COMPARISON OF DIGITAL AERIAL CAMERAS WITH ANALOGUE CAMERAS

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ABSTRACT:Digital aerial cameras have replaced analogue aerial cameras in several countries. The development for operational aerial photogrammetry started with the line scan camera ADS40, followed by Z/I Imaging DMC and Vexcel Imaging UltraCam. The capacity of the UltraCam was enlarged by replacing the used CCDs with 9µm pixels over 7.2µm to 6µm for the UltraCamXp, having 196 Mpix instead of UltraCam D . The DMC and the UltraCam are system cameras, reaching the large number of pixels by a combination of the DMC and the UltraCam are system cameras, reaching the large number of pixels by a combination of 4, respectively 9 CCDs. Even if the large format line scan cameras have demonstrated their geometric potential, the major replacement of analogue cameras came by the digital large frame cameras, while the line scan cameras found their major field with orthoimages.

In the meantime digital mid-format cameras, equipped with a single CCD-array, with approximately 39 Mpix took also a share by the replacement of the analogue aerial cameras. Their combination with GPS and inertial measurement units (IMU) compensates partially the disadvantage of handling a high number of images. The mid-format cameras are equipped with Bayer pattern, limited to 3 spectral bands in relation to the 4 spectral bands offered by the large format frame and line scan cameras. This changed by the introduction of mid-format system cameras RMK D from Z/I Imaging DMC and UltraCamL from Vexcel Imaging. In addition now camera systems equipped with 4 mid-format cameras as the IGI Quattro DigiCAM and the Trimble Aerial camera (former Rolleimetric) AIC-x4 are offered. These cameras are not offering homogenous virtual images as the DMC and UltraCam.

A new situation now came with the development of large format monolithic CCDs. Based on this Z/I Imaging introduced now the DMC II 140, having 11712 x 11200 pixels on one CCD with 2 sec frame rate. In the fall the DMC II 230 (230 Mpix) and in the spring 2011 the DMC II 250 with 17216 x 14656 pixels with 1.7 sec frame rate will follow. This corresponds to the dream of photogrammetrists replacing the film just by one CCD.

This reserch have been working with the early test flight data captured by the new Vexcel UltraCam D digital camera and the GPS / IMU position and attitude system into their aircraft, product range and photogrammetric work flow.

This paper presents results from the early flight trials which have started to explore the potential of the UltraCam D digital camera. The quality of products produced from any imagery is often

dependent on a variety of parameters and influences whether they have been produced from a digital or traditional film camera. The research is starting at the beginning of the photogrammetric processes by investigating initial results primarily from direct geo-referencing and aerial triangulation. The imagery was not taken specifically for the purpose of this scientific trial but the results are interesting and a further scientific trial is being planned.

KEY WORDS: Digital cameras, Aerial triangulation, GPS, IMU, Digital images

1. INTRODUCTION

1.1 Introducing New Technology

There are now a wide range of digital imaging systems available for use on an airborne platform (Cramer, 2005). These range from single lens 'small' format digital cameras typically used by the general public through to 'larger' format multiple lens systems and linear array 'push boom' scanners. With the change in imaging system come a new range of issues that have to be addressed to use the images for the collection of geospatial information. The purchase of the image capture system can be just a part of the overall cost of introducing the technology into a production environment.

Although the photogrammetric community is familiar with handling digital images from scanned film based cameras, existing production methods may not lend themselves directly to accommodate different scales and formats of imagery often found when using a digital imaging system. Alterations in photogrammetric work flow and product range need to be optimised to ensure the highest economic benefits of the new technology.

The introduction of new technology necessitates a steep learning curve in technical expertise, new production methodologies and quality control. Fundamental to this learning process is the need to understand the capabilities of the technology which often comes from experience and specific trials.

The benefit of a digital aerial camera UltraCam D can be measured by several parameters. One way of assessing performance is by comparing a digital camera to the traditional film based camera. The comparison between digital and film-based data could be performed by taking into account photographic and photogrammetric issues, not only radiometric quality, but also the geometric performance of digital and analogue cameras (Perko et al., 2002). However, there is also a good case for not undertaking a direct comparison in this way, as the cameras are of such different design and this is discussed further in Section 3.2.1.

