ULTRACAM$_X$, THE LARGE FORMAT DIGITAL AERIAL CAMERA SYSTEM BY VEXCEL IMAGING / MICROSOFT

Michael Gruber[a], Martin Ponticelli[a], Stefan Bernögger[a], Franz Leberl[b]

[a] Vexcel Imaging / Microsoft Photogrammetry, Anzengrubergasse 8, A-8010 Graz, Austria
{michgrub, mponti, stefanb}@microsoft.com
[b] Institute for Computer Graphics and Vision, Technical University Graz, Inffeldgasse 16, A-1810 Graz, Austria
leberl@icg.tu-graz.ac.at

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ABSTRACT:

In this contribution we show details about the large format digital aerial camera system UltraCamX. The sensor was introduced into the market in 2006. It is currently the largest digital frame camera for photogrammetric applications. The system consists of several hardware component as well as software to operate the camera during the flight mission and to process image data after the photo flight. UltraCamX is manufactured by Vexcel Imaging GmbH, Graz, Austria. This company is 100% owned by Microsoft Corp. since May 2006 and contributes to the Virtual Earth initiative of Microsoft. Within this huge project high quality aerial images are used to digitally reconstruct urban areas in an automated processing chain. We show details about the camera system and the newest results from the urban modeling project.

1. INTRODUCTION

Vexcel Imaging GmbH was founded in Graz, Austria in 1992 and is known as the manufacturer of photogrammetric devices. The first product was the precision film scanner UltraScan5000. In May 2003 the digital large format camera system UltraCamD was presented and – three years later – the new large format digital aerial camera system, the UltraCamX was introduced. The sensor did find its way into the international mapping market and serves since then as the versatile airborne sensor for application in many different project scenarios. The short frame interval enables the sensor to acquire images at large scale and at rather high stereoscopic overlaps. This offers new methods of photogrammetric processing, namely a highly redundant and therefore robust analysis of such frame images. These advantages of that new digital workflow and photogrammetric processing chain are successfully used within the digital city modeling task of the Virtual Earth program.

The radiometric bandwidth and the multispectral capability of the camera offer a dynamic range of more than 12 bit per band and simultaneous infrared acquisition. This enables to introduce a multispectral classification process into the workflow. In combination with the geometric analysis of the large panchromatic images the multispectral classification supports the automated workflow.

The geometric accuracy of the sensor is maintained from sophisticated postprocessing methods as well as from a highly accurate laboratory calibration. This makes possible to achieve remarkable results from aerotriangulation and bundle adjustment. In this contribution we show results from several aerial photo missions an present the radiometric and geometric performance of the camera.

2. ULTRACAM X, THE LARGEST DIGITAL FRAME CAMERA

The UltraCamX camera system exploits valuable developments of the industry in the fields of sensor technology, data storage technology and data transfer technology as well as Vexcel's in-house experience and know-how.

The advantages of UltraCam X are

- large image format of 14430 pixels cross track and 9420 pixels along track
- excellent optical system with 100 mm focal length for the panchromatic camera heads and 33 mm for the multi spectral camera heads
- image storage capacity of 4700 frames for one single data storage unit
- almost unlimited image harvest due to exchangeable data storage units
- instant data download from the airplane by removable data storage units
- fast data transfer to the post processing system by the new docking station.

The camera consists of the sensor unit, the onboard storage and data capture system, the operators interface panel and two removable data storage units. Software to operate the camera and process the image data after the flight mission completes the system. Additional software for project set up and automated aerotriangulation is in preparation.

Fig.1: UltraCam X digital aerial camera system with the Sensor Unit (right), the airborne Computing Unit including two removable Data Units (center), the Docking Station (left) and the Interface Panel.

3. THE ULTRACAMX SENSOR HEAD

The UltraCamX sensor head is designed as a digital frame camera It consists of eight independent camera cones, 4 of them contributing to the large format panchromatic image, 4 contributing to the multi spectral image. The sensor head of the UltraCamX is equipped with 13 FTF5033 high performance CCD sensor units, each producing 16 mega pixels of image information at a radiometric bandwidth of more than 12 bit.

