INVESTIGATION INTO THE ORIENTATION OF OBLIQUE AND VERTICAL DIGITAL IMAGES

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ABSTRACT:

This paper provides an investigation into the orientation of oblique and vertical images using images from the Pictometry system and the UltraCamD digital aerial camera.

The Pictometry system creates libraries of a new form of digital, full colour aerial imagery enabling the capture of a vast amount of geospatial information. Pictometry, with its five camera system can capture a site of interest from many directions typically with a ground sampling distance (GSD) ranging from 15 to 60 cm. While Pictometry libraries contain vertical images (from a downward pointing camera) over 80% of the images are oblique (taken from sideways and, backward and forward pointing cameras) so that all the sides of ground features can often be seen. This flexibility of viewing angle provides an excellent system for geospatial data acquisition. The images can be supplied with software to enable the user to select and view the images with a small amount of information extraction capability. As the system is relatively new the full potential of the images for information extraction has not been fully exploited.

The Pictometry images are provided with georeferencing information so that potentially, efficient photogrammetric processing can take place. The quality of the orientation of the images will have a direct influence on the quality of the 'mapping', 3D point coordination. This paper will present the experiences from the research undertaken to date at the IESSG. It will show the results from various photogrammetric aerial triangulation scenarios which will allow the basic geometry to be assessed. As the widespread use of the UltraCamD starts providing extensive coverage, the combining of this vertical imagery with the Pictometry may provide added benefits for mapping and in particular for 3D city/urban modelling.

The IESSG has coverage of The University of Nottingham Campus from both Pictometry and the UltraCamD images and therefore forms an ideal test site for the research described. Ground control has been established and will form the basic control for the Pictometry and UltraCamD images. The benefits of self-calibration of the images are investigated during the various block configurations. The results of measurements from the GPS ground survey can be used to provide check points for the evaluation. Some interesting results have been obtained from the block of 86 UltraCamD images with approximately 6cm GSD and vertical/oblique Pictometry digital images covering approximately a 2 km^2 region with a GSD of approximately 10cm to 15cm.

1. INTRODUCTION

1.1 Background

There is an increasing demand from a growing range of applications, for 3D computer 'digital' models of our environment. Dependent on the application defines the level of detail required in the 3D model. This is comparable to the traditional concept of the scale of mapping required to ensure fitness-for-purpose. In many applications there is no need for a geometrically correct 3D model of an environment as there is only a need to view an area of interest to support a decision making process. This has major financial benefits as the creating of 3D models is a costly process. A geometrically accurate 3D landscape model may be necessary in some cases particularly where for example; there is a need for the integration with engineering design information. Extensive research is now taking place to create 3D urban models from various data sets and methodologies (Remondino and El-Hakim, 2006).

To enable visualization, particularly in urban areas with deep building canyons, the most appropriate viewing angle is often from the air looking obliquely at the ground and facades of the surrounding buildings. The benefits of oblique aerial photography are not new and examples of their application can be found in many classical text books (Thompson, 1966). As small format digital cameras have become available their use for taking oblique aerial images has stimulated interest (Warner et al., 1996).

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A further development in the technology has come about with the combining of cameras into clusters to create a merged 'single image' (Intergraph DMC, 2007) or to retain individual separate images (Pictometry, 2007). This has improved efficiency and enabled complete computer based workflows. It has also provided imagery with high radiometric qualities which can enhance the potential for automation of many image processing operations.

Further improvements of the digital computer workflow have been achieved through the use of integrating GPS and inertial measurement units (IMUs) with the digital imaging system. This has enabled direct measurement of exposure position and image attitude. The quality of the position and attitude will determine the potential application of direct georeferencing using these measurements.

1.2 Aims and objectives

The overall aim of the research is to investigate the geometric potential of using the Pictometry images for 3D modelling and texturing. The aim of this paper is to present results from the initial stage of this research which is investigating the orientation of the oblique and vertical digital aerial images from the Pictometry system. This will be investigated through the following objectives:

1. assessment of the images;
2. assessment of camera calibration;
3. benefits in combining Pictometry imagery with UltraCamD images;
4. investigation into the geometric quality of feature extraction.

