UltraCam Eagle Prime Aerial Sensor Calibration and Validation

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Abstract

We present details about calibration and validation of the UltraCam digital aerial sensor product UltraCam Eagle prime. This includes geometric calibration as well as radiometric calibration. Our calibration laboratories consist of several tools, installed equipment and software to analyze radiometric and geometric image data. In this contribution we focus on our new flagship camera product, the geometric and radiometric performance and results from flight missions. This image data is used to illustrate the image quality of our large format digital aerial camera. Based on the high dynamic range, different parts of a high contrast scene can be resolved. Details are well distinguishable and thus the value and information content of the digital image is at a very high level.

Introduction

UltraCam Eagle prime is the new flagship product of the UltraCam Sensor family. The large footprint of about 23 k by almost 15 k pixels and the superior image quality are key characteristics of this sensor. The calibration procedure of our cameras was developed in 2003 and has been continuously improved. This includes the recording of the temperature close to the CCD sensor arrays for every image taken with the camera and the improvement of the geometric processing of the images based on this information. In addition to that we introduced the temperature reading at the optical lens system. These temperature values now contribute to the workflow of the image stitching procedure. Post-processing of UltraCam images as well as the photogrammetric production pipeline are implemented in the UltraMap software product. UltraCam and UltraMap together offer a complete photogrammetric system, which empowers our user to achieve more.

UltraCam Eagle Prime

The flagship product of the UltraCam Sensor family is the UltraCam Eagle and since 2016 the Eagle Prime. Both cameras are based on the multi cone concept, which was already introduced in 2003. For geometric performance it is essential to understand this concept. The panchromatic subsystem consists of four independent camera heads with identical camera geometry. The backplanes of the four camera heads are equipped with 9 CCD sensor arrays which allow to completely cover a rectangular footprint on the ground and provide distinct overlaps. The transformation of image content from each CCD detector array into a seamless image frame is computed from the so-called stitching procedure exploiting the image content of the overlap areas.

PAN pixel across track	**23,010**	**PAN focal length**	**80, 100, 120, 210 mm**
PAN pixel along track	**14,790**	**b/h (f80, f100, f120, f210)**	**0.34; 0.27; 0.23; 0.13**
Max. frame rate	**1.65 s**	**AGL for 5cm GSD (f80, f100, f120, f210)**	**870 m; 1,090 m; 1,304 m; 2,283 m**
Pan-sharpening ratio	**1:3**	**Max. speed for 5cm/10cm GSD @ 80% front-lap**	**159kts / 318kts**
FMC	**Non mechanical, TDI implementation**	**Max. speed for 5cm/10cm GSD @ 60% front-lap**	**318kts / 637kts**
Lens system	**Exchangeable w/o new calibration**	**Max. front-lap for 5cm/10cm GSD @ 140 kts**	**82% / 91%**

Tab. 1: UltraCam Eagle Prime Key Camera Parameters

CCD Sensor Arrays at 4,6 µm Pixel size

UltraCam Eagle Prime is equipped with thirteen monochromatic full frame CCD detector arrays at a pixel size of 4.6 µm by 4.6 µm. Thus each array consists of 7.8k by 5.2k elements (41 MPix). The radiometric bandwidth of this senor is about 72 dB and the 16 bit readout channel produces intensity levels of up to 12000 DN. Later in this contribution we show results from a large scale flight mission to illustrate the capability of this excellent CCD imager.

It is also noteworthy that for aerial application we still see huge advantages of the CCD technology over current CMOS sensor concepts. This can be easily understood, when we refer to the well-known FMC implementation by TDI (time delayed integration), which works without any mechanical components.

We are also convinced that CCD technology is superior to CMOS technology especially for aerial applications due to the larger full well capacity of the sensor elements and therefore the better signal to noise ratio achievable in real life signals, which is mainly dominated by shot noise. However, image quality should be judged from real images from a flight mission and not from single specification parameters.

The design of the UltraCam sensor head includes another advantage: The multi cone multi detector array concept supports a highly parallel architecture which enables the sensor to acquire images at a remarkably fast frame rate.

