The Use of Different Data Sets in 3-D Modelling

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Key words: oblique, triangulation,3D modelling, texturing, photorealism

SUMMARY

The needs for photo-realistic, modelling of the complete details, and geometrically accurate 3-D models are growing rapidly in several fields, especially in engineering and cultural heritage documentation. Photorealism and better details can be achieved through using terrestrial imagery but it is a very time-consuming process particularly in large modelling projects. It is possible to improve efficiency by image capture from a moving ground based vehicle but this requires an extra process in the work flow if the initial modelling has been undertaken by aerial photogrammetric processes.Pictometry imagery has been used for visual inspection especially in life-saving situations due to the fact that the Pictometry aerial imagery contains oblique (angled) images which provide better view and greater detail. The more conventional method of collecting aerial images with for example the UltraCamD, can also provide excellent views of roof tops and some of the building facades when located away from the nadir on the images.

This paper explored the geometry of the Pictometry images (vertical and oblique) and the possibility of using this imagery in 3-D modelling to produce photo-realistic and accurate models. In addition, merging terrestrial imagery with Pictometry imagery to get more ground level details has been investigated. All work has been carried out using the available software packages at the Institute of Engineering Surveying and Space Geodesy (IESSG) and using data provided by Blom Aerofilms Ltd.

The results of the aerial triangulation of different Pictometry blocks showed that high quality image measurements have been achieved for all the image blocks. Extraction of 3D geometry for all buildings in the study area has been performed using both vertical Pictometry imagery and UltraCamD imagery. The successful combining of vertical and oblique Pictometry images provided an excellent opportunity to produce an efficient method of high quality urban model texturing. The integration of terrestrial images of building facades (whose texture needs enhancement) with the combined aerial imagery block has been successfully and automatically performed.

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1. INTRODUCTION

1.1 Background

Site recording and modelling has been an important topic in photogrammetry from its very beginning in the middle of the 19th century. Since then technologies have changed several times fundamentally (Gruen, 2000). The recent rapid development of multisensor and multimedia technologies has made it possible to construct and visualise detailed 3D models of our built environment. Three-dimensional modelling of objects and scenes is an intensive and long-lasting research problem in the computer graphic, vision and photogrammetric communities (El-Hakim and Remondino, 2006).For 3D city models, the most important features are buildings which have to be acquired in densely built-up areas, centres of cities and towns where very complex, highly irregular house and roof patterns are common. Figure 1 shows some of the different roof patterns that are present in the study area.

Figure 1: Examples of different roof patterns in the study area

Other features that might be included in 3D city models are street-level scenes such as roads, urban vegetation, trees, and cars. 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.

1.2 Importance of 3D Models

The needs for 3D city models are growing and expanding rapidly in a variety of applications in recent years. In a steady shift from traditional 2D-GIS toward 3D-GIS, an increasing amount of accurate 3D city models have become required to be produced in a short period of time and provided widely on the market. The biggest advantage of the 3D model is its mobility and its convincing effect on users for future decision making processes. It has the potential to be shown everywhere and allows people who cannot or do not want to travel to get to know the region (Tunc et al., 2004).Digital 3D models have some advantages over traditional ways of geospatial data handling (Lerma et al., 2004):

- Due to its digital storage, models can be supplemented and reconstructed into different environments by means of importing and exporting tools.
- Realistic presentations of the model can be produced by using some kind of interactive animation and simulation environments (for example, VRML or X3D).
- Last but not least, digital models can always be updated and rebuilt individually or just be considered as a part of a complex model.

1.3 Aim and Objectives

The overall aim of this paper is to investigate the geometric potential for using Pictometry imagery to provide 3D city modelling and texturing. This aim will be assessed through investigating the following objectives:

- Assessment of the images.
- Benefits in combining Pictometry imagery with UltraCamD images.
- Investigating the geometric quality of feature extraction.
- Assessment of 3D geometry of all buildings extracted using both photogrammetric systems: Pictometry and UltraCamD.
- Investigation into the quality of texturing the 3D models using vertical, oblique and combined blocks of both camera systems.

2. TEST SITE AND DATA SETS

2.1 Test Site

Images were available covering The University of Nottingham Campus with both Pictometry and the UltraCamD images and formed an ideal test site for the research described. Ground coordinated points have been established and formed the basic ground control for the Pictometry images and UltraCamD images. A small area in the city centre of Nottingham will be used as a further application case study where only Pictometry images are available. GPS ground survey has been used to provide independent check points for the evaluation.

