EVALUATION OF DIGITAL AERIAL SENSORS IN AN OPERATIONAL MAPPING ENVIRONMENT

Brian Pilemann Olsen[1], Thomas Knudsen[2], Morten Nielsen[3], Kristian Keller[4], Lars Tyge Jørgensen[1], and Poul Frederiksen[1]

[1]National Survey and Cadastre—Denmark, Rentemestervej 8, 2400 Copenhagen NV, Denmark, {bpo|ltj|pof}@kms.dk
[2]Danish National Space Center, Juliane Maries Vej 30, 2100 Copenhagen Ø, Denmark, tk@spacecenter.dk
[3]BlomInfo, Vejlegade 6, 2100 Copenhagen Ø, Denmark, mn@blominfo.dk
[4]COWI A/S, Parallelvej 2, 2800 Kongens Lyngby, Denmark, krke@cowi.dk

KEY WORDS: Photogrammetry, Remote Sensing, Digital Cameras, Production, Work Flow

ABSTRACT:

We summarize the procedures and preliminary conclusions from an inter-institutional project group evaluating the feasibility (economically and practically) for introducing digital aerial imagery into the work flow used in connection with maintenance of a national map database. Not surprisingly, the main conclusion is that “it depends…”: there are in many cases good technical reasons for switching, but the final decision must depend heavily on the price level of the digital vs. the analogue imagery. In a few years time we expect that digital imagery will be much more widespread than analogue.

1 INTRODUCTION

“Is digital photogrammetry ready for prime time” or, in other words, is it technically and economically advantageous to introduce digital photogrammetric products (digital imagery) in a traditional photogrammetric map update workflow? In an attempt to answer this question we summarise below the procedures and main points from an inter-institutional project group, including members from the operational mapping industry, as well as a national mapping agency and a governmental research institution.

In the summer of 2005 the National Survey and Cadastre—Denmark (Kort & Matrikelstyrelsen, KMS) was preparing the annual tender material for the photo campaign to be carried out the following season. The normal procedure had been to ask for traditional analogue images, but with digital photogrammetric cameras getting more common there was a general consensus that sooner or later, the procedure would *have* to be extended to allow for bids based on digital imagery.

As the upcomming photo campaign was to be part of the operational workflow of the KMS, it was evident that opening up for digital imagery could not be done without having reliable answers to at least a few key questions:

- What are the photogrammetric characteristics of the cameras currently on the market?
- What kind of derived products can be expected?
- How will it affect the production workflow for maintenance of map databases?

In order to answer these questions, a project group was set up. Initially the group consisted of representatives from KMS and the Danish National Space Center (DNSC). It was, however, soon extended as BlomInfo, COWI, and ScanKort (the three largest photogrammetric companies on the Danish market) showed interest and were invited to participate.

The project group organized itself into 5 overlapping work groups, each taking care of one work package. The work packages were defined as follows:

Techniques: collect and summarize literature about the different digital cameras; describe the different recording techniques; carry out a test campaign acquiring digital and analogue imagery from a test site.

Products: determine advantages and disadvantages of digital images with regards to derived products such as orthophotos and digital surface models.

Automation: what kind of automation benefits can be expected? Especially with respect to change detection and generation of digital terrain models.

Production: will the primary task of maintaining digital map databases need major work flow modifications when introducing genuine digital imagery?

Economy: estimate the economic consequences of an all digital work flow.

The remaining part of the paper is structured in order to give answers to the three main questions posed above, with one section dedicated to each question. Each of these sections integrate work from all work packages, to the extent that it is relevant for the question being answered. Before turning to that we must, however, give an outline of the data used in the project.

2 DATA

As we are considering a main task of maintenance/update of a digital map database, we need a heterogeneous set of vector data from the map database, and raster data from the digital and analogue photogrammetric cameras.

2.1 Map Data

The map data used were extracted from the KMS TOP10DK topographic database (Kort & Matrikelstyrelsen, 2001). TOP10DK registrations are fully 3D with a mean accuracy better than 50 cm. It is used for production of map series at scales of 1:10 000 and lower and is typically updated in a 3–5 year cycle, such that 20–33 % of the coverage area is updated each year.