Geometric Calibration

The geometric calibration of the UltraCam sensor products is a laboratory calibration, which relies on a highly redundant set of images taken from a three dimensional calibration rig and the automatically derived image positions of the three dimensional targets (cf. Figure 1). The set of image coordinate measurements is then introduced into the bundle adjustment and thus all unknown camera parameters are the result of this procedure.

Since the camera is ready for operation a validation flight mission is performed and proofs the results of the laboratory calibration. Figure 2 shows the remaining image residuals for the UltraCam Eagle Prime f100 and UltraCam Eagle Prime f210.

Fig. 1: UltraCam Calibration Laboratory: The three-dimensional calibration rig covers a horizontal field of 12 m.

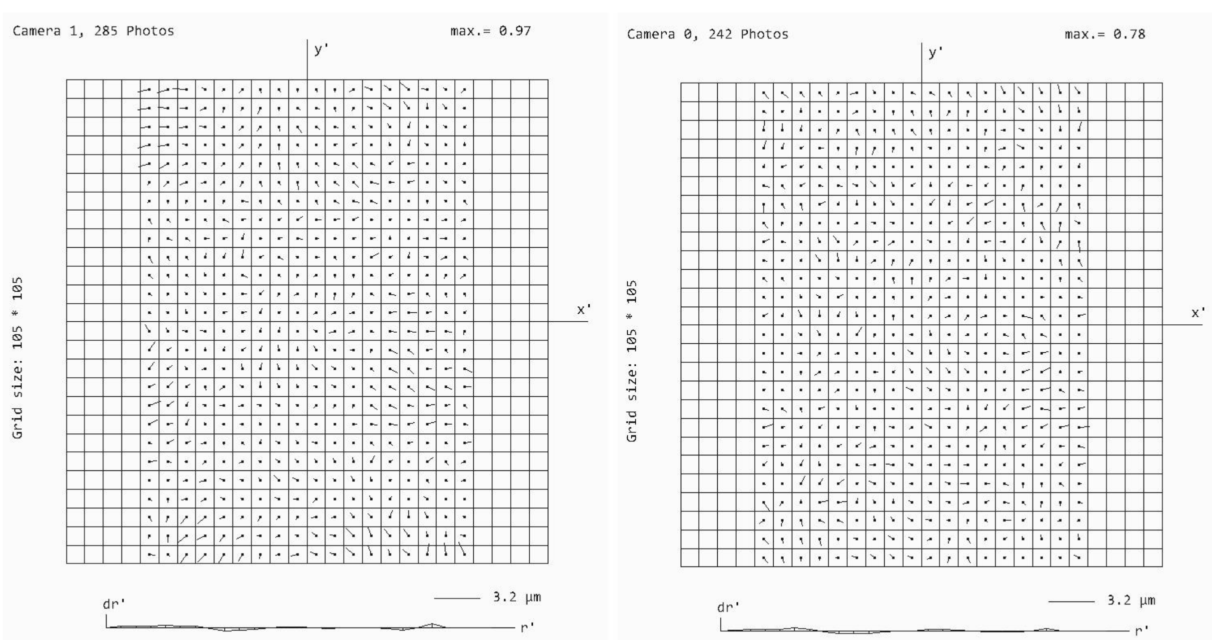

Fig. 2: Geometry results from a validation flight. Remaining image residuals are below 1 µm.

Camera Temperature

The influence of the camera temperature and temperature changes has always been a topic for aerial photography. Such temperature compensation is an important part of the geometry modelling concept of UltraCam sensors. Thus a permanent temperature monitoring during the laboratory calibration as well as during every flight mission is implemented. Temperature readings from every lens cone and for each frame are available for all UltraCam sensors of the 3rd generation architecture (Eagle, Falcon, Hawk and Osprey). All temperature readings of a production image are compared to the temperature readings from the laboratory calibration (cf. Figure 3). These temperature differences are used within the post-processing (a.k.a. stitching procedure).