In cooperation with LINOS/Rodenstock a high performance optical system with the focal length of 100 mm for the panchromatic cones and the focal length of 33 mm for the multi spectral cones was developed. This set of two lenses supports the pan sharpening ratio of 1:3.

The image format of 14430 pixels cross track and 9420 pixels in flight direction contributes to productivity in the air. At 25 % side overlap between strips the UltraCamX covers more than 1650 m at 15 cm pixel size.

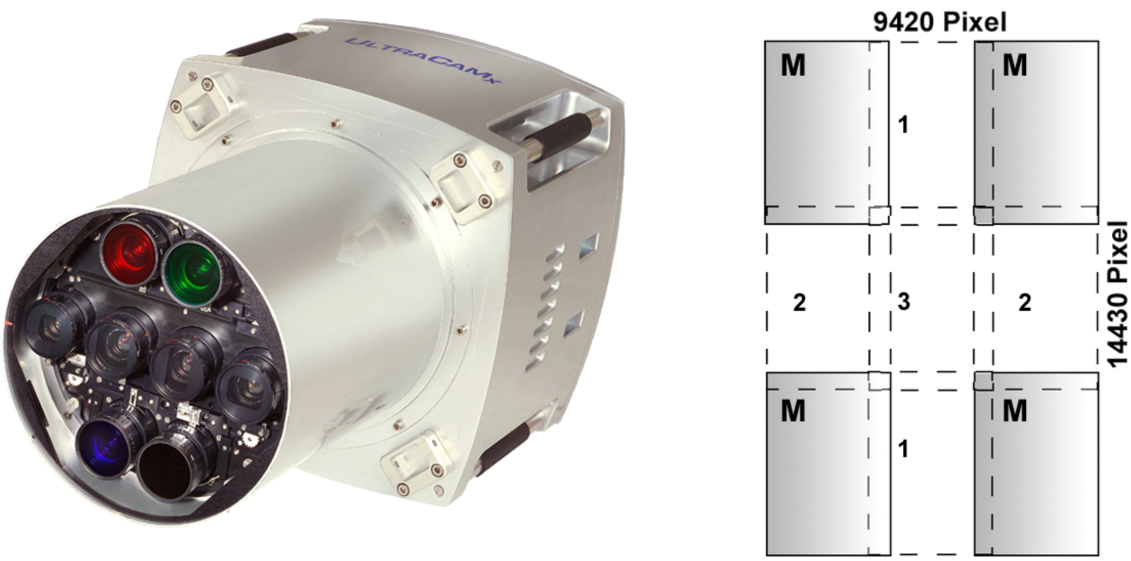

Fig. 3: The UltraCamX sensor head (left) consists of 8 camera heads, 4 of them contributing to the large format panchromatic image. These 4 heads are equipped with 9 CCD sensors in their 4 focal planes. The focal plane of the so called Master Cone (M) carries 4 CCDs (right).

Technical Data UCX Sensor Unit	
Panchromatic Channel	
Multi cone multi sensor concept	4 camera heads
Image size in pixel (cross track/along track)	14430 * 9420 pixel
Physical pixel size	7.2 micron
Physical image format (cross track/along track)	103.9 mm * 67.8 mm
Focal length	100 mm
Lens aperture	f = 1/5.6
Angle of view (cross track/along track)	55° / 37°
Multispectral Channel	
Four channels (Red, Green, Blue, Near Infrared)	4 camera heads
Image size in pixel (cross track/along track)	4992 * 3328 pixel
Physical pixel size	7.2 micron
Physical image format (cross track/along track)	34.7 mm * 23.9 mm
Focal length	33 mm
Lens aperture	f = 1/ 4
General	
Shutter speed options	1/500 sec – 1/32 sec
Forward motion compensation	TDI controlled, 50 pixels
Frame rate per second	1 frame in 1.35 sec
A/DC bandwidth	14 bit (16384 levles)
Radiometric resolution	> 12 bit /channel

Tab. 1: Technical Data and Specifications of the UltraCamX Senor Unit

4. THE ULTRACAM X ON BOARD STORAGE SYSTEM

The on board data storage system of the UltraCamX improves the end to end workflow of the aerial mission and meliorates the working conditions of the aerial crew. The system contains two independent data units for redundant image capture. The data units are able to capture up to 4700 images of 136 mega pixels each and – most valuable for large scale missions – can be replaced by spare units within a few minutes. Thus one can increase the entire number of images for one single mission by a factor of two or three and enjoys practically unlimited image storage capacity on board. Disconnecting the data units from the camera system after the completion of a flight mission and shipping the raw data to the office is then an easy play.

