LARGE SCALE MAPPING DATA FROM ULTRA-SMALL FORMAT DIGITAL 'PHOTOGRAPHY'

J. P. MILLS
Department of Surveying
University of Newcastle upon Tyne
Newcastle upon Tyne, NE1 7RU
UK
Email: j.p.mills@newcastle.ac.uk

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ABSTRACT

This paper outlines work carried out with a Kodak DCS200 digital camera and low cost photogrammetric software to produce large scale mapping data by aerial survey. Two surveys are outlined, the first using imagery taken from a Cessna light aircraft to verify and update existing large scale mapping. The second survey, utilising larger scale imagery taken from a microlight aircraft, was used to produce a map and orthophotomap of a small rural area. Details and problems of the surveys are discussed, as are the assessments of the accuracy obtained.

1. INTRODUCTION

Newcastle University's interest in the use of a Kodak DCS200, a digital camera with the ultra-small format size of only 14 x 9.3 mm, for aerial survey began in the summer of 1994 with trials from a Cessna 337 light aircraft over the town of St. Neots in Cambridgeshire (Graham and Mills, 1995). Although no meaningful results were obtained from the test, image quality was encouraging and convinced a commercial aerial photography firm to investigate further the possibility of utilising such imagery in photogrammetric work. Mills and Newton (1996) details the work carried out in a second test to verify and update existing Ordnance Survey (OS) large scale mapping of an area around Hitchin railway station in Cambridgeshire. The imagery was again taken from the Cessna aircraft at a flying height of 760 m providing an image scale of 1: 22,000. The photogrammetric processing, carried out on low cost PC software, yielded ground co-ordinates with an RMS error of 1.0 m (5 pixels) in plan when compared to the existing OS mapping (with a quoted RMS error of 0.4 m), despite the fact that the imagery was not rectified for either lens distortion or relief displacement.

The work outlined in this paper concerns two further tests conducted since the Hitchin survey of 1994. The first continues in the vein of the Hitchin work, with imagery of a city centre site being used to verify and update OS mapping. The second survey was carried out using a microlight aircraft to produce imagery at a larger scale which was subsequently used to map, from scratch, a small rural village. In both cases details of the survey are given and an accuracy assessment is made.

The research is being carried out to further the use of photogrammetry within the civil engineering environment. It is anticipated that a low cost, user-friendly photogrammetric system would be of use to engineers in applications such as route planning, reconnaissance and mapping of small sites that would otherwise be carried out using conventional ground survey.

2. NEWCASTLE UNIVERSITY'S DIGITAL PHOTOGRAMMETRIC SYSTEM

The work was conducted using the Digital Photogrammetric System (DPS) assembled in the Department of Surveying, University of Newcastle upon Tyne. The system is made up of low cost and mainly off-the-shelf software and hardware The principal components of the DPS are a Kodak DCS200 digital camera for image acquisition; Adobe Photoshop for pre- and post-processing of imagery; R-Wel Desktop Mapping System (DMS) for image measurement and AutoCAD Release 12 from AutoDesk for editing vector data. All of the software in the system runs under Windows NT on a standard Personal Computer (PC). The PC running the DPS has a 60 MHz Pentium processor and is equipped with 32 Mb RAM; 1 Gb hard disk; 2 Mb VRAM and 17 inch Super VGA monitor displaying at a resolution of 1024 x 768 with 32,000 colours. Such a system can be purchased for around $20,000 (March, 1996). Each of the components, and the operations they perform are described briefly below.

2.1 Image Acquisition

The DCS200ci is one of the cameras in the Digital Camera System (DCS) range manufactured by Kodak. This is a high resolution (1524 x 1012 array with 9 μm square pixels) Charge-Coupled Device (CCD) 'still video' camera built around the popular Nikon N8008s amateur camera body. The 'c' suffix stands for 'colour', the chip recognising colour through the use of a mosaic filter; and the 'i' suffix for 'internal' hard disk, the camera being able to store up to 50 images on an 80 Mb hard disk before downloading becomes necessary. The DCS200 has recently been superseded by the DCS420 - a camera with the same geometric resolution but improved radiometric qualities over its predecessor. Full details of the cameras in the Kodak DCS range, and their potential suitability for aerial survey work, can be found in Graham (1995).

