THE EUROSDR DIGITAL CAMERA PROJECT

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ABSTRACT:

A number of digital cameras have been developed for photogrammetric applications. First results indicate performance parameters superior to those of conventional film cameras. The project is designed to yield performance parameters such as positional and elevation accuracy and geometric and radiometric resolution using images taken over the same area for a wide-angle film camera several digital cameras and thereby provide for potential purchasers of digital cameras information needed to plan aerial photographic missions. The mission planning is motivated by an economical aspect: the same swath width is to be used with each camera; it has been chosen such that the largest possible scale will be obtained for the ADS40. It is planned to also place ground targets for evaluating geometric and radiometric image quality and to establish a small calibration area for the control of GPS/INS equipment If successful the project results will provide data useful for planning projects to be flown with digital cameras and experiences useful in efforts to develop camera calibration and validation procedures.

KURZFASSUNG:

Ein EuroSDR-Projekt mit dem Ziel, in der Anwendung digitaler Luftbildkameras Erfahrungen auch im Vergleich zur Verwendung herkömmlicher Filmkameras zu gewinnen, wird vorgestellt. Erläutert werden die Projektziele, die für das Projekt in Erwägung gezogenen Aufnahmesysteme, das gewählte Projektgebiet mit einer Begründung seiner Wahl und die gewählten Projektparameter. Eine erfolgreiche Projektdurchführung sollte Erfahrungen für die Planung zukünftiger Projekte, die mit digitalen Kameras ausgeführt werden, und für Bemühungen zur Entwicklung von Kalibrier- und Validierungsverfahren liefern.

1. INTRODUCTION

This paper presents a description of a EuroSDR project with objectives, description of the systems to be used, project area and intended project parameters and their derivation. EuroSDR is a research platform for national mapping agencies, academic institutes, the private sector, industry and other groups concerned with European spatial data infrastructures vital to sustainable spatial planning and development. It was established in 1953, in accordance with the recommendation passed by the Council of the Organisation for European Economic Co-operation, as the European Organization for Experimental Photogrammetric Research (OEEPE). EuroSDR activities are organized through commissions which propose projects; a steering committee consisting of two delegates from each of the eighteen member countries – one from the national mapping agency and one from an educational/research institute – together with representatives from the private sector and geographical information user groups oversees all activities. The paper reports on the project "Test for digital aerial cameras - Performance of hardware and software" of Commission 3 (Production systems and processes) and includes references to the project ″Digital aerial camera calibration″ of Commission 1 (Sensors, primary data acquisition and referencing).

2. PROJECT OBJECTIVE

The projects aims at a comprehensive test of modern digital photogrammetric data acquisition and evaluation techniques in comparison to the use of aerial photographs and, if realizable, LIDAR data, INSAR data and high-resolution space data, to obtain reference data such as achievable accuracies for different photogrammetric processes such as aerotriangulation, DTM derivation and orthophoto-mosaic production in regard to the planning of data acquisition missions. The project also aims at the development of image evaluation parameters which can be derived from image data without the use of ground targets; however, the use of ground targets is planned for the project. Such parameters are desirable for the characterization of the micro-image structure (e.g. resolving power or transfer functions derived from edge analysis), for a radiometric evaluation (e.g. linear sensor response to all reflectances within the subject range, the relationship between subject range and exposure range, automatic exposure metering) and for colour rendition (e.g. derivation of true-colour images from the partial images under consideration of the spectral characteristics of the sensors, the illuminating light and the Rayleigh scattering in the atmosphere).

3. DIGITAL AIRBORNE SENSORS

Digital sensors today are usually based on CCD arrays and fall into two categories; frame sensors using square or rectangular arrays with geometric characteristics similar to a film camera, and line scanners using linear arrays with a different geometry. Five different digital sensors are considered here, two multi-line scanners (ADS40, HRSC), two multi-lens frame cameras (DMC, UltraCamD) and one-lens camera (DSS).

