THE ULTRACAM LARGE FORMAT AERIAL DIGITAL CAMERA SYSTEM

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ABSTRACT

The race is on to introduce an aerial digital camera system to outperform the current aerial film cameras in quality, accuracy and economics. We introduce the UltraCam-D *large format digital aerial camera*. It achieves superiority over conventional aerial film imaging. The system produces aerial "photography" as if a film camera had taken film images that then were scanned. As a result, images that get produced by the novel camera will feed into a current softcopy photogrammetry workflow without significant changes, yet with many advantages. These include *quality advantages* with superior radiometry and geometric stability resulting from the use of CCD technology. There are *cost advantages* due to the avoidance of film and scanning. Finally there are *operational advantages* due to instant quality control, image based navigational support reducing the need for imaging skills, and very short repeat intervals in the range of 0.75 seconds, optionally producing very high forward overlaps at no added cost. The technical specifications of the camera meet the requirement that it outperform a modern film camera system.

INTRODUCTION

Advantages of digital cameras are widely understood: No film, no photo lab, no scanning, no noise from film grain and no cost of duplication (Leberl et al., 2002). Superior radiometry promises more flying days and easier interpretation, also more success of automated procedures. And does the lack of film not permit one to abandon the perennial photogrammetric ideology of minimizing the number of photographs to map a given area? Can one now more fully exploit the promise of optical imaging by the use of more forward overlap and greater redundancy? After all, there are no extra costs associated with extra images.

Ideally, one will be able to maintain the traditional photogrammetric workflow used with scanned photography. The digital camera would have to produce digital photos much like they had been obtained from a film camera and were then scanned. A camera is needed to replace traditional aerial film cameras.

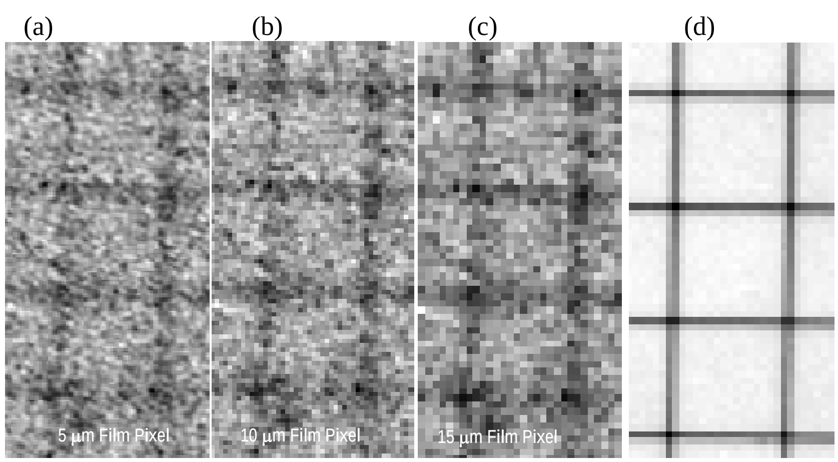

Figure 1: Images of a grid pattern. (a) through (c) were obtained by scanning a film image using pixel sizes of 5µm, 10µm and 15µm. The digital image in (d) has a pixel size of 12µm. It clearly outperforms all of the film scans. Film does not seem to contain sufficient information to compete with a 12µm digital pixel (Perko and Gruber, 2002).

To illustrate the advantage of digital imaging without film grain, compare Figures 1, 2 and 3. In Figure 1 a test area is being imaged with a film camera and a digital sensor, using the same scale. The lack of film grain and the higher radiometric resolution of the digital sensor produce a strikingly superior image. Film of course must first be scanned before it can be compared with a digital image. The example in Figure 1 has been scanned at three different resolutions. It is obvious that increasing the scanning resolution from 15µm via 10µm to 5µm does not improve the interpretability of the object.

