OPERATION OF THE ULTRACAMD TOGETHER WITH CCNS4/AEROCONTROL – FIRST EXPERIENCES AND RESULTS

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ABSTRACT:

Digital aerial cameras are ready to become the predominant sensor for photogrammetric image acquisition. One among a few others is the $ULTRACAM_D$ large format digital aerial camera of Vexcel Imaging, which was introduced in May 2003.
Besides the optical and electrical properties of an aerial camera system, the environment for tasks like the mission planning, aircraft guidance, sensor management and the precise determination of position and angles play an important role for the successful operation of an aerial sensor. The *CCNS4* guidance and sensor management system together with the GPS/IMU option *AEROcontrol* of IGI has been successfully used for these tasks with different aerial sensors like analog aerial cameras, LIDAR systems and SAR for many years.
The $ULTRACAM_D$ of Vexcel Imaging is the first large format digital camera that is integrated with the *CCNS4/AEROcontrol*. We present the status of the integration and the impact on the photogrammetric workflow as well as the roadmap of the ongoing development.
Based on the technical specifications of both, sensor and guidance/management system, we show a variety of possible applications where the benefit of the joint use is obvious.

1. INTRODUCTION

In the recent years the development in the technology of digital aerial cameras has led to a small number of commercially available high resolution digital aerial cameras. Today, these digital aerial cameras are ready to become the predominant sensor for photogrammetric image acquisition. One among a few others is the $ULTRACAM_D$ large format digital aerial camera of Vexcel Imaging, which was introduced in May 2003. $ULTRACAM_D$ offers a conic image format of 11500 by 7500 pixels and a frame rate better than 1 image per second. The camera is based on a novel multi-head design and allows flight missions for stereo mapping even at large image scales.

Besides the optical and electrical properties of an aerial camera system, the environment for tasks like mission planning, aircraft guidance, sensor management and the precise determination of position and angles play an important role for the successful operation of an aerial sensor. The *CCNS4* guidance and sensor management system together with the GPS/IMU option *AEROcontrol* of IGI has been successfully used for these tasks with different aerial sensors like analog aerial cameras, LIDAR systems and SAR for many years [e.g. Cramer 2003 or Kremer 2001].
To enable the $ULTRACAM_D$ and the CCNS/*AEROcontrol* to work together, an electronic, mechanic and software interface was established. This interface was demonstrated in the first common projects in beginning of 2004. In these first projects the $ULTRACAM_D$ together with the *CCNS/AEROcontrol* proved to be an operational system for every day work.

This paper describes the different components of the two systems and how they work together.
An aerial survey flight mission that was conducted with the described system is presented and the results are shown with respect to the

- image quality of the digital images, the
- quality of the directly measured position and orientation data and
- to operational aspects.

2. $ULTRACAM_D$

Vexcel's large-format digital aerial camera $ULTRACAM_D$ is a metric frame camera, designed for precision photogrammetric applications. The sensor unit is based on a multi-head design, which combines a set of 9 medium format CCD sensors into a large format panchromatic image. The multispectral channels are supported by four additional CCD sensors.
Each of the 13 CCD sensors builds the front end of a separate imaging pipeline. It consists of the sensor, the sensor electronics, a high end analog/digital converter (ADC) and the IEEE 1394 data transfer unit. The inflight storage and computing unit of the camera system offers a redundant image storage unit for each of these 13 channels.
Thus $ULTRACAM_D$ offers a frame rate of more than 1 frame per second, exploiting the benefit of its parallel system architecture.
The panchromatic image consists of 11500 pixels cross track and 7500 pixels long track. Color is simultaneously recorded at

a frame size of 4k by 2.7 k pixels for red, green, blue and near infrared [Leberl 2003].

Fig. 1: ULTRACAM$_D$ Sensor Unit (SU) and Storage/ComputingUnit (SCU)

2.1 Design issues

ULTRACAM$_D$ was designed to replace the analog film camera. This concept leads to specific design issues, among them the image format, the frame rate and quality parameters of the digital output of the camera.
The size of the image across track is related to the number of flight lines one needs to cover a distinct project area at a specific image scale. We have assembled evidence that 11,500 pixels across the swath will outperform aerial film with its swath width of 23 cm. Therefore, the CCD pixel to improve on scanned film will be at an equivalent spacing of 20 μm (20μm x 11,500 pixels = 230 mm). This perhaps surprises, but is supported by superior image quality.
The image format along track has its major influence on the ability of the camera in taking stereoscopic image sequences. ULTRACAM$_D$ offers 7500 pixels, which is a perfect trade off between image data quantity and stereoscopic quality. Together with its focal length of 100 mm and a frame rate of better than 1 frame per second ULTRACAM$_D$ is well prepared to be assigned to nearly every kind of photo mission.