The ultra-small format size of the DCS200 CCD chip creates difficulties in achieving a base / height ratio that is suitable for the successful recovery of height data from an aerial survey carried out with the 'normal' stereoscopic configuration. Combined with the problems of a four second download time delay and other factors concerning the construction of the camera, there are many drawbacks associated with using such equipment from an airborne platform for photogrammetric purposes other than it simply being of non-metric origin (Mills *et al.*, 1996). Nevertheless, the advantages of a completely digital flowline far outweigh the disadvantages providing accuracy requirements can be met (Mills and Newton, 1996).

2.2 Pre-Processing

Raster imagery from the DCS200 camera is downloaded directly to the PC via a SCSI interface into any TWAIN compliant software. The DPS uses Adobe Photoshop, where the proprietary Kodak image is saved into TIFF format for subsequent processing in the DMS. Before being saved a number of radiometric and geometric operations are performed on the images. The camera has been calibrated in a manner similar to that described by van den Heuvel (1993) so that both the radiometric and geometric distortions in the camera can be corrected. Corrections are made using a series of in-house C++ programs and Photoshop filters.

'Fiducial marks' are added to each frame using a template so that the principal point can be located within the measuring software (Mills *et al.*, 1996). Although these 'fiducial marks' locate the calibrated principal point position, it is important to note that the chip is spring mounted inside the camera and can move relative to the optical axis when placed under external force. Tests have shown the principal point can only be located with an RMS error of +/- 15 pixels in both x and y axes when the camera is subjected to movement. Any calibration can therefore only provide a 'best' position for the principal point. For aerial photogrammetric work it means that precautions must be taken to prevent vibrations affecting the camera during the flight.

Any pre-processing of vector data takes place in AutoCAD prior to conversion into a binary format suitable for reading into the measurement software.

2.3 Image Mensuration

Measurement of the imagery is carried out with the DMS software, a 'low cost, powerful software package that facilitates image processing for photogrammetric, remote sensing, and GIS applications using off-the-shelf personal computers' (Welch, 1989). The software, although quite basic, is effective, and the addition of a Visual Basic Windows interface provides a user-friendly, low cost entry into digital photogrammetric processing.

The bulk of the photogrammetric processing takes place in the Softcopy Photo Mapper (SPM) module of the software. Here the user is led through a process of model orientation, which uses a rather unorthodox space resection approach; image rectification; stereo and monoplotting; autocorrelation and orthophoto generation.

Plotting accuracy is quoted as +/- 1 pixel in plan and +/- 1 pixel / b/h ratio in height. Use of the zoom facility allows the sub-pixel measurement of x parallax which theoretically improves the accuracy. The autocorrelation module uses area based least squares matching to one pixel. Unfortunately the search only takes place in the x axis, so any y-parallax in the registered images will cause a correlation failure. The DMS does not allow for the input of any camera calibration data other than the focal length. This is a particular problem with imagery from the DCS200 since it primarily makes use of a 28 mm lens, encompassing a high amount of lens distortion and causing y-parallax. Hence the need for resampling the imagery to the calibration values during pre-processing.

2.4 Post-Processing and Output

Although the DMS includes modules for vector editing and orthophotomap creation, the editing is limited and other software is better employed. The raster imagery is therefore loaded back into Photoshop for any cartographic enhancement that needs to take place prior to printing. Similarly the vector data is fed back into AutoCAD. Vector data is printed on an A1-size Hewlett Packard DesignJet 650c, whilst raster imagery can be printed, up to A4 format, on a Kodak XLS 6000 dye sublimation printer. Whilst this provides outstanding photographic quality output, the consumable costs in using such a printer are high.

