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ECONOMICAL LARGE FORMAT AERIAL DIGITAL CAMERA

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Is A Novel Camera Threatening the Future of Aerial Film?

A new digital aerial camera has been announced to compete directly and purpose fully with traditional aerial film cameras. Its first "*killer advantage"* concerns savings of film, photo processing and scanning, yet it produces true RGB color and NIR at all times. *Second* is image quality without any noise from film grain and with a radiometric range at 12 bits (versus 8 bits in film). *Third* is increased redundancy by high forward overlaps, resulting in superior robustness of all automated procedures and reducing the need for manual interventions. Is this spelling the end of aerial film?

The digital revolution has yet to significantly erode aerial film in photogrammetry, while consumer photography has gone digital and professional photography is following suit rapidly. We believe that also aerial film is coming to an end. The economic advantages of digital cameras are overwhelming. Their data quality is superior, workflow benefits are great, automation promises to relieve operators from tedious manual edits, the accuracy is robust, web-based approaches ease the archiving and accessing of image data, and the camera system becomes an internet-connected computer tool. If photogrammetry can verify and believe in these advantages, then film will be out.

Digital Sensing versus Film

An area CCD array produces at each CCD-element/pixel a clean gray value at 12 bits radiometric range. This combines with the absence of grain noise. **Figure 1** illustrates the result in a black & white example, and a more formal illustration is presented with a Siemens star in **Figure 2**. The radiometric advantage translates into superior stereo matches. The rather feature-less terrain in **Figure 3** is being matched with a matching noise of ±2 to ± 6 cm in the terrain when 20 µm film pixels are used, and with ±1 to ±2 cm from digitally sensed data.

What is the required number of pixels across the image format to outperform film? Photogrammetric firms decide on the digital pixel size often with the notion that these pixels come for free. However, if pixels are chosen too small, subsequent matching may deteriorate since one no longer matches object features but film artifacts of the grain. The data in Figure 3, if scanned with 10.0 µm, produce matching noise of ±2 to ± 8 cm, and show more stray shots than those from 20 µm pixels.

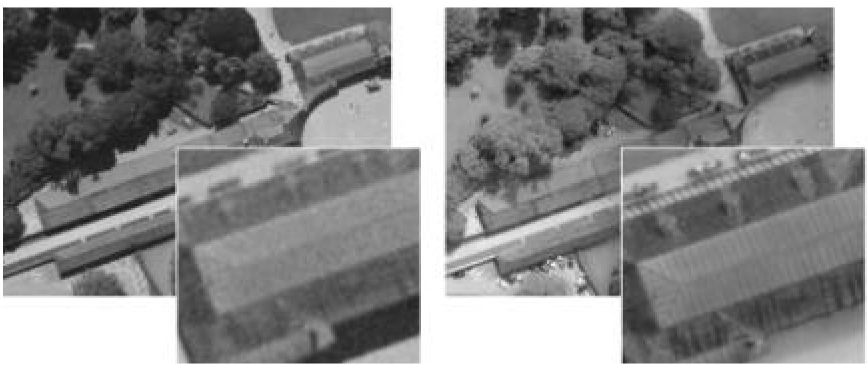

Figure 1: Segment of a scanned film image (left) versus a digital camera image (right). Ground sampling distance is 17 cm on the digital image and 16 cm on the film image. Film was scanned with 12.5 µm pixel size.

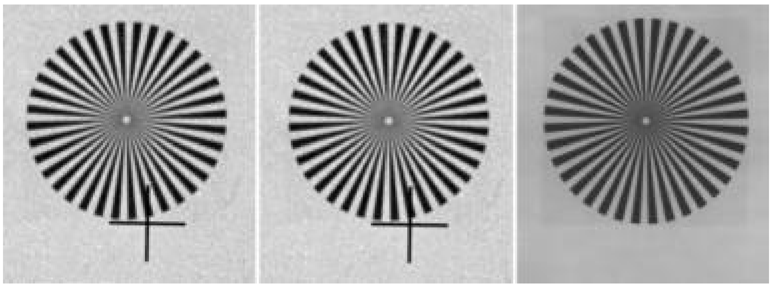

Figure 2: Imaging the Siemens Star to determine geometric resolution. At left is a scanned film image taken with AGFA APX film, scanned with 10 µm and 15 µm pixels, resulting in a GSD of 0.34 and 0.51 mm. At right is a digital image with GSD at 0.4 mm on the object. The resolution is computed to be 9.0 mm and 9.5 mm for the film, and 4.9 mm in the digital image.