Thurgood et al. (2004) identifies some of the advantages of the Vexcel Ultracom D camera as:

- Superior economy since there is no cost for film, development and scanning; and the operational cost is the same as the traditional film camera since the number of flight lines is almost the same. This is based on design issues, because the UltraCam D large format digital aerial camera has been developed to offer an image of nearly 90 Megapixels at a frame size of 11,500 pixels across track (equivalent to the 230mm aerial film scanned @ 20 µm pixel size) and 7,500 pixels along track.

- A maximum frame rate of 1.3 images per second allows extremely large image scales, and enables the system to operate for a large scale stereo imaging mission with 60 % overlap at a GSD of 1 inch.

- Gruber et al. (2004) suggests a more reliable means of automated production can be achieved by using the UltraCam, because the design of this camera with its parallel architecture permits a very high framing rate, thus affording flexibility to select a forward overlap of up to 90%.

The full exploitation of this complex new mapping tool will take time to achieve but some early results are very encouraging. The quality of products produced will be dependent on a wide variety of parameters and influences, ranging from the calibration of the integrated system to the image measurement quality and data processing strategies.

The flights took place over a small area containing only a limited number of existing ground control points, and unfortunately for the first flight the GPS base section was further from the test site than preferred (30km). This test area has been used in the past as a test area for traditional 230 x 230mm metric camera photography. The data collected from the test site has enabled some interesting analysis to take place.

1.2 Aims

The general aim of the research is to investigate the potential and capabilities of the Vexcel UltraCam D digital camera. Of particular interest at this early stage is the positional accuracy of the geographical information that can be extracted. This is initially being explored by analysing results from aerial triangulation and direct geo-referencing. This normally forms the first stage of a photogrammetric activity and it is therefore appropriate that this is the starting point for these studies.

1.3 Methodology

As part of the early flight trials with the UltraCam camera a small test area was flown containing only a limited number of ground control points and a GPS base station some distance away. Although it was not planned to undertake a rigorous scientific analysis from this flight it was felt part of the data collected could be used for preliminary photogrammetric analysis. The control distribution within the block of images is not ideal but there is sufficient to perform aerial triangulation and start to appreciate the capabilities of the camera. A further flight trial was undertaken over approximately the same area but with a more local GPS base station (10km) and at a different flying height. To act as a comparison, the results from a similar photogrammetric sortie but using scanned images from a traditional metric frame camera are presented.

1.4 GPS and IMU

The direct measurement of position and attitude is produced by an Applanix POS 510 GPS/IMU system using the post processing software, POSPac (4.02). The specification provided by the manufacturer for the GPS/IMU system is given in Table 1.

Position (m)	0.05 - 0.30
Velocity (m/s)	0.005
Roll and pitch (deg)	0.005 (1/200th)
True heading (deg)	0.008 (1/125th)

Table 1. Specification of the Applanix system for direct measurement of position and attitude

This system provides the potential for in-flight control for aerial triangulation, enabling a reduced amount of ground control to be used, or direct geo-referencing of individual images.

2. TEST SITE

2.1 Aerial Triangulation Tests

As discussed above the images and data collected were collected from an early ‘general performance’ test flights and not specifically for a scientific test. So the amount and distribution of ground control points (GCPs) is not ideal and the GPS base station used for the first flight was at Northampton some 30km from the test flight. This is a relatively long baseline for high quality kinematic GPS, however, the results do start to give useful information about the potential of the system. There is also considerable interest in the use of long baselines between the base station and the aircraft in both the research and commercial communities.

3.2.1. Comparison of digital camera with traditional frame camera performance

There are a number of parameters that influence the quality of photogrammetric results using scanned traditional 230 x 230 mm metric frame photography and a similar but potentially different set of parameters that control the results from a digital camera. A key general parameter that establishes the quality of frame photography is the image scale, or more specifically the focal length and the flying height. The important question to ask is: do these parameters, focal length and flying height, adequately define the potential quality of the photogrammetric results from a digital camera? If the answer to the question is no or possibly not then it becomes difficult to do any direct comparison based on the traditional key parameter. Perhaps the answer is that this issue needs to be investigated further.