Downloading of the image data is supported by a docking station, which allows the complete data transfer of 4000 images within 8 hours through four parallel data transfer channels. A 24 hour cycle of flying, copying and QC can be achieved.

5. ULTRACAM POST-PROCESSING AND IMAGE QUALITY CONTROL

Since aerial cameras continuously increase the number of pixels (~130 Mpix, UltraCam-X), handling of aerial imagery is getting to a problem for the operator. This is getting worse if the quality control (QC) requires the visualization of geo-located high resolution images, in order to validate whole projects (usually >2,000 images, about 253 Gpix). In most cases, quick views (downsampled to 1/100 of the original size) are used for doing a quick quality check. The downside of this approach is obvious. Neighboring information cannot be taken into account if a block of images should be evaluated. In addition, the quick views may not reflect the actual image content since they are also radiometrically reduced (8 bits instead of the original radiometric resolution).

Our recently developed visualization engine eases the handling of this large amount of data by using tiled image pyramids, and graphics card acceleration. This allows fast access to multi-resolution image data. During visualization, the required information is retrieved from the according images and is used for fast display. With this approach, the visualization performance only depends on the screen resolution and not on the resolution of the images or the number of images anymore.

Fig. 4: UltraCamX on board computing unit and removeable Data Unit. The download of image data to the post processing station is supported by four parallel data streams of the Docking Station.

Another advantage of our approach is that we maintain the high dynamic range of images (>12 bit) within the pyramid data. The 8 bit conversion is done directly on the graphics card and can therefore easily be changed interactively for the whole block.

Our engine supports various visualization modes:

- The footprint view shows the image outline projected down to the ground level using the available GPS and/or IMU data.
- Indexmap view shows a block of geo-located images. A slider can be used to define the scale of the image footprints and can therefore virtually remove the image overlap.
- Heatmap view is a visualization type for showing the degree of overlap of the image block. The color-coded regions allow immediate visual recognition of flight patterns.
- Thumbnail view allows a more semantic image clustering. For instance, images may be grouped by their strip number or histogram statistics.
- The overlay concept is designed for visualizing additional meta information on top of image data. This may include image IDs as text, footprints, projection centers, ground control points, tie points, and so forth.

Besides the visualization, the interaction is also a very important aspect. Easy pan and zoom functionality is done by using the mouse. Image selection is important for grouping or removing individual images. High level interaction is required when it comes to measuring (ground) control points. Especially for the last task, the multi-image block visualization eases tremendously the amount of time for interaction.

Our approach allows for seamlessly browsing through the whole image collection, beginning with an overview of the image, to a close-up view (100%) of individual images. Radiometric inconsistency, missing images, and high crab angles can be seen at once (cf. Figure 5)..

Figure 5: Close-up view to individual high resolution images. Left images shows a high crab angle of the inspected image. The right image gives a 100% view.

The right image of Fig. 6 shows the *heatmap view*. Green regions indicate high overlap, whereas red regions denote lower overlap. The user can then browse seamlessly from the overall block overview to the individual image as shown in Fig. 5.