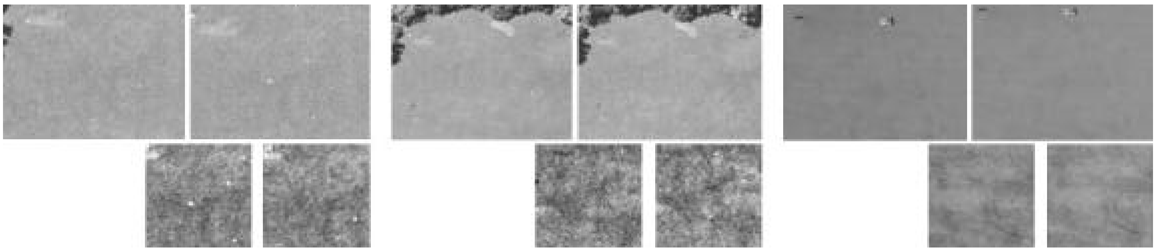

Figure 3: Illustrating the stereo matching quality with scanned film and with a digital camera at a rather feature-less terrain. The mean correlation coefficient in film scanned with 10 µm pixels (left) is at 0.29 and for 20 µm scans (middle) it increases to 0.52. In contrast, the digital image (right) matches at correlation factors of 0.81. This translates into a matching noise of 2 – 8 cm on the ground for film scans at 10 µm, of 2 - 6 cm at 20 µm scans and at 1 - 2 cm in digital images.

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.

About the Camera Technology

In an interview in the July 2002 issue, the then CEO of Z/I Imaging Corp. expressed his belief that *"…there is nobody coming into the large-format camera market; they cannot afford it. The R&D is tremendous….".* This view may have ignored the possibility of smart new ideas that limit the R&D expense. The basic principle of the new UltraCam with its nearly 90 Mpixels is the use of multiple smaller, widely available area array CCDs and arranging them to achieve a single image coordinate system with a single perspective center at a modest cost, and without presenting major engineering headaches.

Figure 4 shows a view of the 8 optical cones in the camera, of which 4 are used to produce a panchromatic image, and the other 4 are used to collect true color RGB and an NIR-image. The panchromatic image cones are aligned behind one another along the flight direction and all have the same field-of-view as shown in Figure 5. One cone is the „Master" with four CCD-arrays, it provides the single image coordinate system. Other cones are „Slaves" to fill in the holes in the master image. The exposures get triggered with slight delays of 1 to 2 msecs so that the plane has flown each cone into the same physical position in 3D space when the actual picture gets taken. This is being denoted as „syntopic imaging", as explained in **Figure 5**. This approach results in a cost far lower than previous large format digital camera approaches, and may be a key to succeed against film.

Figure 4: View of the UltraCam-D digital aerial sensor with a view of the 4 panchromatic and the 4 color cones. All cones have the same field-of-view.

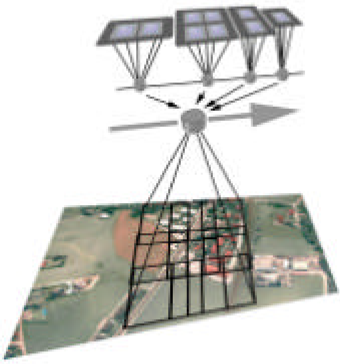

Figure 5: Illustrating the 4 panchromatic cones with their 9 CCD-arrays. The concept of "syntopic" imaging ensures the existence of a single perspective center with 4 different optical cones, producing "content" from a single field of view.