The whole range of digital cameras/imaging systems, from single cone, to multiple cone, to the scanner imagery have a variety of design characteristics and geometries. This makes it even more difficult to undertake a comparative study of photogrammetric results from digital cameras based on specific parameters. There is perhaps some merit in making comparisons based more on just the final results achieved after the photogrammetric processing rather than having comparison criteria based on the parameters used. Using this for method of comparison the quality of performance might be judged against cost and efficiency, thus a commercial criteria rather than technical issues such as image scale.

However, some parameters might be useful in making comparisons as well as be needed for flight planning for digital imagery for example, the quality of image point measurement and base to height ratio. Flying height is a significant parameter in any sortie being influenced by aviation regulation through to economics of the project and it also affects the scale of the image. So this might be one of the key parameters in a comparative study. As this study is based on an early 'general performance' test flight, the flying heights in our tests are typical of the heights used in traditional frame photography (see Table 2).

Flying height (m)	UltraCam Ground sample distance (GSD) (m)	UltraCam Imagery nominal scale (f=101.4mm)	Metric frame photography nominal scale (f=153.967mm)
1500	0.13	1:14793	1:9742
880	0.08	1:8679	1:5716

Table 2. Test flight characteristics

3.2.2. Aerial triangulation software: The software used includes Leica LPS, ORIMA, ORIMA was used for all aerial triangulation computations and 3DB was used to calibrate the misalignment between the IMU and camera.

2.2 Results and Discussion

The tests were divided into four groups:

1. direct geo-referencing (DG);
2. aerial triangulation based only on ground control;
3. aerial triangulation based on ground control and in-flight GPS and IMU measurements;
4. aerial triangulation with scanned standard frame camera photography and ground control.

Tests were carried out at two flying heights, with different block sizes and with different distances between the GPS rover and GPS base station. The following data sets were utilised within the test process: Figure 5 shows the 18 UltraCam image block taken from a nominal flying height of 1500m with a GPS base station 30km away and the 60 image block taken at a nominal flying height of 880m with the GPS base station 10km away. A traditional flight plan was used with a nominal forward overlap of 60% and nominal side overlap of 20% for all flights.

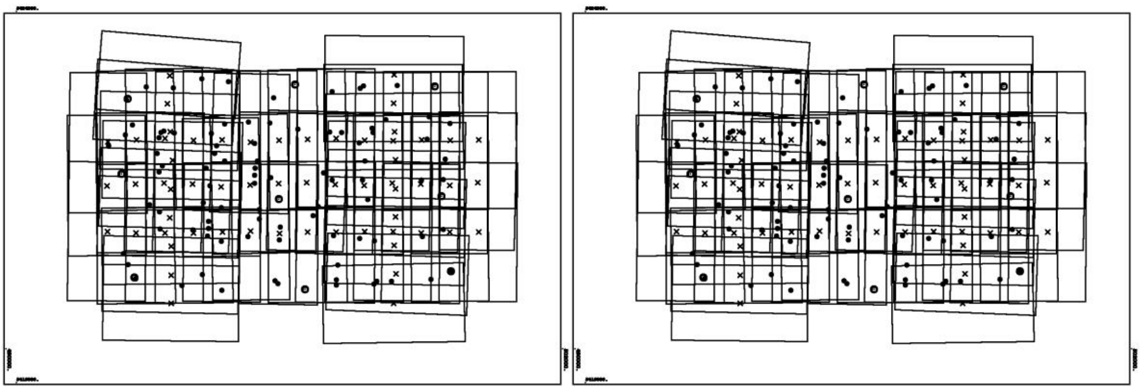

Figure 5. Block of 18 images taken at 1500m flying height (left) and block of image taken at 880m flying height (right) – using the UltraCam D

To enable some comparison to take place with a frame camera, results from a photograph metric frame camera block taken at 880m flying height over the same test area have been included, see Figure 6.