3. MAP REVISION OF NEWCASTLE UNIVERSITY

3.1 Aerial Survey

The 'photography' for the survey was flown in the summer of 1995 over the campus of Newcastle University from a flying height of 1425 m, providing an image scale of 1: 50,000 (ground pixel size of 0.45 m). The camera was mounted in the Cessna aircraft with its major axis perpendicular to the line of flight. This was necessary in order to cover the campus in a single strip. A fore and aft overlap of 50 % would require a base to height ratio of 0.2 and the area of stereo overlap would be 700 x 225 m. This would provide a theoretical RMS error of 0.45 m in plan and 2.25 m in height when processed in the DMS. The high flying height, necessary because of the 4 second download time had the advantage of providing minimal relief displacement for the many high rise buildings in the survey area.

3.2 Ground Control Survey

After downloading, the imagery was examined to identify possible ground control points (GCPs) on a suitable stereopair from the strip. Although the pixel size (and theoretical planimetric resolution) was only 0.45 m, the resolving power of the camera was impressive with features such as road markings 0.1 m wide being easily identifiable. Areas with features suitable as GCPs were identified and enlargements printed for use in the field.

GCP co-ordinates were collected using a Trimble Navigation Pro XL GPS system. This uses an 8 channel parallel L1 C/A code Maxwell receiver with data logger for collection of GIS attributes. Its compact, light weight, back-packed design makes single man surveying feasible and it is ideally suited to the collection of photogrammetric control points. Using post-processed differential correction, Trimble claim the corrected C/A code provides an accuracy of 'better than one metre' on a second-by-second basis. There are however several degrading factors to this, such as the distance to the base station and the number of satellites available. The survey was carefully planned to avoid times of poor satellite configuration and the Surveying Department's SciNet pillar was used as a base station in the centre of the survey area so keeping the distance between base and rover below 1 km. The main degrading factor (other than selective availability) of the survey in this case was found to be that of multipathing - a problem that is very difficult to overcome in a city centre site when using only C/A code differential processing. In an attempt to surmount this problem, each control point was observed with the antenna mounted on a bipod for a period of five minutes so as to provide an averaged position.

The points were differentially post-processed and converted from WGS84 to OSGB36 using a four parameter local transformation. This allowed the referencing of the imagery to the OS data of the area. A check on a point of known co-ordinates at the periphery of the survey area showed this method of GPS observation to give average errors of 0.84 m in plan and 1.25 m in height. Unfortunately this is larger than the ground pixel size, although the collection of some 60 control points allowed rejection of any inaccurately co-ordinated points. The two images being used for the survey were orientated and rectified using the GCPs. The space resection performed to orientate the imagery yielded the orientation parameters shown in Table 1. It can be seen from the GCP residuals that the RMS error is at the sub-pixel level.

	Image 81	Image 82
X (m)	424784.37	424634.54
Y (m)	565100.22	564858.91
Z (m)	1494.56	1494.43
(degrees)	-4.160	-2.993
ϕ (degrees)	3.305	0.689
κ (degrees)	151.605	151.149
Datum height (m)	58.46	64.28
Base/Height ratio	0.19	
No. of GCPs	36	43
RMSE (pixels)	0.96	0.86
RMSE (m)	0.44	0.39

Table 1: Orientation parameters and GCP residuals of the imagery used in the Newcastle survey.

3.3 Photogrammetric Processing

Stereoscopic tests on the 15 GCPs on the overlap produced RMS errors of 1.02 m (2.3 pixels) in plan and 1.79 m (4.0 pixels) in height. The accuracy to which one can measure is, however, degraded by the DMS's anaglyph stereoviewing facility. Despite the fact that the monitor can display 32,000 colours, the display driver only supports 8 bit colour with each of the images displayed using four bits (16 grey levels) to represent the 256 levels recorded by the camera. This gives a posterizing effect and setting the measuring mark can prove difficult in areas of low contrast.