The Leica Geosystems ADS40 Airborne Digital Sensor was developed in co-operation with the German Aerospace Centre (DLR) in Berlin using an extended three-line concept. A vertical panchromatic (465 – 680 nm) image is obtained using two linear CCDs each having 12000 6.5 µm large pixels; an offset of 3.25 µm yields a useable length of 24000×3.25 µm = 78 mm. A lens angle of 64° translates into a focal length of 62.8 mm. The camera achieves stereo capability by means of two additional single linear CCDs taking panchromatic images, one looking forward 28.4° and one looking backward 14.2°, the look angle difference of 42.6° corresponds to that of a normal angle aerial film camera with c = 305 mm. The data transfer rate from the CCDs is up to 800 Hz; combining this with a (minimum) aircraft speed of 370 km/h = 200 knots = 102.8 m/sec yields a (smallest) pixel size on the ground of 15×15 cm^2, a (minimum) swath width of 3600 m, a (lowest) flying height above ground of 2880 m (9449') and a (largest) image scale of 1 in 46154. Smaller ground pixel sizes and larger image scales can be achieved by using slower aircraft; it has been reported that one owner uses the camera routinely at a flying height of 1500 m yielding an image scale of 1 in 30769 and a swath width of 2.4 km. In addition to the panchromatic arrays, three linear arrays located at 14.2° off nadir are used to capture blue (430 – 490 nm), green (535 – 585 nm) and red (610 – 660 nm) images with perfect co-registration. One near infrared line (835 – 885 nm) located at 2° off nadir is also provided.

The HRCS High Resolution Stereo Camera was originally developed for (failed) Mars missions by the Institute of Planetary Exploration of the German Aerospace Centre DLR in Berlin-Adlershof. First experiments were carried out with an airborne version (HRSC-A) in early 1997; their success prompted the further development (HRSC-AX). A vertical panchromatic (520 – 760 nm) image is obtained using one linear CCD having 12000 6.5 µm large pixels yielding a useable length of 78 mm. A focal length of 150 mm translates into lens angle of 29°. The camera achieves stereo capability by means of two additional single linear CCDs taking panchromatic images, one looking forward 20.5° and one looking backward 20.5°, the look angle difference of 41° corresponds to that of a normal angle aerial film camera with c = 305 mm. A shortest exposure time of 0.6 msec and an aircraft speed of 300 km/h = 162 knots = 83.3 m/sec yield a (smallest) pixel size on the ground of 5□5 cm^2, a (minimum) swath width of 600 m, a (lowest) flying height above ground of 1153 m (3786') and a (largest) image scale of 1 in 7692. In addition to the panchromatic arrays, two linear arrays located at +2.3° and -2.3° off nadir are used to capture green (530 – 570 nm) and red (635 – 685 nm), and two linear arrays located at +4.6° and -4.6° off nadir are used to capture blue (450 – 510 nm), and near infrared (770 – 810 nm) images. The camera includes two further panchromatic arrays located at +12.0° and at -12.0° enabling 5-line stereo evaluation in critical areas.

The DMC from Z/I Imaging uses four CCD arrays of 7168× 4096 pixels^2 (probably Philips Icam28, 111×86 mm^2, pixel size 12×12 µm^2, readout time 2 sec/frame, 12 bit radiometric resolution) to take high-resolution panchromatic images; the four images with slightly diverging optical axes are afterwards combined to one image with 13824×7680 pixels^2 (Fig. 1). The larger dimension of the 166×92 mm^2 image area is oriented perpendicular to the flight direction. A focal length c = 120 mm results in a field of view of 69.3° perpendicular to and of 42° in flying direction, the latter corresponds to that of a normal angle aerial film camera with c = 305 mm. A maximum frame rate of two images per second allows extremely large image scales; hence, rather small pixels can be obtained. In addition to the four panchromatic cameras, four cameras with arrays of 3072×2046 pixels capture blue (400 – 580 nm ?), green (500 – 650 nm ?), red (590 – 675 nm ?) and near infrared (675 – 850 nm ?) images using a focal length of c = 25 mm. Hence, the pixel size ratio pan to colour amounts to 1 to 4.75.