Figure 2 presents railroad tracks. The film image was obtained at scale 1:5,500 and scanned with a pixel size of 5.5 cm on the ground, thus a scanner pixel at 10 µm. The tracks are far less well defined than in the digital image taken with a larger pixel size of 12 cm. This suggests that the film's resolution can be captured with 20 µm pixels, may be even larger pixels. Figure 3 concludes this review with a detail of roofs and of shadows, also at a pixel size of 12 cm.

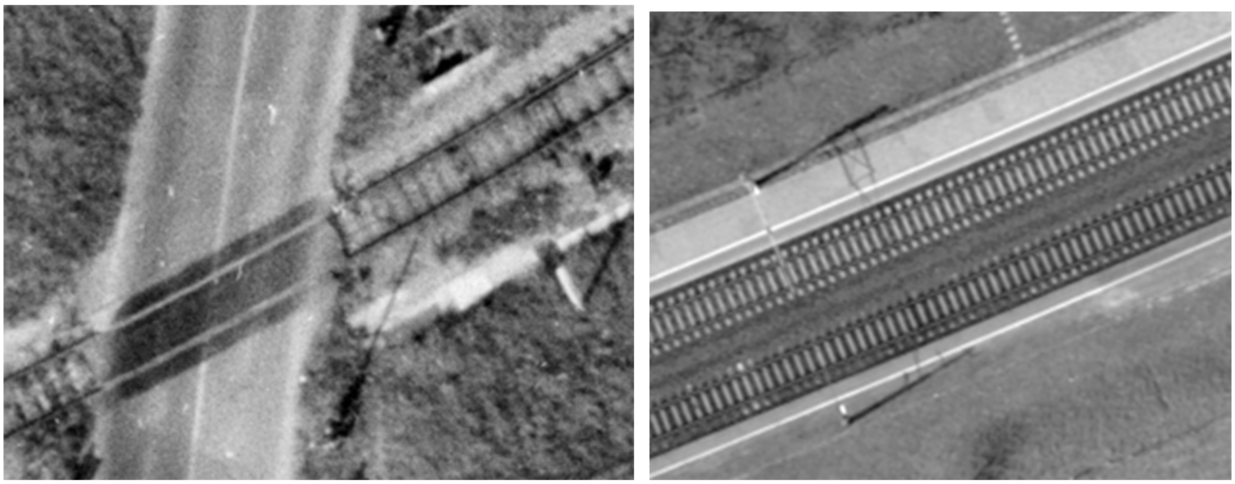

Figure 2: Left is a railroad track on AGFA Pan80 fine grain film, scanned with 10 µm pixel size. Taken at scale 1:5,500 and producing a ground sampling distance GSD of 5.5 cm. Right is an UltraCam-image of a similar type object using a GSD of 12 cm.

Figure 3: Detail from an UltraCam-image at a pixel size of 12 cm on the ground. Note the definition of the roof surfaces and the detail in the shadows.

The effect of this superior radiometry on the very challenging task of image matching is illustrated in Figure 4 (derived from Perko and Gruber, 2002). A film-based close-range image pair was scanned and submitted to a match. Then the digitally sensed image pair was also matched, both sets taken at the same scale. A "match error" is defined as the distance of the match-point from it's epipolar ray. Figure 4 reveals that a match of the digitally sensed data is at an accuracy of 2.4 times better than the accuracy of the scanned film, in terms of pixel size. Note that the film was scanned with a pixel size of 15µm. Reducing the pixel size to 10 or 5 µm does not improve the film result.

Figure 5 illustrates the differences between a scanned color film image and a digital image also in color. The digitally sensed image has more detail, although both images feature the same pixel size on the ground. The scanner pixels at 11.3µm are too small for the content of the film image.

We suggest two conclusions. First, a pixel on the ground, obtained from a digital camera, is superior to the same pixel obtained from film scanned with 20 µm pixels. Second, the film result will not significantly improve even if it gets scanned with smaller scanner pixels, say at 15µm or 10µm. We conclude that a digital aerial camera needs to resolve 11,500 pixels to be superior to the 23cm dimension of a traditional film image.