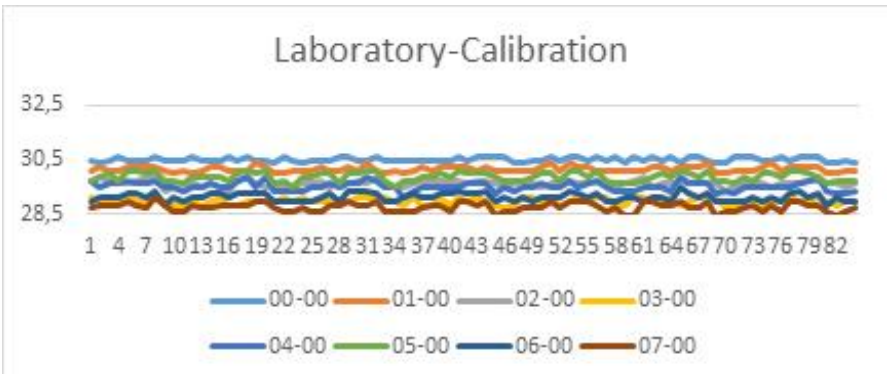

Fig. 3: Temperature Readings from the UltraCam Eagle Prime laboratory calibration.

Radiometric Calibration

The radiometric calibration of every UltraCam sensor unit includes dark field and bright field images and images from a color target. For this task our laboratory is equipped with a set of high quality Hedler Daylight lamps as well as a white board for bright field exposures and a color target. All components of such a set up are well positioned in the laboratory and thus images are taken under specified conditions (cf. Figure 4). In order to control the laboratory equipment a calibrated Ulbricht Sphere and a spectrometer are in place.

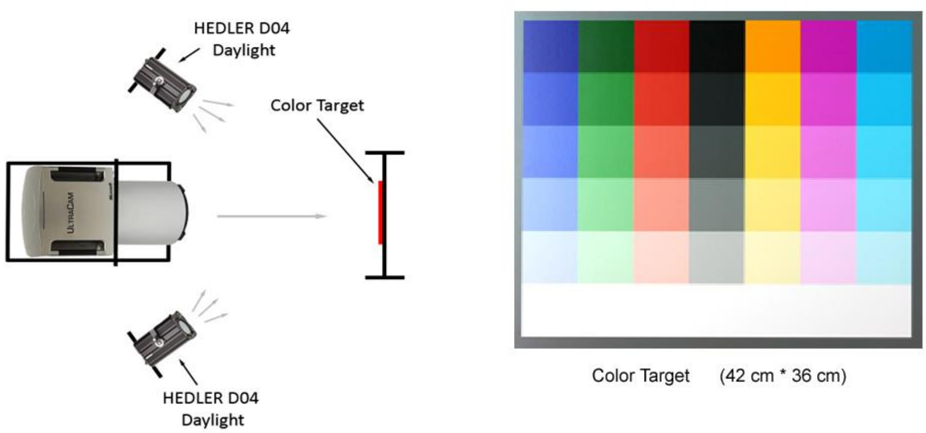

Fig. 4: Well defined position of camera, light source and color target as part of the radiometric calibration.

Radiometric Quality of UltraCam Eagle Prime f210 Images

The radiometric performance of the UltraCam Eagle Prime f210 is illustrated from a recent flight mission on January 12th, 2016 in a project area near Graz. Figure 4 shows a full frame of the flight mission. Shadow areas and winter colors are dominant in this image. At the altitude over ground of 1140 m a ground sampling distance of 2.5 cm was achieved from the 210 mm lens system. The image content shows a built up area with tied roof buildings, pedestrian areas, industrial zones and traffic areas. Thus the image quality, image sharpness and radiometric performance are impressively illustrated.

Fig 5: UltraCam Eagle Prime f210 full frame (image 383) with 23,010 by 14,790 pixel. The Image was taken on Jan/12 2016 at an altitude of 1,140 m AGL and 210 mm focal length. The resolution on the ground (GSD) is at 2,5 cm. Long shadows and brownish colors from the winter landscape dominate the image content.