The UltraCamD from Vexcel Imaging uses nine CCD arrays of 4008×2672 pixel^2 (pixel size 9×9 µm^2, readout time 1.3 sec per frame, 12 bit radiometric resolution) to take high-resolution ″synoptic″ panchromatic images through four lenses in flight direction with slightly diverging axes and small time delays; the images are afterwards combined to one image with 11500×7500 pixels^2 (Fig. 2). The larger dimension of the 103.5×67.5 mm^2 image area is oriented perpendicular to the flight direction. A focal length c = 100 mm results in a field of view of 55° perpendicular to and of 37° in flying direction. A maximum frame rate of 1.3 images per second allows extremely large image scales; hence, rather small pixels can be obtained. In addition to the four panchromatic cameras, four cameras with arrays of 4008×2672 pixels capture blue, green, red and near infrared images using a focal length of c = 28 mm.

The DSS Digital Sensor System from Applanix is a ready-to-use, directly geo-referenced, medium format, airborne digital sensor using a single three-colour CCD array of 4077×4092 pixels^2. A focal length c = 55 mm (optional 35 mm) results in a field of view of 37°, the latter nearly corresponds to that of a normal angle aerial film camera with c = 305 mm. The DSS is available as true-colour or as false-colour version. In the latter case, the filters integrated into the sensor form a basic 2×2 matrix: one element sees infrared (720 – 920 nm) radiation, two elements see green (510 – 600 nm) and infrared radiation and one element sees red (600 – 720 nm) and infrared radiation.

4. PROJECT AREA

The extended area of the confluence of the Elbe and Mulde rivers was selected as project area. This area was subject to extended flooding in August 2002 resulting from almost concurrent extremely high water levels of both rivers. The damages to valuable vegetation partly non-native to Germany were high. At this time the lack of available digital terrain data with sufficient point density and elevation accuracy to predict the effects of further water level rises and of dam breakages became apparent. Expectations to gain financial support for the project from the state government of Saxony-Anhalt were not fulfilled.

This area is part of the UNESCO biosphere Mid-Elbe which contains the largest floodplain forest in central Europe. Biosphere reserves are large-scale, representative sites of natural and cultural landscapes. They are not simply schemes to protect the environment but model concepts of conservation, development and management are developed under the UNESCO Man-and-Biosphere program.

Located within this larger area is the Garden Kingdom of Dessau-Wörlitz, a UNESCO Cultural Heritage site. The Garden Kingdom is a product of the Age of Enlightenment in the 18th century and portrays the connection among nature, regional planning, and architecture. The socially-minded Prince Leopold Friedrich Franz of Anhalt-Dessau developed an artistically-enhanced landscape between 1760 and 1817, with the help of his advisor and friend Friedrich Wilhelm von Erdmannsdorff. In addition to its aesthetic appeal, the entire Garden Kingdom should be understood as an educational program. The parks and individual buildings were connected with each other through levees, avenues, oak trees, meadows and fruit orchards. Visual corridors and plantings along the avenues increasingly developed a network, which connected Wörlitz and the other parks. These include, in chronological order, the Luisium, Georgium, the Sieglitz Park and the Kühnau Park. Pre-existing parks, such as the Tiergarten, the Mosigkau Palace, and the Oranienbaum Park were worked into the landscape plan. Efforts are now underway to raise dams; however, dams located in historical visual corridors will either not at all or only to a lesser extent be raised. The data to be gathered with the project could be used to simulate e.g. the effect of that decision.

If critical gauges at both rivers are to be included, the test area would have a size of 42×20 km²; it is bordered by the following four geographical border lines:

west: 12°03'10, east: 12°40'02" eastern longitude,
north: 51°54'06", south: 51°42'18" northern latitude.

Smaller meaningful areas would be that of the Garden Kingdom rounded to a rectangular area (25×15 km²) or the extended confluence area (17×10 km²).