	Ultracam (Vexcel)	DMC (Z/I Imaging)	JAS (Jena Optronik)	ADS40 (LH Systems)
Camera type	Frame	Frame	Pushbroom	Pushbroom
Radiometric resolution	12 bit	12 bit	12 bit	12 bit
Pixel size	$9\mu m$	$12\mu m$	$6.5\mu m$	$6.5\mu m$
Colour Channels	4	4	4	4
Colour resolution	Half	Half	Full	Full

Table 1:
Selected characteristics of the new digital sensors. In some cases conflicting information has been published. The data used here is compiled from (Sandau et al., 2000, Georgi et al., 2005, Leberl and Gruber, 2003, Leberl and Gruber, 2005, Dörstel, 2005)

2.2 Image Data

In connection with a test campaign, two sets of digital imagery were acquired using digital aerial frame cameras from Vexcel (Vexcel, 2003, Leberl et al., 2003, Leberl and Gruber, 2005) and Z/I (ZI-Imaging/Intergraph, 2006, Dörstel, 2005). The test site had been covered with traditional analogue imagery recently, so all in all three different test image sets were available. No attempts have been made to make use of the pushbroom line scanner cameras from Jena Optronik (Georgi et al., 2005) and LH systems (Fricker, 2005) in the test campaign; primarily because the pushbroom geometry was seen as too much of a departure from traditional frame based photogrammetric production, making it too risky and complex to enter into the operational workflow.

The test imagery was acquired in such a way that geometric as well as seasonal differences were kept to a minimum. Thus the resulting ground sample distance (GSD) is comparable to the one obtained by scanning of the analogue images. Also the center coordinate and the rotations for two corresponding images (analog and digital) were attempted to be made equal.

On the European market there is apparently a very high degree of market penetration by the Vexcel Ultracam. In our region this is exemplified by recent introductions of Ultracam products by two out of three of the major photogrammetric companies operating in the Danish market. Since this implies that we are most likely to meet Ultracam data in an operational context, our main emphasis has been on comparing the analogue data with the digital data set from the Vexcel camera. The main characteristics of these data sets are outlined in table 2.

3 PHOTOGRAMMETRIC CHARACTERISTICS

In this section we have as our primary focus to describe the photogrammetric characteristics of the purely digital images. Analogue imagery is only described to the extent that it is necessary for comparison. The main points investigated are resolution (radiometric/spectal/spatial), image quality (also in subjective terms) and registration accuracy.

3.1 Image recording

At least four different digital photogrammetric cameras exist in the market today (Leberl and Gruber, 2005, Dörstel, 2005, Georgi et al., 2005, Fricker, 2005). Some of their major characteristics are outlined in table 1.

Generally speaking two different acquisition methods exists: *line scanning* using CCD line arrays scanning the area in question (comparable to pushbroom scanner technology used in satellites), and *frame recording* using several two dimensional CCD arrays, mosaicking the resulting images to create one large image.

	Resolution	Flying height	Date
Digital	35 cm (9μ)	4000 m	2005-04-02
Analogue	35 cm (14μ)	3800 m	2005-04-01

Table 2: Characteristics for the test datasets used for evaluation of accuracy.

3.1.1 coverage For the multiple array sensor systems it is evident (as seen from figure 1) that the coverage from a specific flying height is limited compared to an analogue image.

The example shown is from the Vexcel camera where the (mosaicked) focal plane has a physical size of $10.35\,\text{cm} \times 6.75\,\text{cm}$.

3.1.2 Physical resolution Most of the sensors have a physical pixel size of around 6–10 μm which, from a nominal flying height of 4000 m leads to a ground sampling distance (GSD) of around 0.4 m. This GSD is comparable to traditional analogue images (from the same flying height) scanned a 20 μm.

For the sensor systems using multiple CCD arrays, different physical pixel sizes are used for panchromatic and colour information: the highest resolution is used for panchromatic data—the colour resoultion may be up to four times more coarse.