2.1.1 Advantages of going digital

The transition from film based aerial cameras to digital sensors closes the last gap in the all digital photogrammetric production line. Not without good reasons we expect advantages from the digital camera. Some of them are obvious.

- Radiometry: Digital images have superior radiometry and no grain. This provides better matching accuracy, better stereo, resolution in dark shadows and more success in automated procedures. The high dynamic range of more than 12 bit as being offered by ULTRACAM$_D$ allows more flying days in marginal weather or under low light conditions.

- Geometry: A superior geometric performance is based on the rigidity of the camera backplane and the fact, that the sensor needs not to be removed from the camera as it is the case at film based photography.

- Work Flow: The end-to-end digital work flow offers numerous advantages. The contributions of the digital camera are in flight quality control and instant availability of the image data without any film processing and scanning.

- High frame rate at no additional costs: Photo missions without costs for film opens the door to new approaches. The transition from the 60 % forward overlap to a 80 % or even 90 % overlap offers better aerial triangulation results, a reduction of occlusions and a significant enhancement in robustness.

- Multi-spectral imaging: ULTRACAM$_D$ produces a set of high resolution panchromatic, true colour and false colour infrared images simultaneously. This goes far beyond what film can do and offers a new kind of photogrammetric application.

2.2 ULTRACAM$_D$ Product Configuration

ULTRACAM$_D$ consist of four main components, namely the Sensor Unit (SU), the Storage and Computing Unit (SCU), the Interface Panel (IP) and the Mobile Storage Unit (MSU).

2.2.1 Sensor Unit

The heard of the system is the SensorUnit (SU) with its 13 area CCD sensors. A distributed parallel sensing concept offers the fast frame grabbing of almost 90 MegaPixel images at one second.

2.2.2 Storage/Computing Unit

The Storage/Computing Unit (SCU) is equipped with a set of 15 small size computers in such way, that each CCD module of the Sensor Unit is accompanied by a separate “private” storage and computing component with a capacity of dual redundant storage of up to 2692 images. The 15 computers (one serves as the controller, one is redundant) can be used to go for a fast post processing of the raw image data.

2.2.3 Interface Panel

The Interface Panel (IP) offers a well designed intuitive graphical user-interface which guides the interaction with the camera system during the photo mission and on the ground. The inflight control of the camera as well as the post-processing of the image data is managed trough the IP.

2.2.4 Mobile Storage Unit

The Mobile Storage Unit (MSU) serves as the image tank for off loading and data transport whenever the SCU needs to be cleared. This offers a huge amount of flexibility and fast data transfer from the aircraft to the office. A dump of a full set of 2692 images from the SCU to the MSU can be performed within about one hour.

3. CCNS / AEROCONTROL

The *CCNS* is a GPS and aircraft directional gyro based guidance, positioning and sensor management system for aerial survey flight missions. The basic system consists of the Central Computer Unit (CCU), at least one Command and Display Unit (CDU) and the mission planning software package *WinMP*. The system can operate two airborne sensors of any

kind at once, most currently available airborne sensor systems are supported by the *CCNS*.
For the precise determination of position and attitude of the airborne sensor, the *CCNS* can be operated with the GPS/IMU system *AEROcontrol*.

Fig. 2: *AEROcontrol-IId*

AEROcontrol consists of the following four components:

- The Inertial Measurement Unit *IMU-IId*:
  The IMU includes three accelerometers, three fibre optic gyroscopes and signal pre-processing electronics. The six sensors are attached rigidly to an aluminium frame. Through wholes in the IMU housing, this sensor block is mounted directly to the used airborne sensor. The *IMU-IId* provides a high accuracy measurement of the angular rate and of the acceleration with an update rate of up to 256 Hz.