The stereopair was then autocorrelated to produce a Digital Elevation Model (DEM) of the area. This enabled the imagery to be geometrically corrected for relief displacement to create an orthophoto. The area based matching technique employed by the DMS is suited ideally to gently undulating areas and inevitably the disjointed nature of a city centre site causes many failures in correlation, leading to lengthy editing times. Every pixel in the image was correlated and rectified in an attempt to correct the buildings for lean. There is considerable masking of ground detail due to building lean on the imagery, and a facility to recover this from adjacent images, such as the technique employed by the Leica Helava system (Simmons, 1996) would be useful in such circumstances. Measurements on the orthophoto of the same GPS control points used in the stereo tests produced RMS errors of 0.94 m (2.1 pixels) in plan and 1.71 m (3.8 pixels) in height.

3.4 Mapping Accuracy

Measurements taken against the GCPs are unlikely to give a true representation of the absolute accuracy of the survey since they have been used in orientating the imagery. To ascertain the absolute accuracy of co-ordinates produced from the images, a total of 70 randomly chosen points were measured from the OS digital mapping of the area. This data has a quoted RMS error of 0.4 m (Ordnance Survey, 1995). The same points were then measured on the stereomodel and the orthophoto (with heights from the DEM). The results of the comparison can be seen in Table 2. Unfortunately the table shows no measure of heighting accuracy or precision since the OS dataset is two dimensional. The stereomodel and orthophoto measurements were therefore compared, yielding an RMS error in height between the two of 0.90 m (2 pixels). Precision (obtained by 10 repeated measurements to 6 different points) for the heighting was calculated as 0.39 m (0.9 pixels) RMS error for the stereo measurement. Orthophoto height measurements showed almost perfect repeatability, although this can be attributed to the resolution of the DEM.

Accuracy				
Method	X RMSE		Y RMSE	
	Metres	Pixels	Metres	Pixels
Stereo	0.79	1.8	0.55	1.2
Ortho	0.52	1.2	0.48	1.1
Repeatability (Precision)				
Method	X RMSE		Y RMSE	
	Metres	Pixels	Metres	Pixels
Stereo	0.09	0.2	0.10	0.2
Ortho	0.10	0.2	0.09	0.2

Table 2: Accuracy and repeatability statistics for the Newcastle survey (comparison against OS).

As a check, the GPS control was also compared to the OS data, resulting in an RMS error of 0.84 m in the east-west (x) direction and 1.16 m in the north-south (y) direction.

4. LARGE SCALE MAPPING OF RASKELF

4.1 Aerial Survey

The results from the Newcastle survey, whilst encouraging in terms of suitability for identifying areas of change, do not suggest that the technique lends itself readily to mapping at large scales. If, however, larger scale imagery could be obtained using the camera then the technique may be useful in terms of mapping small areas from scratch. Unfortunately, the 4 second image download time of the DCS200 will not allow sufficient overlap to be acquired at larger scales in an aircraft with stalling speeds as high as that of the Cessna. As a result, it was decided to use a microlight aircraft to obtain imagery at a larger scale with sufficient overlap. Although the use of such aircraft is not allowed for commercial purposes at present in the United Kingdom, the method provided the opportunity to achieve the kind of ground resolution, all be it over a much smaller area, that will be available with cameras of the future.

Figure 1: The Thruster microlight aircraft.

The Thruster microlight that was used in the project can be seen in Figure 1. This is a 60 hp aircraft with a stalling speed of 18 m/s, enabling large scale image acquisition with the DCS200. Details of the Thruster can be found in Graham (1988). Because of the cramped nature of the cockpit, the camera was slung behind the cockpit and fired by the co-pilot using a cable release. The mount (Figure 2) was constructed of lightweight aluminium with foam padding and was suspended using tapes so as to be free of vibration.