3.1.3 Spectral resolution All digital cameras are capable of delivering red (R), green (G), blue (B) and near infrared (N) information in addition to the panchromatic (P) main image at the nominal scan resolutions. For the multiple CCD sensor systems pan-sharpened products (where panchromatic information is used to artificially increase the spatial resolution of the colour bands) are also available.

All digital sensor systems investigated have a radiometric resolution of at least 12 bits/band. Normally scanned analogue images have a radiometric resolution of 8 bits/band. This means that the digital data sources have a higher information density which also results in dramatically increasing image sizes.

3.1.4 Image Quality Not surprisingly (since a separate scanning step is eliminated and the spectral and radiometric resolution is improved), the digital recordings tend to be much more sharp than their analogue counterparts (see figure 2).

There is, however, limitations in the general software support for the high radiometric resolution of the digital cameras (i.e. more than 8 bits/band). This leads to the necessity of radiometric downsampling to 8 bits/band, which in many cases results in poor recognizability in shady regions.

Area 3	**Analogue**	**Digital**
Correct registrations	76	69
Incorrect registrations	14	12
Missing registrations	2	7
Total number of registrations	90	81

Table 3: Results from one test site for registration completeness. See section 3.2 for details

3.2 Accuracy

To analyse the *accuracy* obtainable from the digital recordings, a test series involving two stereo analysts was carried out. The overall goal was to investigate whether the geometric accuracy and registration correctness/completeness was different when using digital and analogue imagery.

In table 2 the characteristics of the datasets corresponding to a test area is outlined.

Correctness and completeness was examined by the two stereo analysts performing (realistic) map updates on a number of test areas. The update was done according to the registration manual of the TOP10DK database (Kort & Matrikelstyrelsen, 2001). To ensure actual update was needed in the test areas, a number of objects were deliberately deleted from the map database.

For a given test area *one analyst* performed the update using the digital test dataset, whereas *the other analyst* used the analogue test dataset. For different test areas the two operators took turns to use the digital dataset.

After the update of an area an experienced supervisor examined the results and reported 1) the number of registrations which were correctly updated, 2) the number of registrations which were incorrect (e.g wrong classification), and 3) the number of missing registrations. The result from one update of a test area is outlined in table 3.

The (somewhat surprising) experiences from the tests were that the digital and analogue workflow resulted in comparable geometrical accuracy with regards to both planimetry and elevation.

However, when it comes to correctness and completeness the digital imagery seemed to have a small advantage compared to the analogue images. The preliminary hypothesis is that this is due to the fact that the digital images are more sharp and the colour reproduction more realistic. Getting a reasonable feeling for the completeness potentially obtainable was, however, not as simple as expected: the nubers reported reflect more than the relative merits of the input data: they also reflect a large degree of ambiguity in the interpretation of the registration instruction (which is a terse document of hundreds of pages). In operational cases, general consensus for the interpretation, is reached during the work with the first few scenes—but in our small test case, we really had *nothing* but "the first few scenes". Hence, the conclusion of slightly higher completeness for mapping based on digital imagery, is based on a reinterpretation of the actual numbers, where the relative completeness obtained by the individual analyst is estimated by the supervisor.

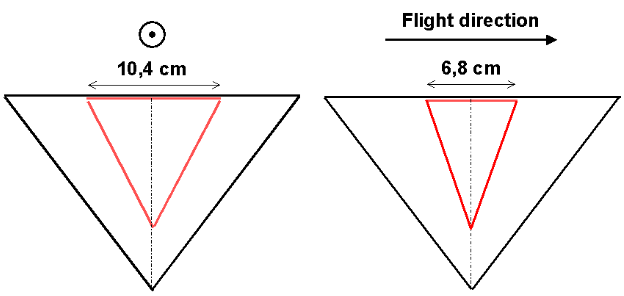

Figure 1: Across track and along track geometry of the digital Vexcel UltraCamD (shown in red) campared with a traditional 150 mm focal length analogue camera

Figure 2: Top: digital image. Bottom: Analogue image.

4 DERIVED PRODUCTS

There are no clear indications that derived products such as digital surface models, orthophotos, etc. will be much harder to generate using digital data; as outlined below, there is an added task of proper metadata handling, but in general we have good reasons to assume that derived products based on digital images will be of comparable or higher quality than their analogue counterparts.