1.3 Methodology

The methodology is based of the following stages:

1. Creation of a test site with available:
   a. Pictometry images;
   b. ground control and check points;
   c. UltraCamD imagery.
2. Assessment of images from aerial triangulation using LPS. The method of analysis is based on image, control and check point residuals. (all imagery refers to the Pictometry images unless otherwise stated):
   a. vertical image block;
   b. oblique image blocks;
   c. combined vertical and oblique images;
   d. UltraCamD images.
3. An analysis will be made of the workflow to obtain the initial values for input of the oblique imagery into the aerial triangulation.
4. An investigation will be undertaken in to the benefits of self-calibration.
5. Comparison between results from the different blocks.

2. TECHNOLOGY

2.1 Pictometry

The Pictometry system (Pictometry, 2007) creates libraries of a new form of digital, full colour aerial imagery enabling the capture of a vast amount of geospatial information. Pictometry, with its five camera system can capture a site of interest from many directions typically with GSD ranging from 15 to 60 cm. While Pictometry libraries include vertical images (from a downward pointing camera) over 80% of the images are oblique (taken from sideways and, backward and forward pointing cameras) so that all the sides of ground features can often be seen. This flexibility of viewing angle provides an excellent system for geospatial data acquisition. The cluster of cameras that are used are believed to be 'non-metric' and typical of high quality 'off-the-shelf' CCD cameras.

The images can be supplied with Pictometry's Electronic Field Study ™ software (EFS) to enable the user to select and view the images with a small amount of information extraction capability. It is possible to measure lengths, widths, bearings and perimeters. There is the ability to add some annotation with texts and lines as well as undertake some of the normal image processing operations for example, zoom and pan. The use of high quality oblique images does provide an excellent opportunity for interpretation and to typically undertake inspections of locations of interest, audits and inventories of facilities. Therefore the system has great benefits for visualization of the landscape particularly in urban areas.

As the system is relatively new the full potential of the images for metric information extraction has not been fully exploited.

2.2 Geometric consideration of the Pictometry system

The Pictometry images are provided with information so that potentially, efficient photogrammetric processing can take place. The quality of the direct measurement of the position and orientation of the images will have a direct influence on the quality of the 'mapping', 3D point coordination. There are a number of issues related to the use of this imagery for mapping purposes, issues such as; camera geometry and calibration, direct image geo-referencing, aerial triangulation quality with and without the directly measured parameters and choice of images for feature extraction and mapping.

3. TRIALS, RESULTS AND ANALYSIS

3.1 Test site

The IESSG has coverage of The University of Nottingham Campus with both Pictometry and the UltraCamD images and therefore forms an ideal test site for the research described. Ground control has already been established and will form the basic control for the Pictometry and UltraCamD images. By combining the two image sets together it is possible to assess the value of using the larger format UltraCamD images with the oblique images for 3D building model texturing. The benefits of self-calibration will be investigated during the various block configurations and GPS ground survey can be used to provide check points for the evaluation.

3.2 Imagery

The available data consist of a block of 86 UltraCamD images with a focal length of nominally 100mm, a pixel size of 0.009mm flown at a height of approximately 500m to give a GSD of approximately 6cm, with 60% forward overlap and 30% lateral overlap. High quality in-flight GPS and IMU data was available.

The Pictometry digital images covering approximately a 2 km^2 region with 27 vertical images, 12 oblique looking E, 15 looking west, 15 looking N and 15 looking S. The GSD for the oblique imagery is approximately 11 - 15cm with the flying height between approximately 1008m and 1038m. The GSD for the vertical imagery is approximately 10 - 14cm. The pixel size is 0.009mm with a nominal focal length for the vertical camera of 65mm and the oblique cameras of 85mm. The forward overlap for the vertical images varies from approximately 45% to 54% and the side lap from approximately 25% to 36%. The forward overlap of the oblique imagery is approximately from 21% to 47% and side lap from approximately 23% to 45%. High quality in-flight GPS was available but the rotation information was possibly of lower quality than normally expected for photogrammetric quality direct georeferencing.

3.3 Aerial triangulation results

3.3.1 Observation techniques:

A total number of 37 coordinated ground points were available. These points were collected using static GPS with an estimated accuracy of 5cm which was used as the standard deviation of the ground control points in the triangulations.

Blocks involving the UltraCamD and Pictometry images: The observation for the GCP both in the Pictometry and UltraCamD images was performed manually. Most of the GCP were easily identifiable due to the good radiometric quality of both blocks. Some difficulties were encountered while measuring GCPs on Pictometry images due to the tilt and the difference in scale. For the combined Pictometry-UltraCamD triangulation most GCPs were identified in both blocks. The tie points for the UltraCamD block were automatically extracted using a cross correlation area based matching technique available in Leica Photogrammetric Suite (LPS). Blunder and mismatched were identified manually by the operator based on the image residuals and were excluded in an iterative process after rerunning the AT. Tie points for the oblique image block were manually observed (see below) and the ground control/check points are also the tie points between the blocks.