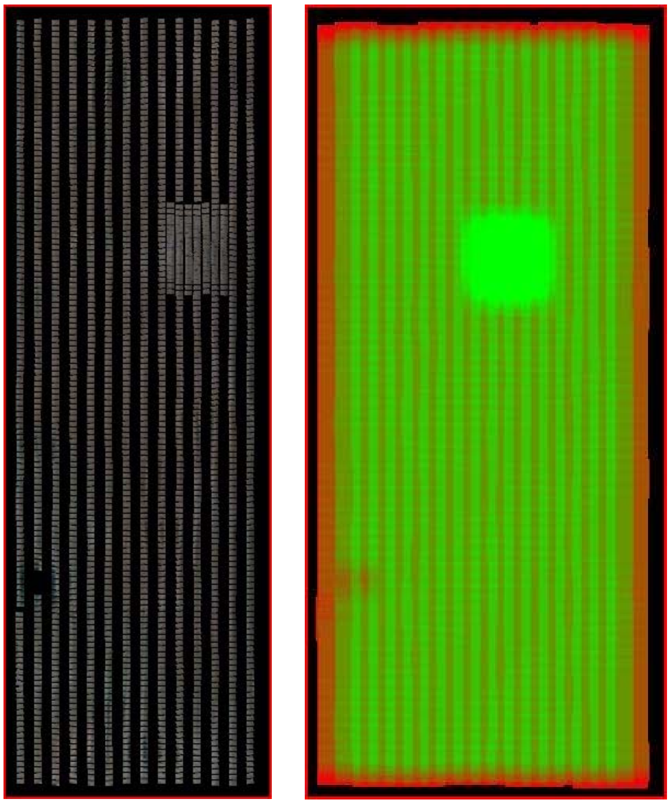

Figure 6: Block overview of 2,000 images. The left image shows at one sight that there are missing images. The right image shows a heatmap for the block.

6. RADIOMETRIC QUALITY AND MULTI SPECTRAL CAPABILITY

UltraCamX exploits the radiometric quality of the high performance CCD sensor FTF5033 manufactured by DALSA. Not much less then 13 bit of radiometric information can be extracted via the 14 bit analog/digital converter. Such broad bandwidth allows resolve dark and bright areas in one and the same scene like from a city area on a bright sunny day with dark shadows in the streets and almost white roofs or other bright objects. The performance in dark image regions shows the full potential of the sensor and its sensibility. Only ± 6 DN @ 16 bit (= 0.4 DN @ 12 bit) of noise could be detected in shadows.
Figure 7 shows frame 1090 from a flight mission over the city of Graz, Austria on March 27th 2007, a clear sunny day. At a flying height of 900 m above ground level a ground sampling distance (GSD) of 6.5 cm was achieved. Two sub areas of the panchromatic camera head containing very bright objects (umbrellas and welded roofs) as well as dark shadows were analyzed by computing the histogram. Levels of intensity from 350 DN to 7800 DN @ 16 bit could be detected, image areas were not saturated. Such huge dynamic range of 7450 DN corresponds to almost 77 dB or 12.9 bit.

Fig. 7: Aerial image of very high intra scene contrast (snow and ice vs. shadows and dark rocks). Different gamma settings were applied to show details of different brightness.

7. FIELD EXPERIMENTS

After the geometric laboratory calibration the performance of every UltraCamX is verified by a flight mission over a well known test area near Graz. A flight pattern with high overlap (80% endlap, 60% sidelap) and cross strips offers a redundant dataset which allows to investigating the interior geometry of the camera.

The automatic tie point matching was done using INPHO's aerial triangulation software packages Match AT. The sigma_o value reflects the quality level of image coordinate measurements of an aerial triangulation project. Such values have been computed for several UltraCamX image datasets. The sigma_o values of the flight missions shown in Figure 8 are close to or smaller than 1 µm at that huge redundancy of high overlaps and additional cross strips.

A cross check and additional self calibration options were applied by BINGO.

Since spring 2008 a new test area could be made available near Philadelphia, VA. First results from a test flight carried out by Keystone Aerail Surveys Inc. show results at the 1 µm level.

Another widely accepted method to proof the geometric performance of mapping cameras is the use of check points. We use the result of 6 individual flight missions and 6 individual cameras to analyze the geometric performance of these cameras. Averaging 199 check point measurements a deviation of 38 mm, 46mm and 56 mm in X, Y and Z was observed. The vertical accuracy of that dataset corresponds to 0.04 o/oo of the flying height.