In order to understand the excellent radiometric performance of the sensor we show details from frame 383 and modify the content by means of histogram conversion (cf. Fig. 6). This allows to boost shadow areas and illustrate the radiometric resolution of dark shadow areas as well as the quality of very bright details. Figure 6 shows details of frame 383 with dark shadows, the surfaces of a white car in the bright sunshine and the fine tile structure on the ground. The area was enhanced about 2 and 4 f-stops (from left to right) in order to present the entire image content.

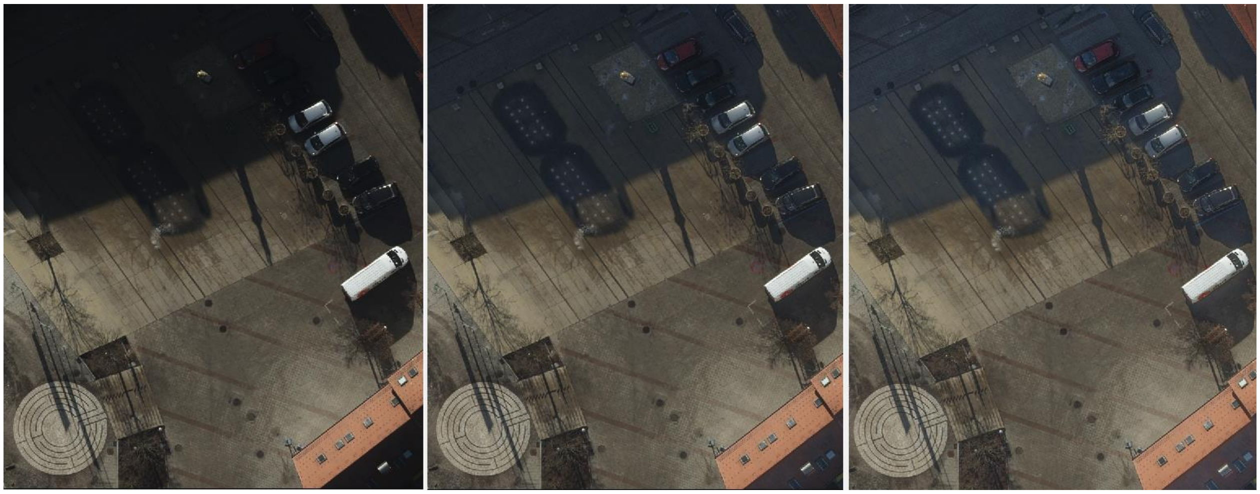

Fig 6: Crop from UltraCam Eagle Prime f210 frame 383: The content of this crop area consists of dark shadows, bright details like white cars and rather fine structures on the ground. The source image (left) was processed in several ways to spread the histogram and enhance the dark areas (center and right).

Figure 7 illustrates the radiometric performance with the help of a high contrast subarea of Figure 6. Dark cars in hard shadows as well as bright cars in the sun are visible. Also small structures on the ground can be easily identified.

Fig 7: Detail of Figure 6: Even dark cars in the shadow are perfectly visible in the enhanced image.

Another crop area in the lower right corner of fame 383 (cf. Fig. 5 and Fig. 8) shows bright roofs with fine structures as well as dark shadow areas. We have analyzed this part of the image and identified the dark areas at the level of 62,90 DN +/- 0,57 and bright areas at 4031,48 +/- 12,48 DN at the 14bit representation (0 ... 4047 DN). This shows that the limiting factor of the radiometric resolution is caused from shot noise and thus from a physical limitation. In this context, the full well capacity is utilized as the key parameter, in understanding the quality of an aerial image sensor.

Fig 8: Crop from UltraCam Eagle Prime f210 frame 383: The crop area consists of a high dynamic band width. A high dynamic range (HDR) process was applied to enhance the image and show the details in bright and dark areas.

Conclusion

In this contributions we have illustrated the details of the new UltraCam Eagle Prime sensor. This large format aerial camera produces a frame image of 23010 by 14970 pixels. The new CCD imager, which is one of the most important components of the camera, offers a 4,6 µm by 4,6 µm pixel size and a stunning radiometric performance. The sensor is available since 2016 and is equipped with different lens cones from 80 mm to 210 mm focal length. Thus the camera is a versatile sensor product and serves for a huge variety of aerial photo missions.

Literature

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