4.1 Digital Surface Models

As the digtal images appear to be sharper, and the images include more radiometric information (12 bits/band vs. 8 bits/band) than analogue images, it could be expected that the quality of automatically generated height models will improve.

Also the fact that more images can be recorded at every flight line for only a minor additional cost, means that multiple stereo viewing and hence improved precision through overdetermination could become economically feasible. Unfortunately no commercial systems (to our knowledge) are currently able to take

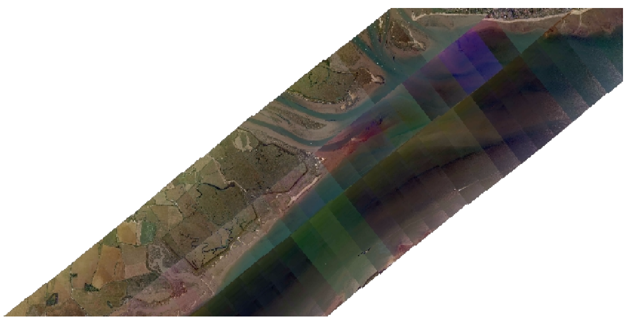

Figure 3: The necessity of colour balancing for ortho photo mosaic production

Figure 4: Change detection in the building theme. Upper panel: digital, lower panel: analogue. Previously unregistered/excluded buildings are shown in blue. Red areas inside the blue frame indicates detection of a new building. Yellow indicates existing registrations which are not redetected. Red indicates additional hypotheses for new buildings. Many of these are actually small building-like structures (car ports, sheds, etc.) which are not registered in the map database; the remaining are false alarms.

advantage of this. Also the baseline (i.e. the distance between images) will decrease, leading to a smaller intersection angle between rays and thus a potentially worse accuracy. Preliminary results from our investigations show that the accuracy (planimetric and elevation) is more or less the same for automatically generated height models based on comparable digital and analogue images: the decrease in baseline seems to balance out the increase in correlation accuracy.

4.2 Orthophotos

Orthophotos are common and very useful products. When introducing the digital imagery that include more than three bands it is (theorethically) possible to produce an RGB and a colour-infrared (CIR/pseudocolour) orthophotos in one operation. CIR orthophotos is of high potential use in the fields of forestry, agriculture, and environmental protection.

Unfortunately the support for multispectral imagery is limited in traditional commercial photogrammetric software.

Other investigations have also revealed (as shown in figure 3) that the increased amount of colour information in the digital images makes it harder to do an automated colour balancing of orthophoto mosaics.

4.3 Change detection

We have carried out a few tests of a particularly simple change detection algorithm especially tuned for detecting changes in the building theme (Knudsen and Olsen, 2006). A sample result is shown in figure 4. The number of new buildings detected were comparable in the digital and analogue cases, but in the digital case a much larger part of each individual new building was detected. Also the redetection of previously registered buildings and the suppression of false alarms were much improved in the digital case. To a large extent, the much higher robustness in the digital case can be attributed to the availability of an extra channel of near-infrared data.

5 PRODUCTION

This section summarizes the experiences from the project with regard to how the production workflow is influenced by the introduction of digital imagery.

5.1 Workflow

Some typical production workflows using digital and analogue data are outlined in figure 5.

As can be seen from the figure the major difference is that the handling, development and scanning of film is eliminated. This leads to a reduction in man-hours and thus costs. To some minor extent these gains are offset by a time consuming data handling step: the post processing where the actual digital images are generated.

When using analogue images, the film forms a long lasting, and physically reasonably small backup for the scanned digital representation. When using digital images, the images must be stored and backed up in another way. Normally Hard Discs or optical media are used and since the lifetime of such devices are limited, a long term data management and maintenance system must be established. As described in section 5.2 some additional difficulties arise when it comes to dealing with or handling image metadata.

Aero-triangulation is also left out in the digital workflow, as the digital systems in general integrate GPS and INS, and the image orientation therefore given automatically (which, at least in our case, has worked satisfactorily, although in general, this is the subject of discussion, cf. eg. (Cramer, 2003, Hofmann, 2005), and references therein). It could be claimed that GPS and INS can be used for analogue cameras as well, but the integration is not as strong as for the digital systems.