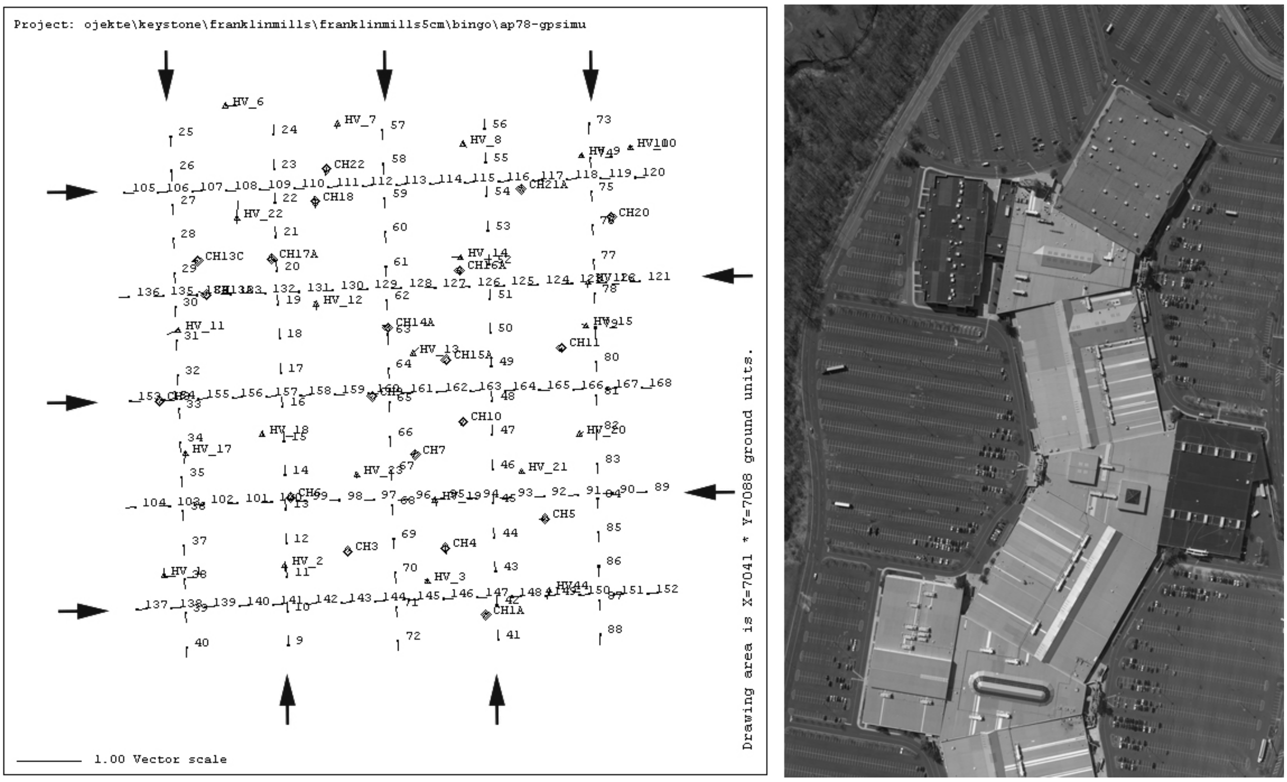

Fig. 8: Test area Franklin Mills near Philadelphia. The flight plan shows 10 flight lines with 160 images at high overlap (80% / 60%). The cross track pattern enables to carefully analyze the geometric property of the images. On the right: Frame 93 of the flight mission on March 25th 2008 performed by Keystone Aerial Surveys, Philadelphia, VA.

8. MICROSOFT PHOTOGRAMMETRY

The main goal of the Virtual Earth Program is to provide a high quality photorealistic three dimensional database of human habitat via the internet. The production chain of this program is based on photogrammetric technology. Aerial photo missions are carried out at a large scale (GSD at 15 cm) at an endlap of 80% and a sidelap of 60%. This huge amount of highly redundant image data supports the automatic process of aerial triangulation, digital elevation modeling and feature extraction. Redundancy from multiple overlaps supports the robustness of the process and the automatic removal of blunders and mismatches. Another important advantage of such high overlap can be recognized in the rigorous reduction of occlusions, a most helpful side effect when working in dense build up areas of city centers. Beside the digital buildings the content of the data base is enhanced by additional information. Vegetation like bushes and trees are introduced as 3-d objects after automated recognition via the multispectral classification. Figure 9 shows Downtown Denver. On the left the state capitol of Colorado is visible at a remarkable quality.

The entire project is huge. In a five year time frame the Virtual Earth data base will contain most of the larger cities of the world.

Fig. 9: Snapshot from the Virtual Earth Web Page (maps.live.com). Downtown Denver is represented by three dimensional building model with photo realistic texture. Trees are recognized by image classification and replaced by three dimensional tree models.

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