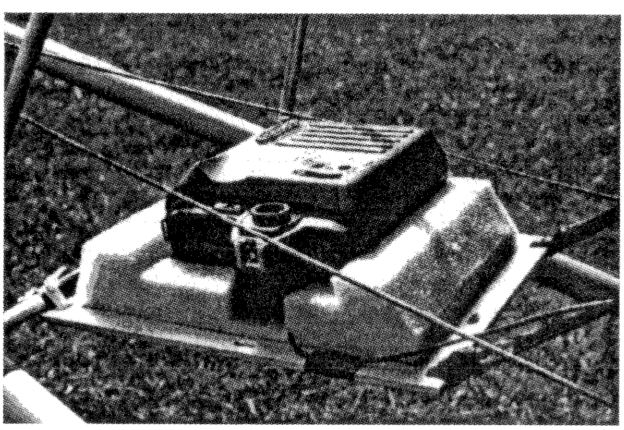

Figure 2: The DCS200 camera mount.

A suitable area for the survey, the village of Raskelf, was chosen close to the airfield in North Yorkshire. The village was covered in two flight lines of 14 images with the camera's major axis parallel to the flight direction. With 50 % fore and aft overlap, a base to height ratio approaching 0.25 was possible. The flying height of 500 m provided an image scale of 1: 17,000 (ground pixel size of 0.16 m). From the block of 'photography', three successive images were chosen for further work. Further survey details can be found in Mills *et al.* (1996).

4.2 Ground Control Survey

Ground control for the survey was carried out using a Leica TC 400 total station. This is a 10 second instrument with EDM measuring to +/-5 mm +5 ppm RMS error. A six station traverse was observed around the survey site and natural ground features, identifiable on the photography, were co-ordinated on a local co-ordinate system by radiation. A total of 60 points were co-ordinated in a single morning. The traverse computed with a misclosure of 22 mm in plan and 13 mm in height. The least squares adjustment of the data showed the worst GCP to have an error ellipse of major axis 16 mm (0.1 pixel) and a minor axis of 14 mm (0.1 pixel) with an RMS error for height of 26 mm (0.2 pixel). These figures are comfortably within the ground pixel size of 0.16 m, allowing a true assessment of the camera's potential for mapping to be made. Sixteen well distributed GCPs were chosen for controlling the three images so as to leave some points for use in the assessment of absolute accuracy. The orientation results are shown in Table 3.

	Image 41	Image 42	Image 43
X (m)	832.90	947.12	1060.49
Y (m)	940.87	954.28	966.48
Z (m)	596.43	596.67	596.98
ω (degrees)	1.678	2.694	3.749
ϕ (degrees)	-2.730	-3.116	-3.971
κ (degrees)	0.896	2.472	1.251
Datum ht. (m)	97.22	99.23	101.51
B / H ratio	0.23		0.22
No. of GCPs	8	9	8
RMSE (pixels)	0.63	0.61	0.62
RMSE (m)	0.10	0.10	0.10

Table 3: Orientation parameters and GCP residuals of the imagery used in the Raskelf survey.

4.3 Photogrammetric Processing

Processing was carried out in a similar manner to the Newcastle survey. The DEM was this time created with a post spacing of 10 pixels (1.6 m), the justification for this being that it was a much more continuous surface than the city centre site in Newcastle and processing time could be saved. The two DEMs produced from the two overlaps were mosaiced together and the central image of the three overlaid onto this to create the orthophotomap. The detail was then plotted directly using the planimetric map option in the DMS. The vector data was subsequently edited in AutoCAD and then overlaid onto the orthophotomap to produce Figure 3. This is a portion of the 250 x 150 m area plotted from Image 42.