Direct sensor orientation based on GPS/INS (inertial navigation systems) provides a high flexibility in mission planning and appears to obviate the need to fly regular block structures. However, the determination of exterior orientation parameters can reach accuracies similar to those of standard photogrammetric procedures only if an overall system calibration (including GPS/INS components and camera self-calibration) and a correct GPS/INS data processing (including efficient GPS/INS error control and datum problems) is guaranteed for the specific mission site. It is for this reason that a small calibration site consisting of targeted control points will be arranged within the project. The flight planning is based on a regular block structure, however, the use of the calibration site would also enable investigations in regard to accuracy of exterior orientation parameters using GPS/INS.

5. PROJECT PARAMETERS

A DTM being part of the national survey activities is available; it consists of a grid of points spaced at 10 m intervals and is quoted to have an elevation accuracy of $\sigma_Z = \pm 0.5$ m. This DTM does not meet the requirements of hydrographical engineers in regard to either point density or elevation accuracy. One important objective is therefore the generation of a three dimensional digital terrain model of the project area with as high an accuracy as meaningfully achievable. If laser scanning is assumed as method of providing a standard, an elevation accuracy of $\sigma_Z = \pm 0.15$ m is an acceptable assumption.

It is assumed that photogrammetric evaluation of aerial photographs on an analytical plotter using the (static) raster measurement method yields elevation accuracies of $\sigma_Z = \pm 0.15‰ \times c \times m_B = \pm 0.15$ m; this translates for a wide-angle film camera with a focal length c = 153 mm to $m_B = 6536$. The corresponding swath width is 1503.28 m. Assuming accuracies for the horizontal coordinates of well defined natural points of $\sigma_{X,Y}$ [µm] = $\pm 10 \times m_B$, one obtains $\sigma_{X,Y} = \pm 6.5$ cm. First published results indicate that improved accuracies can be obtained when using digital aerial cameras.

Digital and film cameras are proposed to be used to obtain comparable image data. After consultation with a private firm interested in purchasing a digital mapping camera it was decided to plan the project for identical swath width for all sensors. This has the advantage that pass and control points can be located into the areas of overlap between adjacent swaths.One could also have chosen identical ground pixel size, however, this would have increased sensor-specific concerns, especially in regard to the line scanners. In addition, an investigation with aerial test-area images scanned at different pixel sizes showed that photogrammetric accuracies are only marginally related to the scanning pixel size in the range from 14×14 to 28×28 µm².

Of the considered sensors, the ADS40 is most limited in regard to obtaining large-scale images, it is proposed to plan the sets of image data assuming for all the same swath width of 2400 m obtainable with the ADS40 at a scale of 1 in 30770. This swath width can be obtained with the other systems as follows: HRSC-AX at 1 in 30770, DMC at 1 in 14285, UltraCamD at 1 in 23188, DSS at 1 in 65168 and aerial film camera at 1 in 10435. The corresponding flying heights would be 1923 m, 4616 m, 1714 m, 2319 m, 3584 (or 2281) m and 1597 m. With an aerial camera with c = 153 mm an elevation accuracy of $\sigma_Z = \pm 0{,}15‰ \times c \times m_B = \pm 24$ cm can be expected. In order to also gain insight into a possible change in elevation accuracy as a result of automatic measurement, it is proposed that at least the aerial photographs should also be measured by an operator using a static or dynamic grid sampling procedure. First results for the DMC indicate that elevation accuracies in the order of $\sigma_Z = \pm 0{,}08‰ \times c \times m_B$ can be obtained; this translates for the indicated project parameters to $\sigma_Z = \pm 13{,}7$ cm, an accuracy similar to that of LIDAR.

The pixel sizes on the ground would be as follows for the different systems: ADS40 10×10 cm² with staggered line sensors and 20×20 cm² without, HRSC-AX 20×20 cm², DMC 17×17 cm², UltraCamD 21×21 cm², DSS 59×59 cm² and aerial photographs scanned at 14×14 µm² 15×15 cm². All these values are, with the exception of that for the DSS, smaller than the pixel size of 40×40 cm² used in the creation of orthophotos for the state mapping authority of Saxony-Anhalt which are the base for the maintenance of the official topographic GIS called ATKIS and the derivation of the digital topographic base map at the scale 1 in 10000.