5.2 Metadata Consistency

For analogue images metadata (camera id, frame number, project id, etc.) is hardcoded directly onto each image through the frame annotation.

The lack of frame annotation when it comes to digital images is an additional logistic challenge in the handling of the digital products. The digital photos have their (typically much more abundant) metadata entered into text fields in the header of the image TIFF file or in a separate metadata file. This means that great care must be taken to preserve the meta data while transforming the images.

5.3 Software and Hardware Limitations

While the situation certainly improved during the project period (fall 2005), there are still large gaps in the support for the digital photogrammetric products in many commercial (as well as non-commercial) processing programs used in a typical photogrammetric work flow.

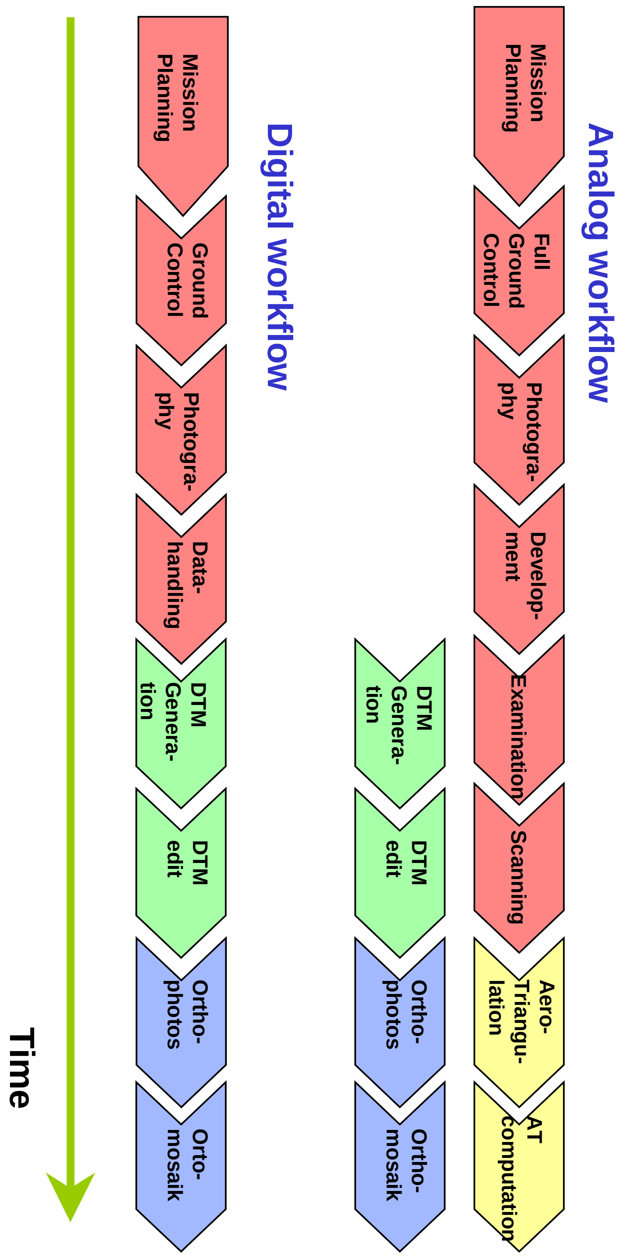

Figure 5: Workflows for analogue and digital production.

As mentioned in section 3.1.4, limitations are encountered in software as well as hardware support for the high radiometric resolution which is generated using digital cameras: most systems still only handle 8 bit data.

In general it is also non-trivial to utilize the full 4 channel (NRGB) products directly as most systems are limited to handling 1 and 3 band data.

These limitations mean that it is often necessary to do the actual work on images that are spectrally and radiometrically reduced to 3 channels and 8 bits per channel.

Due to their original high radiometric resolution, the reduced images typically exhibit a very high degree of clarity and contrast, compared to analogue photos processed into 8 bit images. In some cases this has the surprising consequence that it is actually easier for the stereo analysts to do registrations in the analogue imagery: objects in shade, such as the north facing part of gable roofs, tend to become so dark in the digital imagery that they are hard to discern when viewed through the polarimetric filters mounted on the display of the photogrammetric work station.