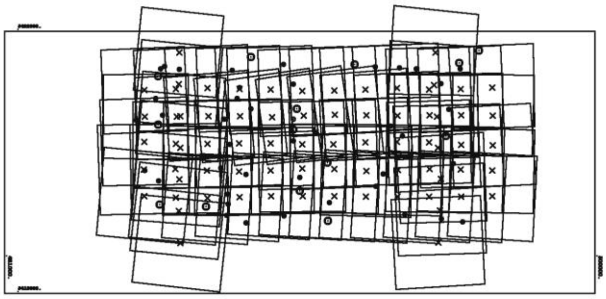

Figure 6. Block ofphotographs taken at 880m flying height – using the metric frame camera

In all cases 49 automatic tie point measurements per overlap have been performed using ORIMA.

2.2.1 TEST 1 – Direct geo-referencing

Direct geo-referencing can arguably be undertaken using only the processed GPS and IMU results or combined GPS and IMU measurements in an aerial triangulation using automatic tie point measurements but no ground control. This test compares these two methods using results from the UltraCam where the GPS base line length is about 10km. There are two basic ways the quality of direct geo-referencing and be quantified; firstly, through the measurement of check points in the stereo model secondly, by the magnitude of residual 'y parallax' in the stereo model, the traditional quality measure of relative orientation. Both are important from a mapping point of view, the second being particularly important from a manual measurement point of view.

The quality of direct geo-referencing using only exterior orientation parameters and no ground control was investigated by examining the behaviour of the y-parallax as produced by the UltraCam and frame camera from imagery of 880m flying height. Figures 7, 8 and Table 3 show the results. The magnitude of the y parallaxes in photogrammetric models has been improved (reduced) by including an aerial triangulation.

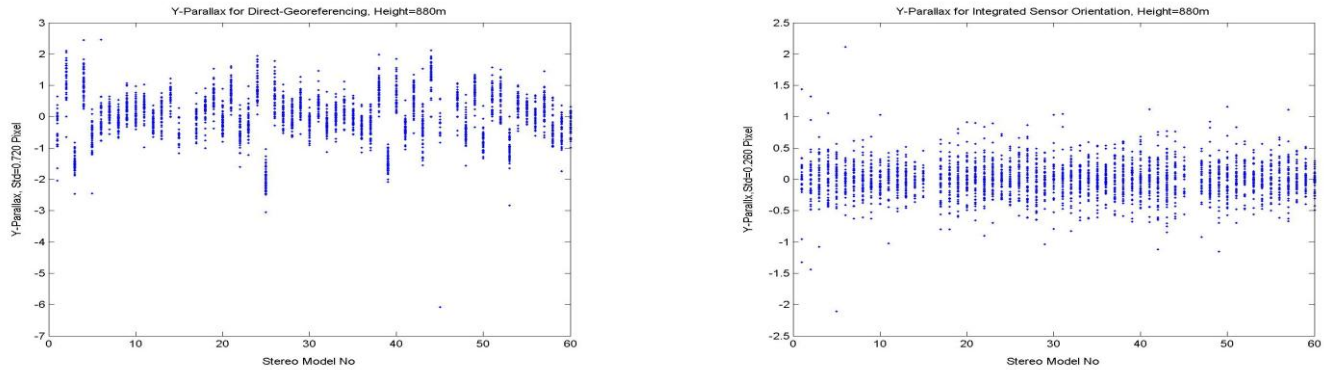

Figure 7. Direct geo-referencing y parallax results for the UltraCam
(left) GPS and IMU and (right) GPS, IMU and aerial triangulation (pixels)