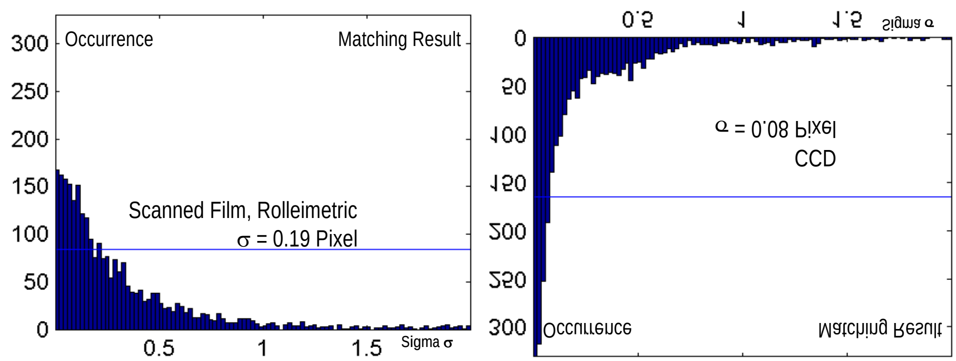

Figure 4: Comparing matches from a pair of scanned film images (at 15µm pixel size) and from a pair of digitally sensed images. The histograms show that the film-based matches have larger errors. The errors are obtained by determining the distance of each match point from the corresponding epipolar ray. The CCD-based matches have a noise level that is 2.4 times smaller than the matches based on scanned film.

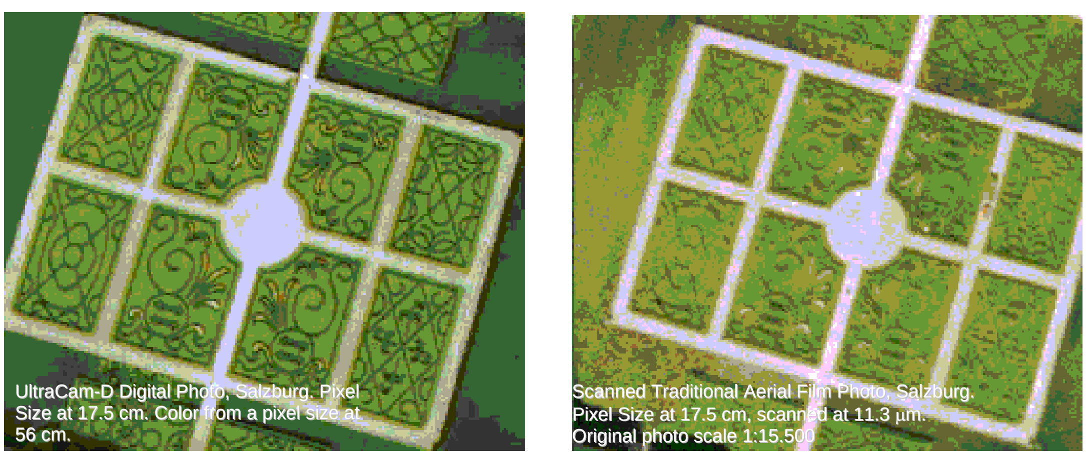

Figure 5: Comparing scanned aerial film with a digital aerial image from UltraCam-D. Both images produce 17.5 cm pixels on the ground. The images were taken one year apart; therefore some changes have occurred on the ground. Important is the fact that the film image was taken after a rain with water on the ground. The digital image was taken during a dry period.

ULTRACAM D: LARGE FORMAT AERIAL DIGITAL CAMERA

We are introducing the novel UltraCam-D large format digital aerial camera (Figure 6). The design is driven by the need to replace the existing base of film cameras. Therefore the images produced by the camera must be "photogrammetric" and must feed into and be compatible with current softcopy photogrammetric work-flows. This means that the images themselves need to carry highly accurate geometric information, independent of any satellite and inertial navigation support.