2.2 Imagery

The available data consists 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 cover approximately a 2 km^2 region of The University of Nottingham main campus and about 0.5 km^2 in the city centre area. The GSD for the oblique imagery is approximately 11 - 15cm with the flying height between approximately 975m 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 38% to 46% and the side lap from 25% to 36%. The forward overlap of the oblique imagery is approximately from 21% to 47% and side lap 23% to 45%.The oblique images were taken at an inclination angle of about 50° from multiple viewing directions. This makes the building facades in both study areas adequately visible. In-flight GPS and rotation information was available but the quality is not fully known.

3. TRIALS, RESULTS AND ANALYSIS

3.1 Observation Techniques

A total number of 39 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 pointswere generated manually to tie the oblique images together.

This was necessary because the automatic generation of tie points did not work 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. 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.

3.2 Aerial Triangulation Results

Aerial triangulation for all Pictometry blocks and for UltraCamD block was performed using LPS software package. Four solutions have been considered; 'float solution', 'constrained solution', 'integrated sensor orientation solution' and finally 'direct georeferencing or only in-flight GPS and IMU' solution.

3.2.1 <u>UltraCamD block results</u>

For the block of UltraCamD images, there are 33 control points. 9 points were selected as ground control points and 24 as check control points for the first two AT trials, while all control points were used as check points for the third and fourth AT trials. The distribution of the tie points and control/check points is shown in figure 2 as well as the images footprint and the camera X-axis.

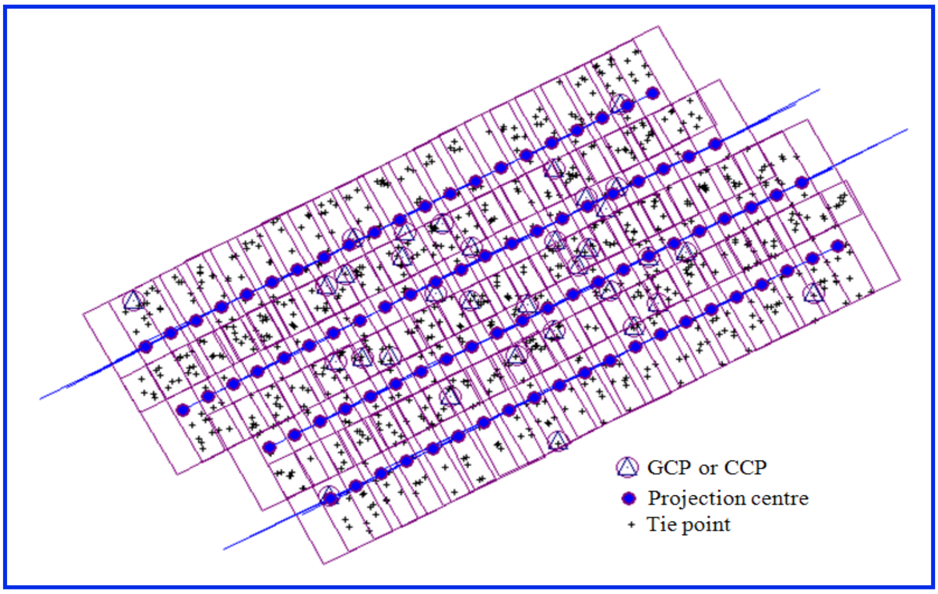


Figure 2: UltraCamD images block showing images footprint, distribution of GCPs and tie points, and camera x-axis.

The AT results of the 4 solutions are shown in table 1. The results show very good image residuals and fit on the ground control points. The check points show more realistic values of what might be achievable for mapping. The GSD is about 5cm, the accuracy of CCPs in float solution reach 4cm, 4cm and 9cm on the ground in X, Y and Z components respectively. These are equivalent to 0.80, 0.80 and 1.8 GSD respectively. As the nominal vertical camera focal length is 100mm and the average flying height is 500m, this corresponds to 8, 8, and 18µm in image scale which is 0.89, 0.89, and 2.0pixels respectively.

Table 1: Results of AT for UltraCamD images vertical block using 4 different solutions.

