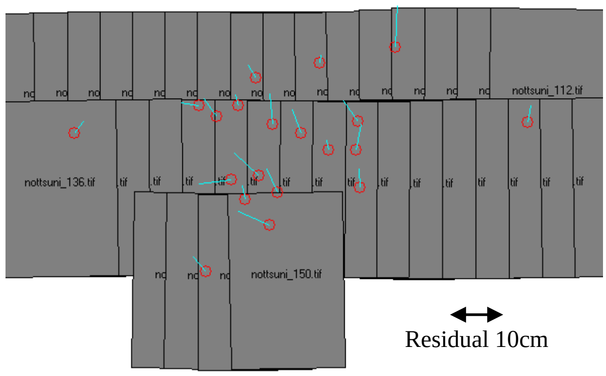

Figure 3. Trial 3 block showing residuals
(Δ = control points, O = check points)

Total image unit weight RMSE = 2.79µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.000 (0)	0.071 (20)
Ground Y m	0.000 (0)	0.100 (20)
Ground Z m	0.000 (0)	0.135 (20)
Image x µm	0.0 (0)	2.03 (109)
Image y µm	0.0 (0)	2.09 (109)

Table 3. AT results from trial 3

Table 5 shows a summary of the variations in the solutions.

Trial No	In-flight control	Self-calibration	No of ground control points	No of check points
1	√	**No**	20	0
2	√	**No**	1	19
3	√	**No**	0	20

Table 5. Summary of variations in AT solutions

3.2.2 Aerial Triangulation Analysis of results

Table 5 shows a summary of the aerial triangulation trials that are presented here. The aerial triangulation results show good image residuals in the order of one-third to one-half pixel size in all trials. The residuals on the ground control points for trial 1 are in the order of 0.5-0.6 of the GSD so within expected quality range as Figure 1 shows there is no significant systematic pattern. No significant difference in results was obtained by the use of a range of self-calibration models (not shown) indicating a good camera calibration was already being applied.

The results for trial 2 with one GCP in the middle of the block show RMSE values on the ground checkpoints at approximately 1 GSD (see Table 2). Trial 3 with no GCP gives an increase in the RMSE on the check points of just over 1 to 1.5 GSD in plan and about 2 GSD in height. So even without ground control a solution of about 2 times the standard deviation of the in flight GPS coordinates has been achieved on the ground.

3.2.3 Digital Surface Model Generation

A cross correlation stereo matching algorithm utilised in Leica Photogrammetry Suite v.9.3 was used to create the digital surface models (DSM) from the benchmark AT (Trial 1) and from the direct georeferencing AT (Trial 3). The DSMs have a sampling distance of 2m. The extracted DSMs were compared statistically.

A shaded relief image of the DSM created from Trial 1 is shown in Figure 4.

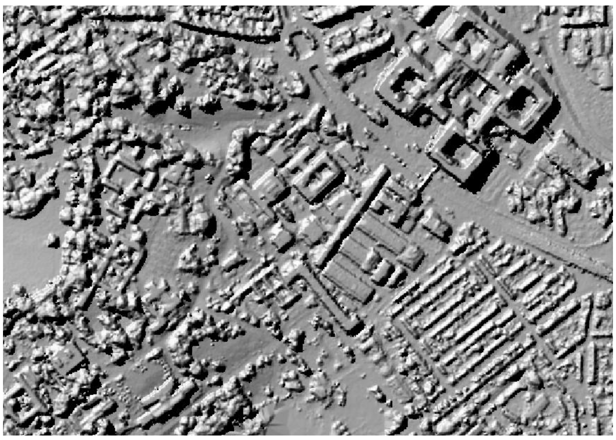

Figure 4. Shaded Relief Image of the DSM created from Trial 1

Table 6 summarises the vertical accuracy from the output statistics generated from the DSM computation using the benchmark aerial triangulation results. These are determined from the residuals on the ground control points.

Vertical Accuracy (using 20 GCPs) Benchmark DSM
Mean Error: 0.0590m
Mean Absolute Error: 0.1896m
Root Mean Square Error (RMSE): 0.2790m

Table 6. Summary of vertical accuracy statistics for the benchmark DSM

Shown in Figure 5 is a shaded relief image of the DSM created from the direct georeferencing solution AT Trial 3.

Table 7 summarises the vertical accuracy of the extracted DSM from direct georeferencing aerial triangulation Trial 3, again based on the residuals at the ground control points.