Planning for a swath width of 2400 m with 30% sidelap and, where applicable, 60% forwardlap in case of the traditional aerial photography would result for the large project area in 12 flight lines of 42 km length or of the following number of images for the different farm cameras: DMC 80, UltraCamD 67, DSS 44 and film camera 44. In addition, there would be several cross fights.

6. CAMERA CALIBRATION AND VALIDATION

The Working Group on Calibration and Validation of CEOS (The Committee on Earth Observation Satellites, an international co-ordinating body comprising 23 Members, mostly space organizations, and 21 Associates, national and international organizations such as ISPRS, charged with co-ordinating international civil space-borne missions designed to observe and study planet Earth) has in connection with space sensors accepted the following definitions:

- Calibration is the process of quantitatively defining the system response to known, controlled signal inputs
- Validation is the process of assessing, by independent means, the quality of the data products derived from the system outputs.

It is obvious that the camera calibration procedures used for aerial film cameras need significant extensions to deal with the complexity of the digital cameras, and that different procedures may be needed for each camera type. Hence, test-field calibrations will play a significant role. Since the digital cameras provided raw data in need of processing prior to being useful, validating the digital image products will also be an important step to be considered. EuroSDR has arranged a working group – the first author is a member of the group – with two objectives:

- Collection of publicly available material on digital camera calibration to compile an extensive report describing the currently used practice and methods (Phase 1)
- Empirical testing with focus on the development of commonly accepted procedure(s) for camera calibration and testing, based on the experiences and advice of individual experts (Phase 2).

The first author is also a member of the working group on international standardization of the German Society of Photogrammetry and Remote Sensing (DGPF). This group contributes to ISO projects such as ISO 19130 "Sensor and data models for imagery and gridded data" (which reached the committee draft level early this year) and to German standardization.

It is expected that the project will result in experiences helpful in developing procedures for in-flight calibration and validation of digital cameras.

7. CONCLUSIONS

The project was conceived in November 2001 knowing the need for DTM data in support of investigations of vegetation damages resulting from ground-water level changes. The flood of August 2002 emphasized the need of the creation of DTM data of sufficient accuracy and point density. Efforts to gain the support of the state government failed in spite of very positive expert opinions. It has since become apparent that the project can only be realized if sponsors can be found for parts of it. Several such sponsors now assure that the first two flight missions can be carried out during the autumn of 2004. However, sponsors may wish to limit the distribution of project data; this would not agree well to past practices of EuroSDR to make data available to all interested members.

8. REFERENCES

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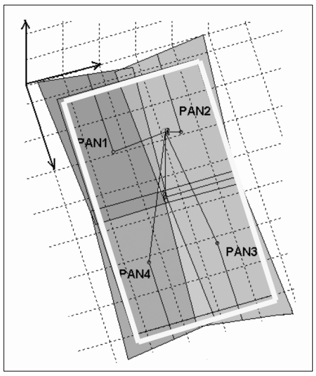

Figure 1. Footprint of 4 DMC pan images projected into the virtual image © Z/Imaging Imaging GmbH, Germany, Copyright 2003

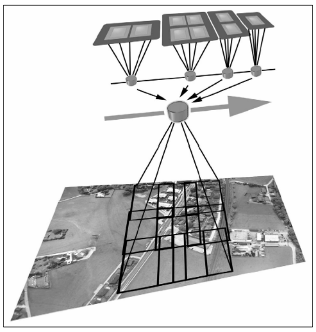

Figure 2. Explaining the difference between „synchronous" and „syntopic" image acquisition. The synchronous mode triggers all 4 separate cones at the same time. The syntopic mode triggers them at an interval defined by the flight velocity, about 1 msecond apart. © Vexcel Imaging Austria, Copyright 2003