Blocks involving vertical and oblique Pictometry images: Aerial triangulation for all Pictometry blocks was performed using LPS.

The number of tie points in the combined Pictometry block (vertical and oblique) is 494 points; 293 were generated automatically to tie the vertical images together and 201 points were generated manually to tie the oblique images together. This was necessary because the automatic generation of tie points did not work well with the oblique images due to different illumination and significantly different viewing directions.

All blocks: During the aerial triangulation computations a number of points were rejected due to large image or ground control residuals. The results from the best self-calibration method have been presented but often it was necessary to hold the focal length and the location of the principal point fixed to enable a solution to be achieved. This is possibly due to the large number (5) of cameras in the combined blocks. This resulted in a solution including only the remaining distortion parameters being computed.

With images with large tilts it is always difficult to produce initial values for the computation. The Pictometry images were provided with rotations that were used, with some modification, as initial values in many cases.

3.3.2 UltraCamD block results only:

To act as a benchmark for the comparison Table 1 shows the results from just the UltraCamD block. Block information: Total number of images: 86 images, see Figure 1; 32 GCPs measured (4 points excluded due to gross errors); total number of automatic tie points extracted: 1000, approximately 100 tie points were manually excluded due to mismatches and gross errors. No in-flight GPS or IMU measurements were used to make the scenario more comparable with the Pictometry image triangulations. Table 1 shows the results obtained although, further investigation is underway in to the quality of the ground coordinated points (control and check points) as many were established for traditional film images and not for considering the small GSD of this UltraCamD block.

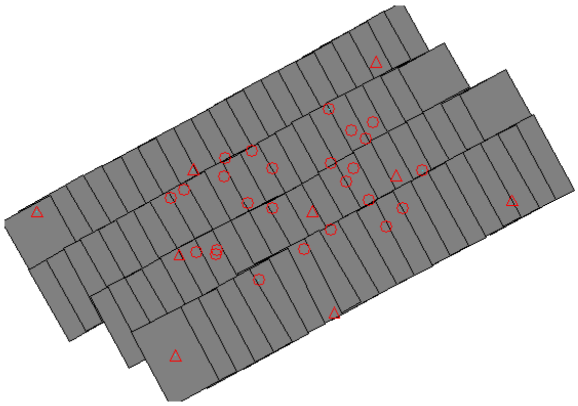

Figure 1. Block of UltraCamD images
(Δ = control points, O = check points)

Total image unit weight RMSE = 2.9μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.044 (8)	0.058 (24)
Ground Y m	0.032 (8)	0.044 (24)
Ground Z m	0.020 (8)	0.095 (24)
Image x μm	2.6 (21)	2.9 (86)
Image y μm	1.9 (21)	2.5 (86)

Table 1. UltraCamD block – good control distribution, Ebner's self-calibration, no in-flight GPS+IMU used
(note: approximately 60% forward overlap)

3.3.3 Combined UltraCamD and oblique Pictometry block:

Table 2 and Table 3 show the results from the combining of the UltraCamD with the oblique images, see also Figure 2. No in-flight control has been used just ground control. Block information: Total number of images: 170 (84 oblique images and 86 UltraCamD images); total number of control points used: 34, with the majority measured on both the oblique and vertical images acting as the tie points between blocks; total number of tie points: 1000 (approximately 200 of them measured on the oblique images); flying heights: 500m for the UltraCamD and 1000m for the oblique images.

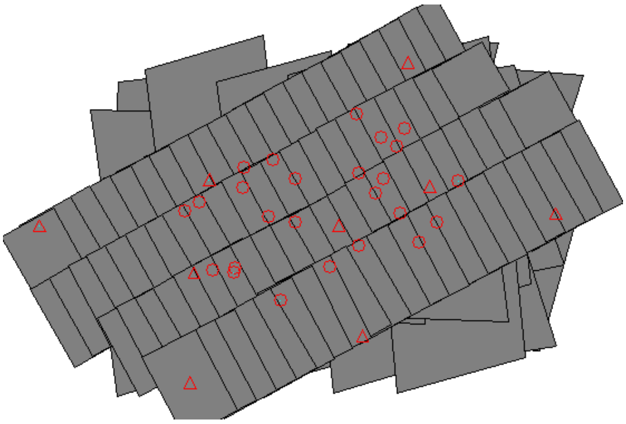

Figure 2. Combined block of UltraCamD and oblique Pictometry images (Δ = control points, O = check points