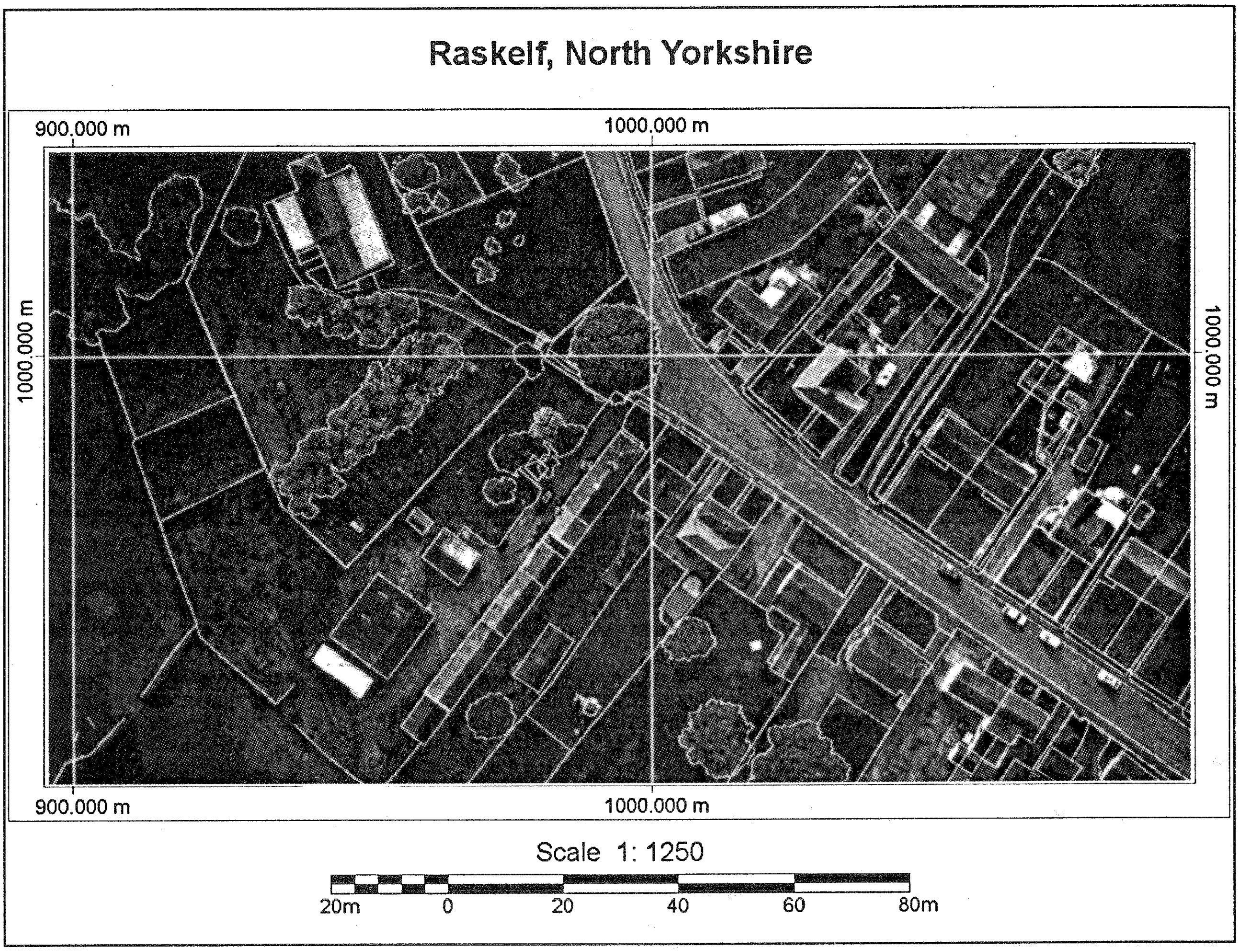

Figure 3: Orthophotomap with vector overlay of Raskelf.

4.4 Survey Accuracy

The accuracy and repeatability results for the stereoscopic and orthophoto measurements can be seen in Table 4. Strangely the repeatability of the measurements was slightly worse than for the Newcastle survey. Although these tests were not exhaustive, the greater clarity provided by the larger scale imagery was expected to provide more reproducible measurements. Nevertheless they are encouraging as they compare directly to those reported by Fraser and Shortis (1995) using a monochrome DCS200 camera which theoretically should provide a higher resolution than its colour counterpart.