Technical Specifications of the Digital Camera

The camera system consists of the sensor unit SU and the storage and computing unit SCU. **Table 1** summarizes some specifications. The resulting image has a format of 11,500 x 7,500 pixels and corresponds to a film image format of 23 cm x 15 cm. Each exposure is being produced with 5 channels: panchromatic and RGB/NIR. Color channels are at reduced geometric resolution.

The maximum repeat rate for images is at 0.75 seconds. At a flying height of 1,500 m, the ground sampling distance GSD is 13.5 cm across an area of 1,550 m x 1012 m. One-second intervals will achieve a 95% forward overlap and each ground point gets imaged 20 times. Robustness and accuracy will benefit from this redundancy, when compared to the 60% overlap used with film.

Table 1: Some of the Specifications of the UltraCam-D. Total power requirement is at 850 watts.

Sensing Unit	
Panchromatic image format	11500 * 7500 pixel @ 9 µm, 103.5 mm * 67.5 mm
Lens system focal distance and aperture	100 mm, f 1/5.6
Field of view cross/along track	55° / 37°
Multi-spectral (RGB, NIR)	4,008 * 2,672 pixel, @ 9 µm
Shutter, seconds	1/500 – 1/60
FMC	TDI controlled
Frame rate	1.3 frames / second
Radiometric resolution	> 12 bit
Dimensions	45 cm * 45 cm * 60 cm
Weight	< 30 kg
Storage & Computing Unit	
Storage Capacity	> 1 TB
Uncompressed Frames	> 1850 frames
Dimensions	55 cm * 40 cm * 65 cm
Weight	< 35 kg

Data Flow

A world deeply trusting film and film archives is puzzled by the absence of any hardcopy. Yet, this is the future. The SCU, as a set of networked 15 computers and 28 hard disks, not only records raw image data but also processes them into deliverable images ready for input into a database. Processing of the digital images can begin while the plane is in the air. On the ground, the SCU can continue processing, either on board the parked plane, in a hotel or the home office. Alternatively, the data on the SCU can be downloaded onto a "Mobile Server" and its external high capacity fire wire disks. Processed images get entered into a fully automated image archive and retrieval system (the *EarthFinder-Aerial* software*)*. The film archive gets replaced by a flexible, Internet-useable database.

Advantages of Going Digital

First: digital images have superior radiometry and no grain. There is better stereo, better interpretability, more success in automation, more flying weather. Second: the repeat rates can be high and are at no cost. This results in an entirely new paradigm: the 100 years of photogrammetric needs to minimize the number of photos are gone. The results are stronger aerotriangulations, better DEMs, fewer occlusions, and the need to use an IMU and extensive manual edits gets eliminated. Third: the economy is overwhelmingly favorable. The costs for consumables and for scanning are gone, true and false colors are free, manual labor hours get reduced, and all this is feasible with a digital camera at the cost about the same as that for a film camera. Fourth: the geometric accuracy is uncompromised. Fifth: a smoother workflow exists without a need to order or stock film, and images can be inspected in-flight. Easy web-based archiving and retrieval of images eliminates film archives in basements. Camera support is via the Internet.

A digital camera should be justified simply by the savings in film, photo processing and scanning for 20,000 photos, possibly even less! Yet there are quality and other advantages (compare **Figure 6**). Can film compete?

Figure 6: Color image segment from aerial film (left) with a GSD of 15 cm, obtained from a 12.5µm scan. The UltraCam-image has a GSD of 16 cm (right). The inserts are 2x enlarged and have a diameter of 150 pixels. Note the definition of the railroad track.

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Biographies

Franz Leberl founded Vexcel Corporation (Boulder, Colorado, 1985), started Vexcel Imaging (Graz, Austria, 1993), spends time as professor of Computer Graphics & Vision (Graz University of Technology), and as CEO of Vexcel Imaging. He moves between the USA and Austria and between academia and business. He is President of ISPRS Commission III (Theory and Algorithms) and a Fellow of the IEEE.

Michael Gruber received his doctorate from Graz Univ. of Technology in 1997 in Computer Vision, building on a Dipl.-Ing. in photogrammetry. He was instrumental in achieving photogrammetric specifications in the UltraScan5000 scanner.