Total image unit weight RMSE = 4.5μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.085 (9)	0.071 (25)
Ground Y m	0.060 (9)	0.070 (25)
Ground Z m	0.049 (9)	0.093 (25)
Image x μm	3.8 (45)	6.7 (207)
Image y μm	3.7 (45)	5.2 (207)

Table 2. Combined block – good control distribution, no self-calibration

Total image unit weight RMSE = 4.5μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.082 (9)	0.054 (25)
Ground Y m	0.044 (9)	0.073 (25)
Ground Z m	0.033 (9)	0.120 (25)
Image x μm	3.8 (45)	6.7 (207)
Image y μm	3.5 (45)	5.2 (207)

Table 3. Combined block – good control distribution, Brown's self-calibration

The use of self-calibration has not made much difference to the results comparing Tables 2 and 3. It was observed that the more parameters used in the camera model the greater the check points residuals became, especially for the Z.

3.3.4 Vertical Pictometry Block:

The results from using just the vertical Pictometry images (see Figure 3) are given in Tables 4 and 5. These show very good image residuals and fit on the ground control points. The check points are showing probably more realistic values of what might be achievable for mapping. Again, no real benefits have been obtained from including self-calibration parameters. The image and the control point RMSE values are very good compared with the UltraCamD results but the check point RMSE values are not as good.

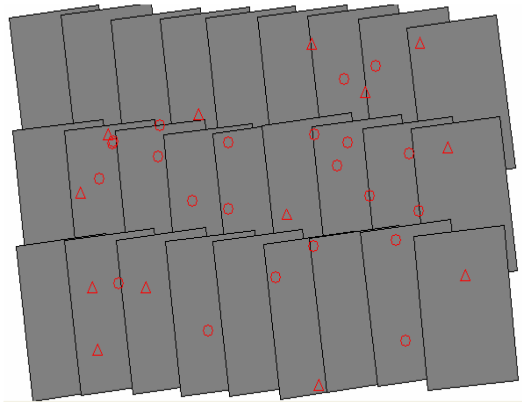

Figure 3. Vertical Pictometry block (Δ = control points, O = check points)

Total image unit weight RMSE = 2.8μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.044 (13)	0.078 (22)
Ground Y m	0.043 (13)	0.122 (22)
Ground Z m	0.006 (13)	0.238 (22)
Image x μm	1.9 (26)	1.8 (49)
Image y μm	2.0 (26)	1.7 (49)

Table 4. Vertical Pictometry block – good control distribution, no in-flight control, no self-calibration

Total image unit weight RMSE = 2.8μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.042 (13)	0.087 (22)
Ground Y m	0.041 (13)	0.125 (22)
Ground Z m	0.005 (13)	0.229 (22)
Image x μm	1.9 (26)	1.7 (49)
Image y μm	1.9 (26)	2.0 (49)

Table 5. Vertical Pictometry block – good control distribution, no in-flight control, Ebner's orthogonal self-calibration model

3.3.5 Combined Pictometry Block:

Combining both the vertical and oblique Pictometry image blocks (see Figure 4) produces the results presented in Tables 6 and 7. The self-calibration has produced a slight improvement in the Z RMSE for the control/check points and a small improvement in the image residuals.

Total image unit weight RMSE = 4.2μm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.058 (9)	0.142 (27)
Ground Y m	0.066 (9)	0.134 (27)
Ground Z m	0.070 (9)	0.137 (27)
Image x μm	3.7 (60)	4.9 (190)
Image y μm	3.5 (60)	4.7 (190)

Table 6. Combined Pictometry block – good control distribution, no in-flight control, no self-calibration

Total image unit weight RMSE = 3.9µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.053 (9)	0.133 (27)
Ground Y m	0.079 (9)	0.145 (27)
Ground Z m	0.030 (9)	0.097 (27)
Image x µm	3.2 (60)	4.7 (190)
Image y µm	3.0 (60)	4.4 (190)

Table 7. Combined Pictometry block – good control distribution, no in-flight control, Bauer's simple model (3) self-calibration