- The airborne computer unit:
  The airborne computer unit collects the raw data of the IMU and of the GPS receiver and stores them on a PC-Card for post-processing. It also provides the time synchronization between the GPS, the IMU and the used sensor. A real-time platform calculation allows the use of the information as navigational input for the *CCNS*.

- The GPS antenna and receiver:
  The system can be operated with a number of different GPS receivers. The default configuration is an integrated 12-channel L1/L2 receiver from NovAtel Inc..

- The postprocessing software *AEROoffice*:
  AEROoffice provides all functions necessary for the handling and evaluation of the collected GPS and IMU data, like:

  - tools for handling the PC-Cards
  - differential GPS post-processing software
  - inertial navigation software
  - transformation to the local mapping system
  - lever-arm corrections for static and variable lever-arms
  - integrated *BINGO* or *BINGO30* AT software package for Integrated Sensor Orientation (ISO) and boresight calibration inside *AEROoffice*

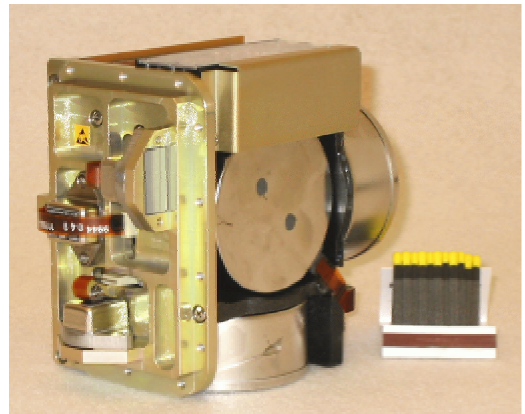

Fig.3: Sensor block of the *IMU-IId*

4. *CCNS* – ULTARCAM$_D$ INTERFACE

4.1.1 Communication in the airborne system

The communication between the *CCNS* is realized via a RS232 interface and a separate cable for the trigger pulse and the feedback signal.
Besides the trigger pulse, the *CCNS* provides the ULTRACAM$_D$ with the necessary information for the forward motion compensation (height and velocity), with the photo specific metadata (exposure number, date/time, position, track over ground) and with the photo specific data from mission planning (project, area, flightline, segment, waypoint number).
At the instant of exposure, the camera sends a feedback signal to the *CCNS*. The approximate position of the camera at the instant of exposure is calculated in near real time and is sent back to the camera. The exact time of this signal is recorded together with the GPS and IMU raw data in the *AEROcontrol* computer for calculation of the exact exterior orientation of the camera in post processing. In addition to the feedback signal, the camera sends status information to the *CCNS*. The display of this information on the CDU enables the pilot or the operator to oversee the status of the complete sensor system by looking at the navigation screen.

4.1.2 Mechanical IMU interface

The IMU is fixed mounted inside the ULTRACAM$_D$ SU housing. To install the unit inside the SU, it is screwed on an aluminium base plate that can easily be fixed to the main frame of the SU. The mounting provides a stiff and durable connection to the optical system of the ULTRACAM$_D$.

4.1.3 Mission planning and GPS/IMU post processing

On the software side, the parameters of the ULTRACM$_D$ are available in the mission planning software *WinMP*, so automatic flight planning for closed (areas) and open (tracks) polygons is possible.
For the identification of the camera events in the GPS/IMU post-processing, the camera events are unambiguously marked by the exchanged information.
In addition to the on-line event handling all relevant data from the flight management and navigation system are stored

together with the image data by the ULTRACAM$_D$ inflight software.

5. PROCESSING OF DIGITAL IMAGES WITH GPS/IMU DATA

The traditional photogrammetric workflow is based on 60% forward overlaps. Therefore a stereo operation employs two intersecting projection rays without sufficient redundancy. The use of digital sensors can change this by increasing the number of images without increasing the project costs, as long as processing is automated. This encourages thinking about the use of higher than 60% forward overlaps.

The benefit of high overlaps is obvious. Each terrain position is mapped more than twice, redundancy is available and blunders and mismatches can be detected automatically.

So the aero-triangulation will become more robust and DEMs will also be without mismatches and all terrain segments will have coverage. An integrated system with geo-positioning tools and multi-ray photogrammetric processing will result in a *DEM-robot* and will also produce true orthophotos without human interaction.