Figure 6: Overview of the UltraCam D large format digital aerial camera. A set of 8 optical cones exists holding a total of 13 CCD arrays to assemble a large format digital image in RGB-color and near infrared NIR. Multiple area array CCDs collect pixels. Each CCD array feeds signals into their own compact and proprietary electronics setup and data path. For dimensions and weight see Table 1.

The UltraCam-D produces digital color RGB and simultaneous Near-Infrared NIR images with 11,500 x 7,500 pixels based on square array CCDs. Figure 6 presents the camera, Figure 7 illustrates the airborne UltraCam-D/SCU storage and computing unit. The system is capable of imaging with time intervals of only 0.75 seconds, offering an option of very high forward overlaps. Forward motion compensation FMC is available to produce very small pixels at 3 cm. Table 1 summarizes the salient features of the camera.

Figure 7: The UltraCam-D/SCU storage and computing unit for distributed parallel UltraCam data collection and on board processing. A total of 15 CPUs and 30 (mobile) hard disks collect and process up to 1 Tbyte of data at a minimum interval of 0.75 seconds per image take. For dimensions and weight see Table 1.

THE TECHNOLOGY: SUSTAINING HIGH GEOMETRIC ACCURACY

Creating a Large Format Image from Sub-Images

The UltraCam-D creates a large format image by means of 4 optical cones, each of which covers the entire field of view. The master cone holds 4 area-array CCDs in the corners of its field of view. The assembly of 4 CCD arrays is rigidly defined and photogrammetrically calibrated to define the *image coordinate system*. The other three cones produce additional 5 sub-images with 2 or 1 CCD-array per cone. These 5 sub-images fill the gaps between the 4

CCD arrays in the master cone. These additional sub-images are "stitched" into the master image strictly by calibration and interpolation.

Table 1: Some Important UltraCam-D Technical Specifications

Digital Camera Technical Data	
Panchromatic image size	11,500 * 7,500 pixels
Panchromatic physical pixel size	9 µm
Panchromatic lens focal distance, standard	100 mm
Angle-of-view from vertical, cross track (along track)	55° (37°)
Color (multi-spectral capability)	4 channels -- RGB & NIR
Color image size	4008 * 2672 pixels
Color physical pixel size	9 µm
Color lens system focal distance	28 mm
Shutter speed options	1/1000 to 1/30
Forward-motion compensation (FMC)	TDI controlled
Maximum FMC-capability	50 pixels
Smallest pixels on the ground at flying height of 300m	3cm
Minimum inter-image interval	0.75 seconds
Analog-to-digital conversion at	14 bits
Radiometric resolution in each color channel	14 bit
Physical dimensions of the camera unit	45cm x 45cm x 60 cm
Weight	<30 kg
Power consumption at full performance	600 W
Controller and Data Storage Unit	
In-flight storage capacity	> 1 TB
Capacity to collect in-flight uncompressed frames	> 1850
Storage and computing configuration	Parallel arrangement with multiple CPUs and disks
Physical dimensions	55cmx40cmx65 cm
Weight	<35 kg
Some Operational Specification	
Maximum data collection period at 70% forward overlap, at scale 1:10,000 (1:3,000)	>6 hours (5hours)
Post-processing of collected raw image streams	< 12 hours (partly in-flight)
Data transfer from aircraft to office	Multiple options

Achieving a single perspective center with 4 optical cones

We introduce "syntopic" imaging ("synthetically at the same place in space"). The 4 optical subsystems are arranged linearly along the flight direction. The sensor flies at perhaps 70 meters per second (7 cm per msec). By some msec-delay in triggering the exposure of each of the 4 cones one achieves a physical translation of each cone by means of the forward motion of the survey aircraft. This concept causes all cones to produce sub-images from one and the same physical location in space. We are theoretically achieving a single perspective center.

Why is this approach photogrammetrically accurate?

A single master cone defines a single image coordinate system, especially considering that the master cone creates the image segments in the 4 corners of the field of view. The remaining sub-images are "slaved" into the master cone's reference. This can be seen as a transformation into the master frame by interpolation, avoiding all extrapolation. Stitching removes residual errors among the cones. These errors could result from a faulty "syntopic" exposure trigger.