6 DISCUSSION/CONCLUSION

While there are (in most cases) good technical reasons for replacing analogue aerial photos by their digital counterparts, the answer to the question of economy is more unclear for the time being: we are still at the dawn of digital aerial sensors, and early adopters must still expect that the surrounding technology is not necessarily fully adapted to take advantage of the high radiometric and spectral resolution of the digital aerial cameras.

This means that the costs of adapting the workflow is probably higher now than in a few years time. On the other hand the technical superiority of the digital photo systems is evident, so the transition will come anyhow (perhaps aided by the rapid decline of film based recording media by the soon all-digital consumer market, which erodes the overall size of the market for photographic films). The actual position of the sweet spot on the cost/benefit curve will depend on both the market driven pricing of the digital imagery, and on the adaptation/development speed of the providers of the specific software packages in use. These factors have changed dramatically during the project work, and we expect to see (and report) a much different, but hopefully more complete, picture at the end of the conclusion of the project, which is scheduled for the end of 2006.

REFERENCES

Cramer, M., 2003. Integrated gps/inertial and digital aerial triangulation—recent test results. In: D. Fritsch (ed.), Photogrammetrische Woche, 2003, Wichmann Verlag, Heidelberg, Germany, pp. 161–172.

Dörstel, C., 2005. DMC—the most versatile digital large format camera in the market. In: D. Fritsch (ed.), Photogrammetrische Woche, 2005, Wichmann Verlag, Heidelberg, Germany, pp. 51–56.

Fricker, P., 2005. ADS40—progress in digital aerial data collection. In: D. Fritsch (ed.), Photogrammetrische Woche, 2005, Wichmann Verlag, Heidelberg, Germany, pp. 105–116.

Georgi, C., Stognienko, R., Knuth, S. and Albe, G., 2005. JAS: The next generation digital aerial scanner. In: D. Fritsch (ed.), Photogrammetrische Woche, 2005, Wichmann Verlag, Heidelberg, Germany, pp. 147–154.

Hofmann, O., 2005. Calibration and georeferencing of aerial digital cameras. In: D. Fritsch (ed.), Photogrammetrische Woche, 2005, Wichmann Verlag, Heidelberg, Germany, pp. 105–109.

Knudsen, T. and Olsen, B. P., 2006. Building (change) detection: a case study comparing results from analog and digital imagery. Manuscript in preparation.

Kort & Matrikelstyrelsen, 2001. TOP10DK. Geometrisk registrering. Technical report, National Survey and Cadastre—Denmark, Rentemestervej 8, 2400 København NV, Denmark.

Leberl, F. and Gruber, M., 2003. Flying the new large format digital aerial camera ultracam. In: D. Fritsch (ed.), Photogrammetrische Woche, 2003, Wichmann Verlag, Heidelberg, Germany, pp. 67–76.

Leberl, F. and Gruber, M., 2005. ULTRACAM-D: understanding some noteworthy capabilities. In: D. Fritsch (ed.), Photogrammetrische Woche, 2005, Wichmann Verlag, Heidelberg, Germany, pp. 57–68.

Leberl, F., Gruber, M., Ponticelli, M., Bernögger, S. and Perko, R., 2003. The UltraCam large format aerial digital camera system. In: Proceedings of the ASPRS Annual Convention, Anchorage, USA, 2003.

Sandau, R., Braunecker, B., Driescher, H., Eckardt, A., Hilbert, S., Hutton, J., Kirchhofer, W., Lithopoulos, E., Reulke, R. and Wicki, S., 2000. Design principles of the LH systems ADS40 airborne digital sensor. International Archives of Photogrammetry and Remote Sensing XXXIII, pp. 8.

Vexcel, 2003. Ultracam, digital aerial camera. `http://www.vexcel.com/products/ultracam.html`. Last visited 2003-11.

ZI-Imaging/Intergraph, 2006. DMC, Digital Mapping Camera. `http://www.intergraph.com/dmc/`. Last visited 2006-04.