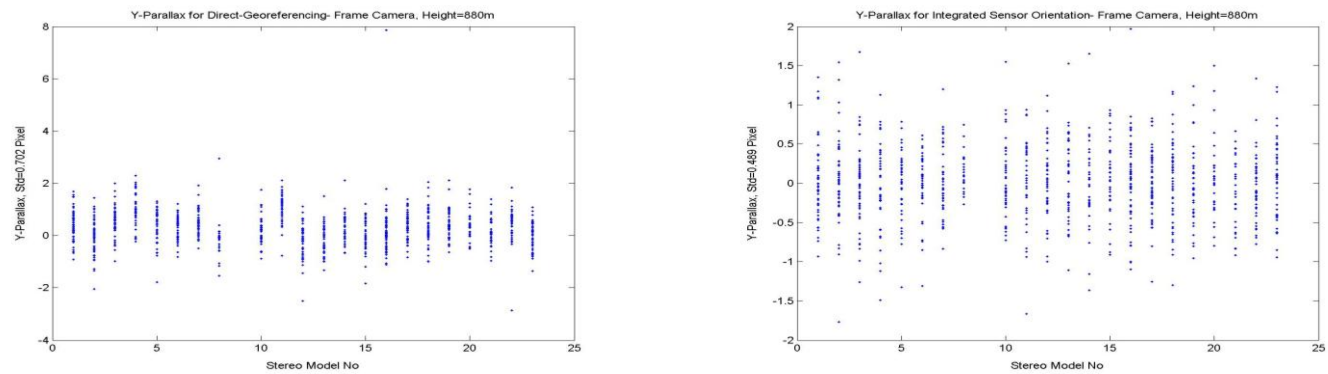

Figure 8. Direct geo-referencing y parallax results for the frame camera
(left) GPS and IMU and (right) GPS, IMU and aerial triangulation (pixels)

	standard deviation of y parallax (pixels)	
	GPS and IMU	GPS, IMU and triangulation
UltaCam D	0.720	0.260
Frame	0.702	0.489

Table 3. Direct geo-referencing standard deviation of the residual y parallax for UltraCam D and frame camera

A comparison of the residual y parallax between the two cameras shows an improved standard deviation for the UltraCam D compared to the frame camera by combining GPS, IMU and a triangulation. Of course, from a quality assurance point of view and enhancing the confidence in the photogrammetric solution a good triangulation is beneficial.

2.2.2 TEST 2 – Aerial triangulation based only on ground control

2.2.2.1 UltraCam D (block of 18 images from 1500m flying height)

The traditional aerial triangulation is performed with ground control but without any additional in-flight observations of GPS/IMU. Table 4 shows the results from various block configurations based on the number of strips and number of GCP used. Tie point RMSE values are reasonably consistent where as there is some variation in the RMSE of the residuals for the GCPs. When the number of control points is small the influence of an individual point becomes more significant. As can be seen there is a smaller control point RMSE in Z compared with X and Y. The Z RMSE for the tie point standard deviations is probably showing the effects of the relatively small airbase (base to height ratio of 0.27). Table 4 shows small image coordinate RMSE values. The values are becoming smaller as the solution is constrained less by the ground control.

No of Strip /GCP/CP	Tie points RMSE (m) of standard deviations			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	Z	x	y
Two /12/0	0.076	0.067	0.271	0.145	0.077	0.029				2.62	2.42
Two /4/8	0.063	0.058	0.271	0.071	0.067	0.004	0.201	0.270	0.310	1.77	1.88
One* /7/0	0.082	0.068	0.260	0.048	0.049	0.019				1.91	1.66
One* /4/3	0.083	0.071	0.313	0.036	0.040	0.020	0.215	0.096	0.320	1.63	1.31

Table 4. Results from aerial triangulation using ground control points only, flying height 1500m (* – left hand strip in Figure 5) (GCP – ground control point, CP – check points)

2.2.2.2 UltraCam D (block of images from 880m flying height)

A comparison of the results in Table 5 with Table 4 show the tie point residual RMSE values are decreased and the check point values significantly improved as we might expect from a block flown lower. Also, there is a better ratio between X, Y and Z point RMSE. The results show consistent image coordinate RMSE values which is similar to the 1500m flying height block, see Table 4.