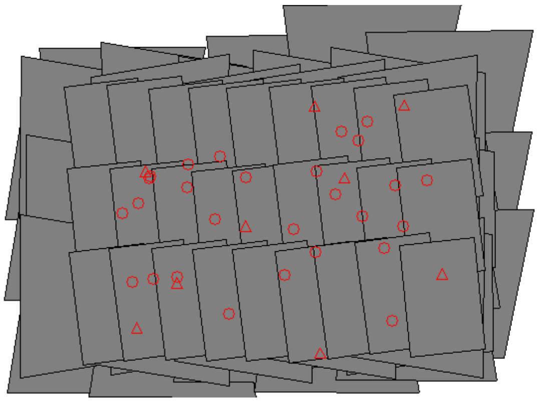

Figure 4. Combined Pictometry block (Δ = control points, O = check points)

3.3.6 Oblique Pictometry images only:

The oblique images are shown in Figure 5 and as can be seen from Tables 8 and 9 good results have been produced for point coordination compared with the combined block. The oblique images have nominally a 50º tilt from the vertical which can produce some very strong intersection angles and therefore good coordinates.

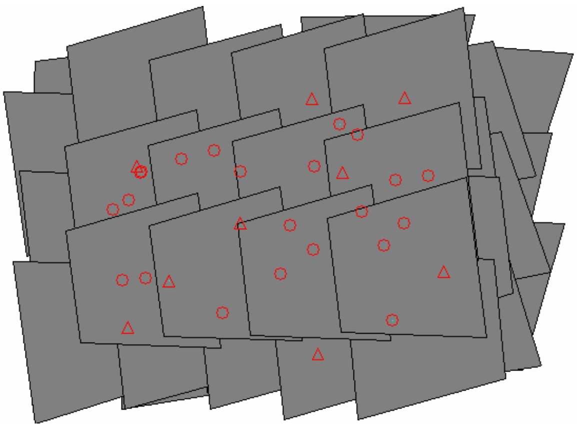

Figure 5. Oblique Pictometry image block (Δ = control points, O = check points)

Total image unit weight RMSE = 4.1µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.035 (9)	0.154 (22)
Ground Y m	0.100 (9)	0.168 (22)
Ground Z m	0.066 (9)	0.107 (22)
Image x µm	3.5 (41)	6.2 (123)
Image y µm	3.3 (41)	5.8 (123)

Table 8. Oblique Pictometry block – good control distribution, no in-flight control, no self-calibration

Total image unit weight RMSE = 3.9µm	Control Point RMSE (no pts)	Check Point RMSE (no pts)
Ground X m	0.048 (9)	0.148 (22)
Ground Y m	0.099 (9)	0.157 (22)
Ground Z m	0.032 (9)	0.094 (22)
Image x µm	3.1 (41)	3.8 (123)
Image y µm	2.8 (41)	3.9 (123)

Table 9. Oblique Pictometry block – good control distribution, no in-flight control, Lens distortion model self-calibration

3.4 Using the Pictometry for extraction of features, mapping

The use of combined blocks of vertical and oblique images in an aerial triangulation has shown that good point coordination can be achieved. The point coordination in an aerial triangulation can come from not just a pair of intersection image point's rays but from multiple rays. The quality is also further improved by the oblique images providing strong intersection angles at the measured points. However, this does not necessarily give a good indication of the feature extraction/mapping that can be obtained, as this is normally undertaken with a stereo pair. In a 'normal' stereo pair, single intersections are used and images would normally not have more than a few degrees of relative tilt between them. Using the Pictometry oblique images with the same viewing direction for stereo viewing is possible but large differential tilts are not helpful for comfortable stereo viewing. Further research is needed to investigate these key issues.

4. CONCLUSIONS AND FUTURE ACTIVITIES

The results have shown that the use of indirect georeferencing can produce good quality coordination of ground points. High quality image measurements have been achieved for all the image blocks. The directly measured Pictometry orientations have been used as initial values for the aerial triangulation computation, with some modifications to suit the rotation matrix.

The use of self-calibration caused some concern when the focal length and location of the principal point were left as unknown. Only a limited amount of benefit was obtained by including additional self-calibration distortion parameters.

The successful combining of the UltraCamD and the Pictometry images provides an excellent opportunity to produce an efficient method of high quality urban model texturing, which will be explored in the future.

There is still further investigation necessary into the quality of the aerial triangulation results to analyze the distributions of residuals (as only the summaries have been presented here), the quality of the ground coordinated points and into the use of in-flight control. Further work is also planned in using the imagery for 3D urban modelling.

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