Solution		Float		Constrained		Integrated		DG	
AP		No	Yes	No	Yes	No	Yes	No	Yes
Total RMSE (µm)		3.0	2.9	3.1	2.9	3.1	3.0	5.2	4.9
GCPs RMS (no.pts)	X (m)	0.062 (9)	0.059 (9)	0.069 (9)	0.059 (9)	-	-	-	-
	Y (m)	0.068 (9)	0.055 (9)	0.056 (9)	0.043 (9)	-	-	-	-
	Z (m)	0.052 (9)	0.020 (9)	0.036 (9)	0.036 (9)	-	-	-	-
CCPs RMS (no.pts)	X (m)	0.062 (24)	0.043 (24)	0.067 (24)	0.048 (24)	0.069 (33)	0.058 (33)	0.090 (33)	0.089 (33)
	Y (m)	0.048 (24)	0.037 (24)	0.056 (24)	0.047 (24)	0.103 (33)	0.073 (33)	0.055 (33)	0.055 (33)
	Z (m)	0.118 (24)	0.089 (24)	0.107 (24)	0.109 (24)	0.105 (33)	0.096 (33)	0.123 (33)	0.102 (33)

3.2.2 Vertical Pictometry Images Block

For the vertical Pictometry images block, the images are in the range of only 29 control points. 10 points were selected as ground control points and 19 as check control points for the first two AT trials while all control points were used as check points for the third and fourth AT trials. The distribution of the control/check points is shown in figure 3 as well as the images footprint. Although a great effort was made to ensure a good distribution of the control points throughout the block, the distribution of GCPs in the vertical Pictometry block was not ideal due to the lack of features that can be recognized or have enough texture and recognizable features in the upper left corner of the block as that area is covered completely by trees. However, since GPS/IMU data observations are available for each image, the weak control point configuration may not be a problem.The results (table 2) show very good image residuals and fit on the ground control points. The check points show more realistic values of what might be achievable for mapping. When the GSD is 15cm, the accuracy of CCPs in float solution reach 9.4cm, 8.2cm and 29.5cm on the ground in X, Y and Z components. These are equivalent to 0.63, 0.55 and 2 GSD respectively. As the nominal vertical camera focal length is 65mm and the average flying height is 1000m, this corresponds to 6.1, 5.3, and 19µm in image scale which is 0.68, 0.59, and 2.1pixels respectively.

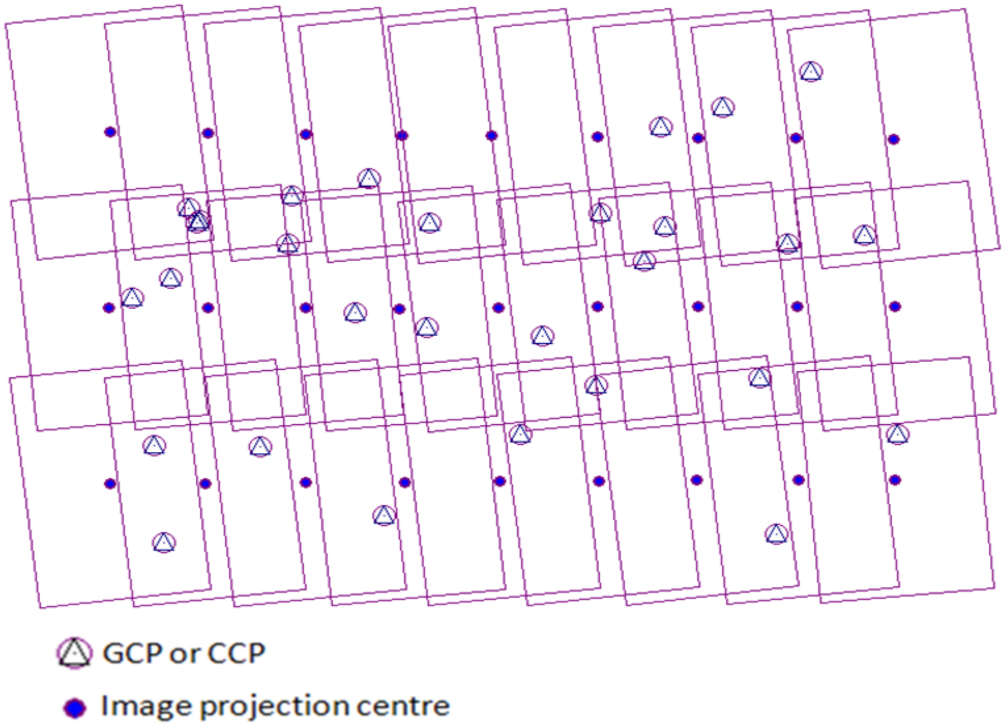


Figure 3: The vertical Pictometry images block showing the distribution of control points and images projection centres.