5.1 Direct Georeferencing (DG) and Integrated Sensor Orientation (ISO)

The use of directly measured EO-parameters in photogrammetric data processing can generally be distinguished in two different concepts:
The use of directly measured image EO-parameters for photogrammetric data processing without conducting an AT over the entire image block presents the principle of DG. On the other hand, the simultaneous processing of GPS/IMU data and image information for the determination of the EO-parameters in an extended aerial triangulation is referred to as Integrated Sensor Orientation (ISO) [Heipke 2001].
Which approach is suitable for a specific task depends on many factors, e.g. the required accuracy, the image scale, the availability of ground control information. In general, DG is used for medium to small scale projects, while ISO is applied to large and medium scales [Kremer 2002, Kremer & Kruck 2003].
In a completely digital workflow, the range of projects where ISO is the method of choice might become larger compared to the projects where DG will be used. Because the images are available in digital form anyway, the additional effort to perform a GPS/IMU assisted automatic AT for the complete block is quite small compared to the advantages of ISO compared to DG.

6. FLIGHT MISSION "GRAZ"

On the 22nd of April 2004, a flight mission was done by near Graz, Austria.
The system was installed in a Cessna 206 survey aircraft of Bildflug Fischer, Klagenfurt, Austria.
The mission consists of a block of seven lines with two cross strips. A forward overlap of 90%, a sideward overlap of 85% and a flying height of 1400m above ground, resulting in ground sample distance (GSD) of 0.12 m, was planned. The images were triggered by the *CCNS* on the planned positions (an automatic mode is possible, where the camera is only sending the feedback pulse to the *CCNS*).

Fig. 4: Installation of the ULTRACAM$_D$ in the Cessna 206 survey aircraft

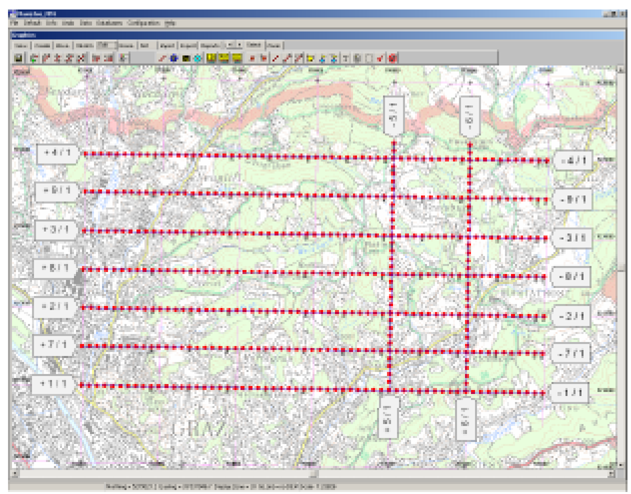

Fig. 5: Missionplanning for the project "Graz" with *WinMP*

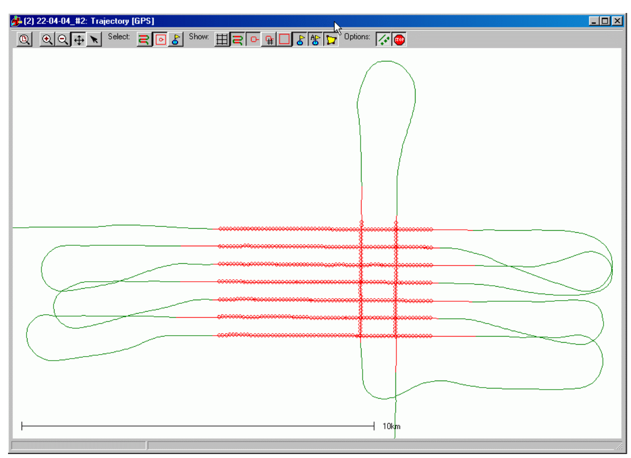

Fig. 6: Recorded trajectory

For GPS post-processing, data from a base station of the Austrian Academy of Science in Graz was used. This base station has a distance of six km from the centre of the project area. The number of satellites was between five and seven with a P-DOP around two.
The GPS post-processing was done with *GrafNav* of Waypoint Consulting, the GPS/IMU processing was executed with *AEROoffice*, the automatic tiepoint measurement with *MATCH-AT* from INPHO and the AT with *BINGO* of GIP.