No of Strip /GCP/CP	Tie points RMSE (m) of standard deviations			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	Z	x	y
Two /15/4	0.023	0.027	0.069	0.085	0.086	0.072	0.072	0.120	0.090	1.77	1.57

Table 5. Results from aerial triangulation using ground control points only, flying height 880m (GCP – ground control point, CP – check points)

2.2.3 TEST 3 – Aerial triangulation including in-flight GPS/IMU

2.2.3.1 UltraCam D with a 1500m flying height and 30 km GPS base station length

Using the projection centres determined by carrier-phase GPS-positioning and IMU measurements as additional observations in the bundle adjustment, an integrated triangulation can be performed. Ground control information can be introduced to assess the performance of the calibration, datum transformation and GPS errors (Wegmann, 2002).

The results are shown in Table 6, which can be compared with Table 4 when no in-flight control is used. The results show no improvement over the original GCP only solutions. This might be the expected effect from the long baseline that was used to compute the in-flight GPS values (30km). The results with no ground control shows that a consistent solution, even slightly improved in height, has been produced even with a long baseline. There is also not much loss in quality over a traditional ground control solution, see Table 4.

No of Strip /GCP/CP	Tie points RMSE (m) of standard deviations			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	Z	x	y
Two /12/0	0.124	0.107	0.388	0.150	0.114	0.044				2.75	3.00
Two /4/8	0.125	0.109	0.357	0.107	0.110	0.045	0.365	0.235	0.384	2.01	2.31
Two /0/12	0.121	0.112	0.276				0.378	0.301	0.290	2.01	1.89

Table 6. Results from aerial triangulation using ground control points/GPS/IMU, flying height 1500m
(GCP – ground control point, CP – check points)

2.2.3.2 **UltraCam D with a 880m flying height and a 10 km GPS base station length**

A direct comparison of results in Table 5 with the same ground and check point configuration in Table 7 shows that the GPS and IMU have improved the results. Check point coordinate improvement are 0.011m in X, 0.040m in Y and 0.013m in Z. On removing the ground control points completely and relying on the in-flight control the internal tie point RMSE values change very little about 5mm in each coordinate. However, there is an increase in size of the X and Y values of the check point RMSE values, although Z improves by 10mm.

No of Strip /GCP/CP	Tie points RMSE (m) of standard deviations			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	Z	x	y
Four /15/4	0.022	0.021	0.059	0.087	0.082	0.041	0.061	0.080	0.077	1.91	1.60
Four /0/19	0.027	0.026	0.063	--	--	--	0.154	0.118	0.067	1.89	1.55

Table 7. Results from aerial triangulation using ground control points/GPS/IMU, flying height 880m
(GCP – ground control point, CP – check points)

2.2.4 Test 4 – Aerial triangulation based on ground control only using scanned metric frame camera photography with a 880m flying height

Results from a traditional metric camera (f = 153.967mm) block of 3 strips of 8 photographs (scanned at 15µm resolution), (see Figure 6), are given in Table 8. These are presented to enable some comparison with the results in Table 5. Interestingly the image residuals for UltraCam are significantly smaller, and the Z RMSE value for the check points is smaller. The tie point RMSE values are similar. The smaller image residuals of the UltraCam identify an improved image point measurement possibly brought about by the increased image quality.

No of Strip /GCP/CP	Tie points RMSE (m) of standard deviations			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	Z	x	y
Two /9/3	0.029	0.028	0.055	0.044	0.059	0.030	0.064	0.082	0.127	3.70	3.90

Table 8. Results from aerial triangulation using scanned frame camera photography and ground control points only, flying height 880m

3. CONCLUSIONS

The Vexcel UltraCam D digital camera has been successfully installed and made operational. Some interesting results have been produced from an informal data set with traditional overlap characteristics. Small y parallax has been produced from direct geo-referencing using the UltraCam and relatively small image coordinate residuals have been obtained compared with the frame camera results. The direct geo-referencing and aerial triangulation results show the importance of in-flight GPS and IMU measurements. It is expected that as experience is gained and with a more rigorous scientific trial these results can be improved particularly if larger forward and side overlaps are used which can be accommodated by the Vexcel UltraCam D digital camera.

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