Compared to the vertical Pictometry block, it is clear that the accuracy of UltraCamD is much better. It is better by a factor of about 2 to 3. The low checkpoint residuals prove the high geometric quality of the UltraCamD camera system. In addition to the quality of the camera system, the other factors that need to be taken into consideration when comparing the two systems are: the distribution of GCPs is much better for UltraCamD block and the overlap is not ideal for Pictometry block.

3.2.3 Oblique Pictometry Images Block

The oblique Pictometry block consists of 57 oblique aerial photographs (photographs taken with the camera axis points between the horizontal and vertical);12 of them looking East, 15 looking West, 15 looking North, and 15 looking South. For this block, the images are in the range of only 31 control points. 9 points were used as ground control points and 22 as check control points for the first two AT solutions while all control points were used as check points for the third and fourth AT solutions.Figure 4 depicts the imagery footprints after the performance of AT.

Table 2: Results of AT for vertical block using 4 different solutions

Solution		Float		Constrained		Integrated		DG	
AP		No	Yes	No	Yes	No	Yes	No	Yes
Total image RMSE(µm)		1.6	1.6	1.7	1.6	2.2	2.1	6.1	2.4
GCPs RMS (no.pts)	X(m)	0.025 (10)	0.024 (10)	0.029 (10)	0.025 (10)	-	-	-	-
	Y(m)	0.038 (10)	0.028 (10)	0.040 (10)	0.035 (10)	-	-	-	-
	Z(m)	0.009 (10)	0.006 (10)	0.011 (10)	0.011 (10)	-	-	-	-
CCPs RMS (no. pts)	X(m)	0.094 (19)	0.089 (19)	0.086 (19)	0.080 (19)	0.283 (29)	0.278 (29)	0.208 (26)	0.204 (26)
	Y(m)	0.082 (19)	0.076 (19)	0.077 (19)	0.071 (19)	0.447 (29)	0.458 (29)	0.552 (26)	0.460 (26)
	Z(m)	0.295 (19)	0.163 (19)	0.157 (19)	0.147 (19)	0.921 (29)	0.498 (29)	0.644 (26)	0.629 (26)

The results of AT for the oblique block are given in Table3. The results show good image residuals and fit on the ground control points. Again, the RMS of CCPs shows the realistic value of what can be achieved in mapping. Including the additional parameters in float and constrained solutions gave a big improvement for the total image RMSE (10 to 20%) and a slight improvement for CCPs RMS.The use of AP model improved the RMS of CCPs significantly which implies the possible existence of systematic errors before applying the additional parameters. It improved the results by a factor of 2 to 3; the biggest accuracy gain was in the height which jumped from 78cm to 28cm.

3.2.4 Combined UltraCamD and Pictometry Imagery Block

This block consists of two blocks: the UltraCamD images block and the oblique Pictometry images block. It comprises 143 images; of which 86 are UltraCamD images and the remaining 57 images are oblique Pictometry images. The number of points that was used as ground control points is 9 and the number of points used as check control points is 30. The distribution of the tie points and control/check points is shown in figure 5 as well as the images projection centres and the camera X-axis while figure 6 depicts the images footprint after the performance of AT.