Again "software-leveraged hardware"

Conceptually this approach implements the "software leveraged hardware" ideology that continues to be the basis for the success of Vexcel Imaging Austria's photogrammetric precision scanners UltraScan5000. It creates robustness by software compensation of hardware limitations, counteracts environmental influences, supports ease of operations, reduces the number of parts and saves costs.

Four color bands

4 additional optical cones are collecting RGB and NIR images. The camera output is a five-band assembly of component images that can be configured into a range of image products. One obtains simultaneously a black & white image, a traditional RGB color image which combines with the panchromatic image into a high resolution color image, and a false color image from RG&NIR, as well as an input to multi-spectral automated analyses.

DATA FLOW

In principle, the UltraCam-D data flow will dovetail with an existing softcopy photogrammetric operation. The modular setup of the UltraCam-D approach supports a flexible connection with a customer's preferred data management arrangements. There are four levels of image data:

Level 00	Raw image segments read out from each CCD, redundancy by mirroring
Level 0	Verified image segments, no redundant storage
Level 1	Image segments radiometrically corrected and rearranged for efficient stitching
Level 2	Stitched (i.e. geometrically and radiometrically clean), color held separately
Level 3	Final color image products

Raw level-00 aerial digital photography gets collected on board the survey plane onto the disk and CPU arrangement (the SCU). A storage volume of 1 Tbyte is available with the basic UltraCam-D configuration. Half of the storage is for the collected image segments, the other half is used to mirror each image onto a duplicate set of disks. Upon completion of a flight mission and some preprocessing into level 0, level 1 or even level 2 on board the survey plane, the images are being transferred from the on-board SCU onto a "mobile server". This consists simply of a notebook computer equipped with large-volume external disks and/or DLT system. The SCU is itself also "mobile" and can be moved from the plane to optionally perform the function of a "ground processing system". Transfer of the digital data to the home office is via DLT from the mobile server.

The camera system will be ready to fly on a daily basis, since processing the collected data and transferring them off the plane can be achieved sufficiently quickly for a survey flight to resume the next day.

IN CONCLUSION: ULTRACAM-D ADVANTAGES

The UltraCam-advantages derive from a series of design goals. The following presents 14 of these goals.

- Ensuring radiometric superiority over film photography,
- Ensuring multi-band photography to include an NIR-band,
- Achievement of classical photogrammetric image accuracy with its geometric rigidity without the need for satellite and inertial navigation support,
- Compatibility with existing photogrammetric procedures and work-flows,
- Realization of the economic advantage of self-financing of the purchase price simply by the savings in consumables and film scanning,
- Effective forward motion compensation to achieve very small pixels down to 3 cm on the ground,
- Very high repeat cycle for image collection below 1 second per image,
- In-flight real-time quality checks onboard the airplane,
- Modular system to be field serviceable,
- Support for easy upgrades as computer technology advances,
- Ruggedness for aircraft operations at high altitudes,
- Ruggedness also in geometry, by a proprietary approach to interleaving and stitching image components that is insensitive to thermal and other effects on a multi-lens camera system,
- A data flow concept that keeps the survey plane in the air for a very long mission, and permits an operation to go for several days on end, even in remote areas, in analogy to film-based operations,
- Implementation of a data flow concept that is modular, can easily be customized to dovetail with local specificities, and is based on standard, globally available personal computer components.

As ambitious as this list may sound, the UltraCam-D satisfies all of these design goals. As a result, the camera not only fits well into an existing softcopy photogrammetric operation. It will also support new approaches to photogrammetry which will emerge once the 100-year ideology of “minimizing the number of photographs” for any given mission gets thrown overboard. Recall that in the digital domain, exposing additional images does not result in additional expenses, and this increase in redundancy may impact the manner in which automation gets implemented in future photogrammetry operations.

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