The stereoscopic accuracy figures reflect the effectiveness of the zoom facility. The theoretical accuracy of the DMS as stated earlier should provide a heighting accuracy of 0.64 m (1 pixel / base to height ratio). This has been improved to 0.25 m by measuring parallax to the sub-pixel level using the zoom tool (0.25 pixel at 4 times magnification). The relatively poor performance in terms of external accuracy for heighting from the DEM can be attributed to the post spacing and subsequent interpolation of heights from this.

The fact that the orthophoto measurements are less accurate than the stereoscopic measurements can again be attributed to the DEM post spacing and subsequent interpolation. The error in x is noticeably worse than the error in y for the measurements made from the orthophoto. This could be related to the heighting errors in the DEM, causing the failure to totally remove x-parallax from the orthophoto.

All of the errors quoted for the mapping come from data that has been observed with the highest measuring care. For an absolute Quality Assurance (QA) check on the planimetric accuracy of the mapping produced in Figure 3, the ground survey measurements were compared with the vector detail after editing in AutoCAD. This is an absolute check on the entire mapping flowline. The check (on 21 common points) yielded an RMS error of 0.5 m in plan. This is just outside the OS quoted error of 0.4 m for their Land Line digital data. Reasons for the degradation of the planimetric accuracy (from 0.2 m to 0.5 m) can be attributed to the editing of the data (squaring buildings, extending lines etc.) and the fact that some points may not be exactly those that were surveyed (for example when plotting a wall, the centre was plotted as opposed to the outside corner which was surveyed). In addition to this, zooming in to a magnification of four times is impractical in many cases since only a small area is covered on the screen at any one time. As a result, much of the mapping was carried out under two times zoom which may have degraded the accuracy.

Accuracy						
Method	X RMSE		Y RMSE		Z RMSE	
	Metres	Pixels	Metres	Pixels	Metres	Pixels
Stereo	0.10	0.6	0.09	0.6	0.25	1.6
Ortho	0.17	1.1	0.11	0.7	1.30	8.1
Repeatability (Precision)						
Method	X RMSE		Y RMSE		Z RMSE	
	Metres	Pixels	Metres	Pixels	Metres	Pixels
Stereo	0.05	0.3	0.04	0.3	0.14	0.9
Ortho	0.04	0.3	0.05	0.3	0.06	0.4

Table 4: Accuracy and repeatability statistics for the Raskelf survey (comparison against ground survey).

5. DISCUSSION

This paper has presented the results of two aerial surveys using a high resolution digital camera and low cost photogrammetric processing software. In the first survey, a method of map revision and intensification has been outlined utilising low cost photogrammetric and GPS techniques. Initial results have indicated that the accuracy of each of the methods used in the process are comparable, and the overall technique suitable for the verification and revision of existing datasets. Imagery at this scale is not, however, suited to large scale mapping from scratch due to its poor ground resolution.

Results from the second survey have illustrated the potential of the camera to produce large scale mapping comparable to the largest dataset in the United Kingdom. More care in the mapping and editing process should ensure that the mapping is within the OS specification. Unfortunately the small format of the camera means that many images are required to map an area of any substantial size and this is labour intensive, both in terms of controlling and processing the imagery.

Both surveys used instruments to control the 'photography' that would already be in place in a civil engineering workplace. Further, results have indicated that monoplotting from orthophotos (a technique especially useful for non-photogrammetrists) yields a similar planimetric accuracy (the main requirement for mapping data) to stereoplotting. The automated low cost production of DEMs (King *et al.*, 1995) is a further incentive for such technology to be implemented alongside surveying tools currently utilised by engineers.

6. CONCLUSIONS

Although, at present, the drawbacks associated with the techniques outlined in this paper mean that it is unlikely to find favour for commercial use in mapping, the potential of 'still video' technology in this area has been shown. Improvements in the size, resolution and capture rate of CCD 'still video' cameras will mean that the kind of accuracies achieved in the Raskelf survey will soon be possible for much larger areas using commercially accepted aircraft. The lack of an aerial digital camera is the last major stumbling block in the world-wide acceptance of digital photogrammetry. The rapid advancement of products being produced, both by photographic and electronic multi-nationals, must mean that such a camera cannot be far away.

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