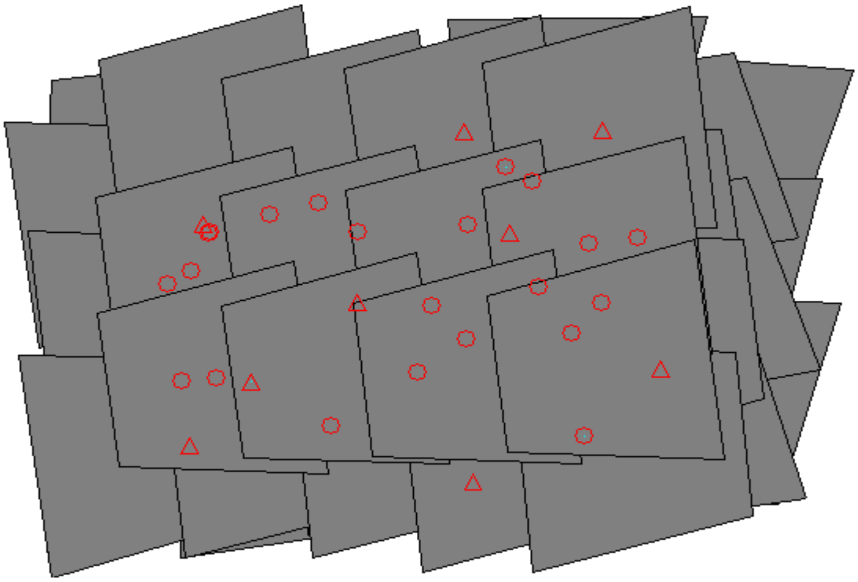


Figure 4: Oblique images footprint after performing AT

Table 3: Results of AT for oblique images block using 4 different solutions

Solution		**Float**		**Constrained**		**Integrated**		**DG**	
AP		**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Total image RMSE(µm)		3.8	3.2	4.2	3.4	4.9	4.0	10.0	5.5
GCPs RMS (no.pts)	**X(m)**	0.030 (9)	0.021 (9)	0.056 (9)	0.025 (9)	-	-	-	-
	Y(m)	0.061 (9)	0.050 (9)	0.093 (9)	0.060 (9)	-	-	-	-
	Z(m)	0.066 (9)	0.027 (9)	0.053 (9)	0.023 (9)	-	-	-	-
CCPs RMS (no. pts)	**X(m)**	0.159 (22)	0.142 (22)	0.160 (22)	0.144 (22)	0.625 (31)	0.240 (31)	0.348 (31)	0.339 (31)
	Y(m)	0.187 (22)	0.181 (22)	0.192 (22)	0.172 (22)	0.398 (31)	0.169 (31)	2.957 (31)	2.282 (31)
	Z(m)	0.113 (22)	0.076 (22)	0.086 (22)	0.071 (22)	0.781 (31)	0.286 (31)	0.803 (31)	0.567 (31)

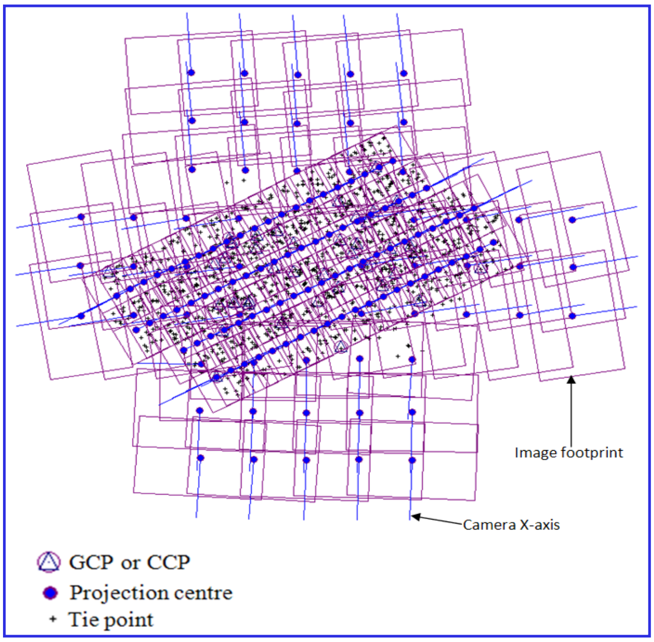


Figure 6: The combined UltraCamD and oblique Pictometry images footprint after performing AT

Figure 5: Distribution of the tie points and control/check points as well as the images projection centres and the camera X-axis of the combined UltraCamD and oblique Pictometry images block

The DG solution was not possible in this block because when the EOP set as fixed values, the graphical display function in LPS shows each type of images as one cluster that has the same projection centre (i.e. one cluster of UltraCamD images, and one cluster from each direction of oblique images). In addition, it shows the GCPs, CCPs, and tie points far away from UltraCamD images which should be exactly on top of them as they are vertical images. The reason behind this might be related to the number of cameras used and the different types of them. Furthermore, different flying height between the two sorties. In addition to that, the quality of the EOP of Pictometry camera system is not known so when setting them as fixed values, they affect the solution. Finally, the software itself could be the reason; it may not support the situation of different cameras with different flying heights as well as setting EOP to fixed values. The results of AT trials are shown in table 4.The results show good image residuals (about one third of a pixel) and fit on the ground control points. Including the additional parameters in float and constrained solutions gave a little improvement for the total image RMSE and a big improvement for the height component of GCPs.With regard to the integrated solution, the use of AP model improved the RMS of CCPs significantly in X-direction (improvement of about 65%) and improved the Y-component slightly. On the other hand, the height accuracy was better before applying the additional parameters.