Vertical Accuracy (using 20 GCPs) Direct Georeferenced DSM
Mean Error: -0.0330m
Mean Absolute Error: 0.1737m
Root Mean Square Error (RMSE): 0.2334m

Table 7. Summary of vertical accuracy statistics for the Direct Georeferenced DSM

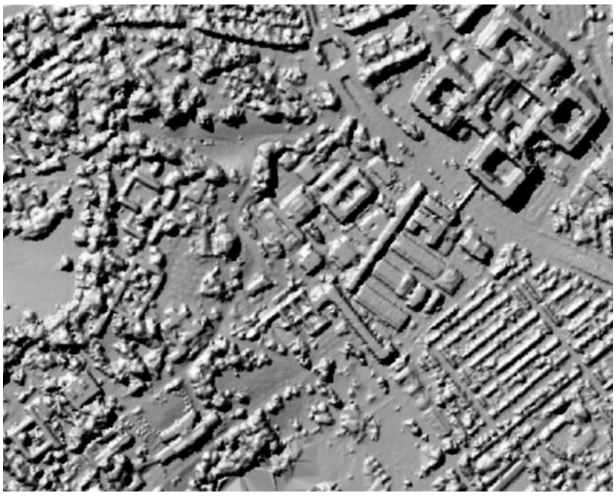

Figure 5. Shaded Relief Image of the DSM created from Trial 3

The vertical accuracy assessment of the DSM indicates that the difference between the direct georeferencing solution and the benchmark DSM is very small for most practical purposes. There is no visually noticeable geometric difference between Figure 4 and 5. Therefore, the DSM results show that the direct georeferencing solution can produce comparable results with an indirect solution.

In addition, a comparative study between the two DSMs was performed by differencing one from the other. The mean value was 0.11m with a standard deviation of 0.42m. Figure 6 shows a difference image between the two DSMs

The larger differences are caused by small planimetric variations in building outlines and vegetation as can be seen in Figure 6. This Figure shows the small planimetric positions on building edges would cause a significant difference in height with one measurement on the ground and one on the rooftop. The brown fan shapes on the bottom left of Figure 6 are due to measurement on a water surface.

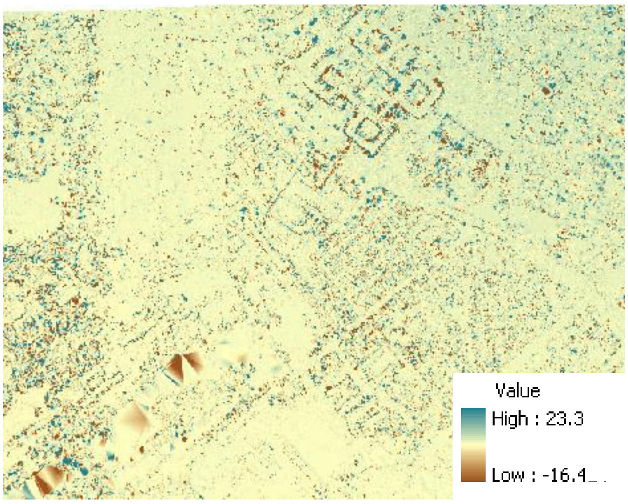

Figure 6. Difference Image from DSM comparison (m)

3.2.4 Ortho-image Generation

Ortho-image mosaics were generated using the digital terrain models from both the benchmark and the direct georeferencing AT solutions. No radiometric adjustments were made to the imagery. Figure 7 shows the entire mosaic created from the benchmark AT and the DSM whose results are summarised in Table 6.

Figure 7. Ortho-image mosaic from the benchmark AT-DSM

To compare the two ortho images the planimetric positions of a number of the control points have been measured and residuals are shown in Table 8 and Table 9. The differences on the individual points ranges from 3-7 cm and the mean values only differ by 5 cm. This can be considered a good result considering they are from a derived product from imagery with a GSD of 6cm.

Ground Control Pt ID	Residual (absolute magnitude, m)
GCP1	0.08
GCP2	0.12
GCP4	0.13
GCP12	0.09
GCP21	0.08
GCP3	0.07
GCP16	0.14
Mean	0.10

Table 8. Planimetric quality assessment of the ortho-image created from AT trial 1 and DSM

Ground Control Pt ID	Residual (absolute magnitude, m)
GCP1	0.11
GCP2	0.16
GCP4	0.18
GCP12	0.12
GCP21	0.13
GCP3	0.14
GCP16	0.20
Mean	0.15

Table 9. Planimetric quality assessment of the ortho-image created from AT trial 3 and DSM

4. CONCLUSIONS AND FUTURE ACTIVITIES

The results above have shown that the use of direct georeferencing using an aerial triangulation can produce results that are very similar to those achievable from a more traditional approach including plenty of ground control points. Even one ground control point can make a difference to the quality of the solution and does have the added advantage that it could provide an independent check on the computation process.

The comparisons of the DSM’s and the ortho-images once again show that the direct georeferencing can produce good quality results certainly extremely useful for geographic and environmental applications and could be useful in the design stage for engineering activities.

The results show that the great value of in-flight measurements of position and attitude supporting the efficient automatic measurement and processing of aerial triangulation tie points and further processes in the photogrammetric workflow

5. REFERENCES

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