6.1 Guidance accuracy

To check the correct timing of the trigger pulse and the feedback signal, the difference between the planned photo position and the measured position of the camera at the instant of exposure was compared.
Figures 7 and 8 show these differences for the flight direction and the perpendicular direction, respectively (for the east-west lines). The comparison shows a RMS of about 2m for the flight direction, and a RMS of about 4m for the perpendicular direction.
The value in flight direction is dominated by the GPS realtime accuracy for the navigation. The position difference perpendicular to the flight direction *reflects the skills* of the pilot to stay on the flightline indicated by the *CCNS*.

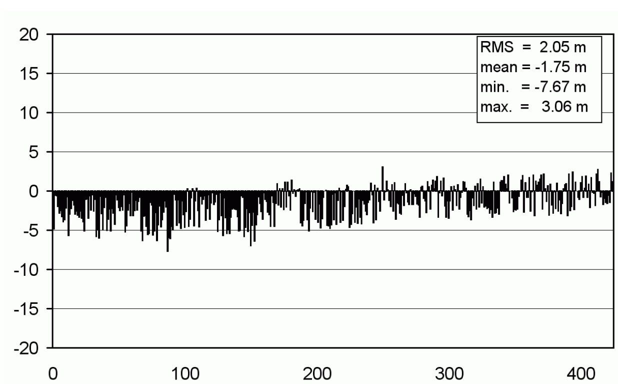

Fig. 7: Difference between planned and flown photo-position in flight direction, number of photos vs. difference in meters.

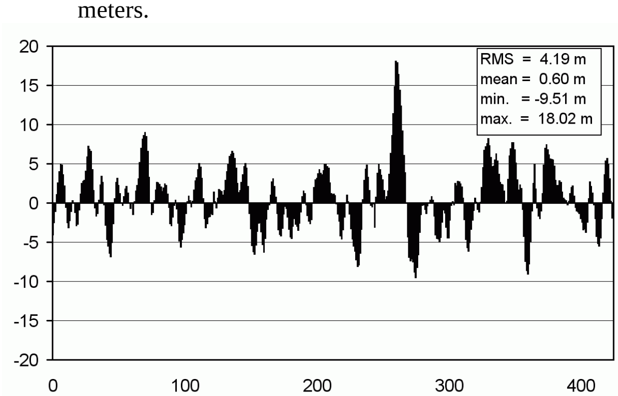

Fig. 8: Difference between planned and flown photo-position perpendicular to the flight direction, number of photos vs. difference in meters.

These results illustrate the capability of the system to reproduce photos within a position accuracy of some meters (“pin pointed aerial photography”).

6.2 Boresight alignment

The relative orientation between the IMU coordinate system and the coordinate system of the camera has been determined with help of an ISO of a sub-block of the project area. For this extended AT a small block of 30 images in the south of the area was used. In this calculation only every third image was used, resulting in a forward overlap of app. 70%.
With this boresight AT the misalignment angles have been calculated with an accuracy of app. 0.7 deg for roll and pitch and 2.6 deg for the heading angle. The datum shift to the local coordinate system was calculated as well.

6.3 Direct georeferencing (DG)

The results of the boresight alignment were used to orient the images in a block 2 km apart the area of the boresight AT.
The positions of known GCPs were determined with help of the directly measured EO-parameters. Deviations between GCP coordinates and measured coordinates over a set of 8 points were investigated as a final proof of the quality of direct georeferencing. Horizontal deviation of about +/- 14 cm in east and north direction and deviations of the z-component of the position in a range of +/- 23 cm could be observed.
For the given mission parameters, these values are within the expected accuracy range. The setup of images was done on the SUMMIT Evolution of DAT/EM and found to be free of vertical parallaxes.

7. CONCLUSIONS

We have shown the integration of the large format digital aerial camera $\text{ULTRACAM}_{\text{D}}$ of Vexcel and the *CCNS4* guidance and sensor management system together with the GPS/IMU option *AEROcontrol* of IGI mbH. A test project was successfully flown and results were presented.
The novel option of the digital camera to transit from the traditional 60% forward overlap to a highly redundant set of images with forward overlaps of up to 90 % was discussed and the need to automate the processing of such datasets was mentioned.

8. REFERENCES

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