Table 4: AT results of the combined UltraCamD and oblique images block

Solution		Float		Constrained		Integrated	
AP		No	Yes	No	Yes	No	Yes
Total RMSE(µm)		3.4	3.3	3.5	3.4	3.5	3.1
GCPs RMS (no.pts)	X(m)	0.074 (9)	0.080 (9)	0.087 (9)	0.092 (9)	-	-
	Y(m)	0.055 (9)	0.051 (9)	0.051 (9)	0.049 (9)	-	-
	Z(m)	0.052 (9)	0.035 (9)	0.056 (9)	0.030 (9)	-	-
CCPs RMS (no.pts)	X(m)	0.075 (30)	0.074 (30)	0.096 (30)	0.095 (30)	0.442 (39)	0.158 (39)
	Y(m)	0.076 (30)	0.072 (30)	0.083 (30)	0.081 (30)	0.226 (39)	0.198 (39)
	Z(m)	0.091 (30)	0.109 (30)	0.103 (30)	0.080 (30)	0.212 (39)	0.275 (39)

3.3 Modelling results

Building modelling using aerial photos requires different processes which can be summarised as following (Smith et al, 2009):

- Extraction of 3D geometry of buildings using the roof outlines.
- Extrusion of the digitised polygons of each building as a whole.
- Texturing the 3D models using different techniques.

3.3.1 Extraction of 3D geometry

The 3D building reconstruction is a difficult problem, mainly due to the complexity of the buildings. The success of automation in this field depends on many factors and is a hot topic in research (Ortin and Remondino, 2008).

For efficient building modelling, it is preferable to first digitize all the small roof details (dormers, chimneys, ventilation equipment etc.) using 3D polygons and then digitize the main roof outline as a separate polygon. In order to create the building facades, all the roof polygons then should be extruded onto the ground level to create the polyhedral model. Extrusion turns points into vertical lines, lines into walls, and polygons into blocks. Extraction of 3D geometry for all buildings in both study areas has been performed using vertical Pictometry imagery block. The UltraCamD block was used to extract the 3D geometry for onlythe University campus test site. Extraction of 3D geometry from the oblique images was not possible because some roof outlines cannot be seen due to the tilt of the oblique images. However, the availability of oblique imagery during digitization provided additional information for the interpretation of geometry by allowing each building to be seen from different angles. Oblique images were of a great benefit in helping the interpretation of building outlines where differences in building height required digitizing of separate polygons.Overall, the level of detail for the 3D models derived from the Pictometry images block is comparable with the level of detail acquired from the UltraCamD images block bearing in mind that the scale of Pictometry images, although it is suitable for extraction of 3D building geometry with some fine details, is much smaller than that of UltraCamD images.

3.3.2 Accuracy of 3D models extracted from Pictometry imagery

The 3D building polygons extracted from Pictometry imagery will be compared with the benchmark (BM) polygons (extracted from UltraCamD) qualitatively and quantitatively.The qualitative evaluation includes a visual comparison between the reconstructed buildings from the vertical Pictometry imagery and the BM building models. This comparison will provide a useful indication of the overall quality. The qualitative comparison for some of the reconstructed buildings in the University main park is given in figure 7.

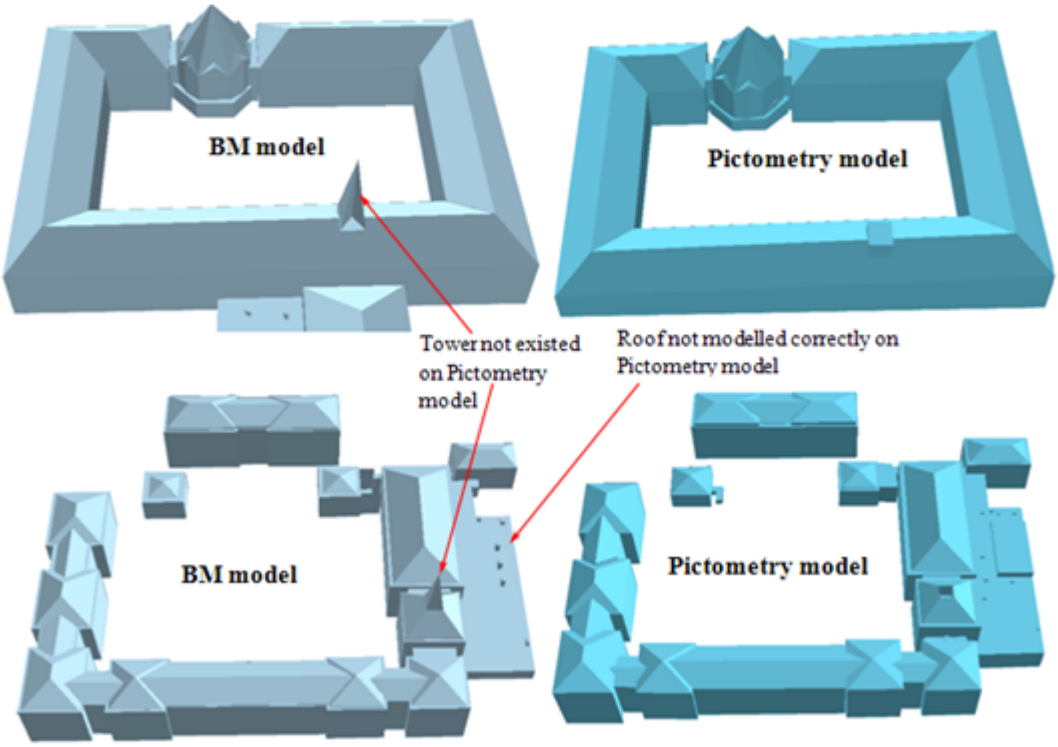


Figure 7: Qualitative comparison between the UltraCamD 3D models (BM) and the vertical Pictometry 3D models for Nottingham University main campus.

For the quantitative evaluation of the Pictometry 3D models, a planimetric and height accuracy were compared with the BM models, figure 8. Table 5 shows a summary of the results achieved from comparing 977 points on 99 buildings in plan (X and Y components). It also shows the results of comparing 762 points on 100 buildings in height (Z component). From the results in Table 5, the GSD and the flying height between the two camera systems must be taken into consideration. The Pictometry imagery has produced good results especially in X and Y taking into consideration the differences in resolution.

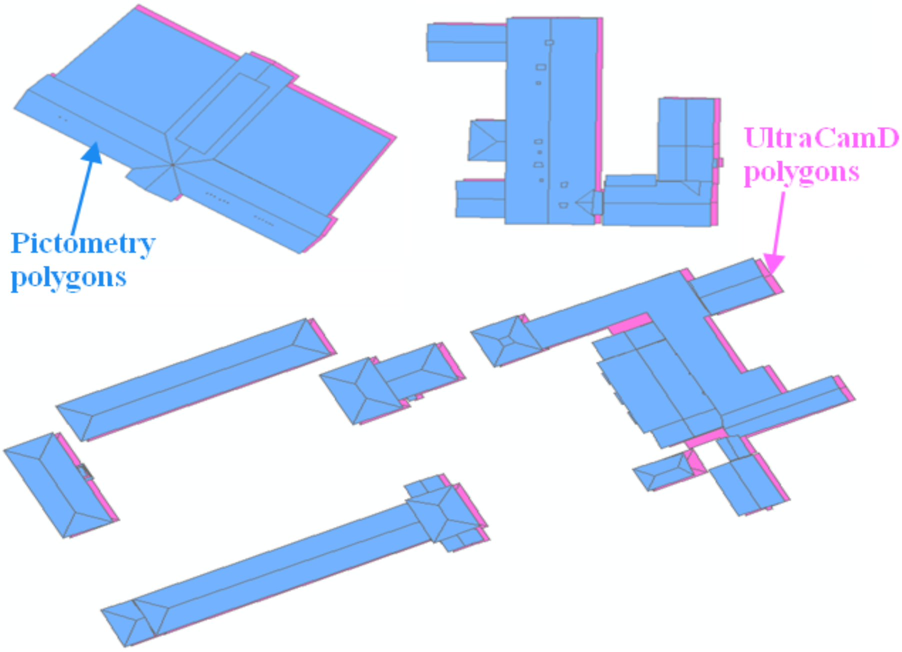


Figure 8: Two roof outlines imposed over each other to be used for Planimetric comparison.

Table 5: Results of quantitative evaluation of 3D polygons extracted from Pictometry and UltraCamD

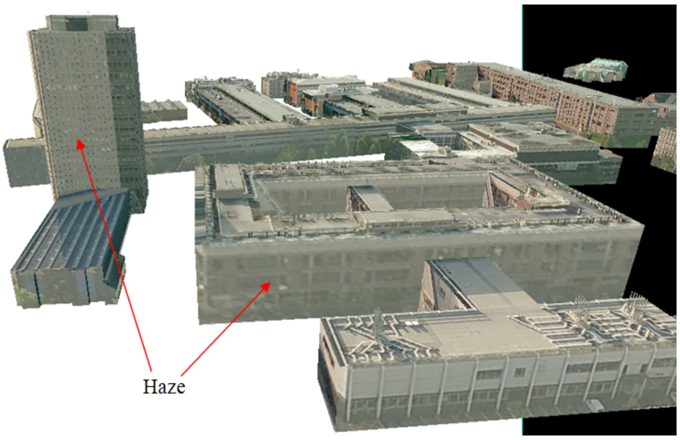
Component	X	Y	Avg. Z
Min.	-0.960	-0.800	-2.380
Max.	0.582	0.590	2.300
St.dev.	0.286	0.187	0.952

3.4 Texturing results

Adding texture to the building models created is important since it makes 3D models more realistic. Texturing of the 3D polygons was performed using the vertical Pictometry block, oblique Pictometry block, UltraCamD block, a combined (vertical and oblique) Pictometry block, and combined UltraCamD and Pictometry block. The visual inspection of the textured models show that using either vertical Pictometry block or UltraCamD block has given very good roof structure but when it comes to façade texturing the quality was not as good as roofs quality, the texture quality of the building facades is considerablydegraded.When only the block of oblique images was used for texturing the 3D models, the façade texturing was of very good quality but the texturing quality of some buildings' roofs was reduced compared with the vertical images, figure 9. Combining both vertical and oblique images gives the benefit of good quality textures for both the roofs and facades, figure 10.

Figure 9: 3D building model textured using Figure 10: 3D building model textured using Pictometry oblique images blockPictometry combined block,

The overall quality of the Pictometry images is characterized in some instances by the presence of haze which affects the texture mapping quality; figure 11.Figure 12 shows the effect of area that cannot be seen from the aerial images due to shadow or perspective view often called 'dead ground'. Figure 12 also shows a building with internal quadrangles which are very challenging to texture from airborne images. Occlusions can occur often due to vegetation or dynamic objects (e.g. moving people or vehicles). Modelling these objects and the buildings behind correctly is often complex or time-consuming. This can only really be overcome by the use of terrestrial images behind the vegetation although it is very time-consuming process particularly in large modelling projects (Meng and Forberg, 2007) or using patches of the visible façade to paste over the obscured surface.The integration of terrestrial image of any building facade with the combined aerial imagery block has been successfully and automatically performed (Hamruni and Smith, 2013). This allows for automatically using terrestrial images in texturing which significantly enhances the facades and at the same time is faster, cheaper, more accurate, and easier to implement.



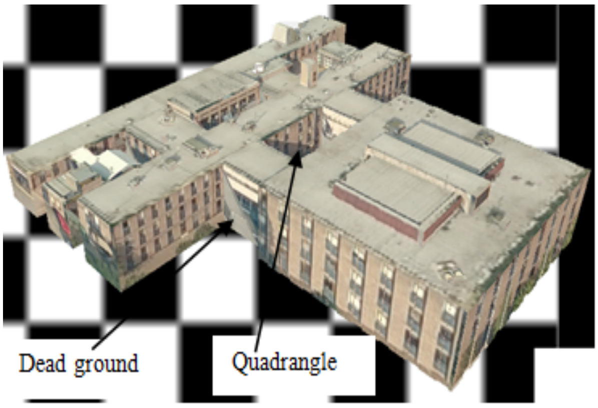


Figure 11: Texturing quality is affected by hazeFigure 12. Texturing quality is aaffected
in some imagesby dead ground in some images

4. CONCLUSION

The use of combined blocks of vertical and oblique images in AT showed that good point coordination can be achieved. The results show thatthe revolutionary Pictometry oblique imagery can be used for texture mapping large models quickly and can enable photorealism. Terrestrial imagery might be combined with oblique imagery in certain areas to give better quality models, particularly when 'ground level' viewing of the models is required.

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