HIGH RESOLUTION COLOR IMAGERY FOR ORTHOMAPS AND REMOTE SENSING

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Abstract
The ADS40 Airborne Digital Pushbroom Sensor is currently the only commercial sensor capable of acquiring color and false color strip images in the low decimeter range at the same high resolution as the black and white stereo images. This high resolution of 12000 pixels across the entire swath and 100% forward overlap in the image strips result in high quality DSM's, True Ortho's and at the same time allow unbiased remote sensing applications due to color strip images unchanged by pan-sharpening. The paper gives details on how the pushbroom sensor achieves these seemingly difficult technical challenges. It describes how a variety of mapping applications benefit from this sensor, a sensor which acts as a satellite pushbroom sensor within the airborne environment.

1. Introduction
In 2001 the ADS40 was the first digital airborne sensor delivered commercially to the photogrammetric community. Since then more the 25 units have been put into production worldwide and have covered vast areas of the earth's surface with imagery later used for orthophotos. In the USDA NAIP project alone last year over 1 Mio km^2 of orthophotos were produced.
In the design phase of this successful sensor there was one guiding principle: to create an airborne imaging system which was not hampered by limitations known to the established photogrammetric community. The new design allowed for an optimal adaptation to the needs of the digital workflow, which eventually could complement software solutions allowing a totally automatic workflow, increasing the users productivity far beyond what digitized frame imagery are capable of.

2. Orthogonal projection and the line sensor
Although digital data processing opens the opportunity to implement computational methods to convert central perspective projection into an orthogonal projection the line sensor offered the unique opportunity to produce images which at least in the flight direction could be considered quasi orthogonal projections. Line sensor data is as close to a maps orthogonal projection as is technically possible.

But apart from this feature the line sensors 100% overlap of stereo strip imagery has other outstanding benefits such as:

- Least amount of data to ensure least amount of occlusions in true-ortho maps
- Base/height ratio which is unachievable by film frame cameras or digital frame cameras
- FMC is inherent in the image acquisition principle
- The nadir image strip only uses the best part of the field of view of the lens
- No image patching and mosaicing necessary within the image strips
- Excellent tool for BRDF (bi-directional reflectance distribution function) research [4].

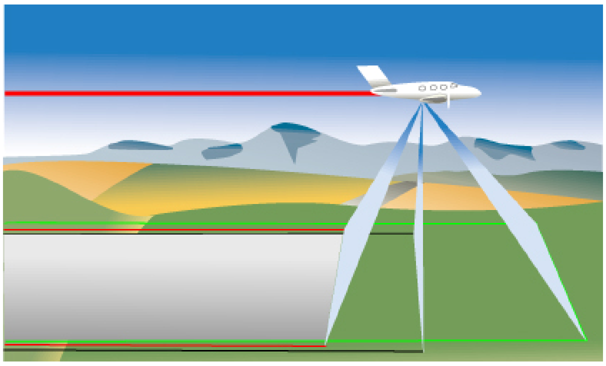

Fig.1: Stereo imagery with 100% overlap and inherent FMC

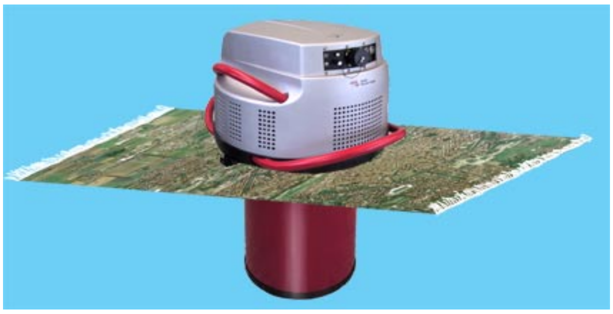

Fig.2: Nadir image with perfectly co-registered RGB pixel carpets

3. Geometric resolution and the line sensor

Since its market introduction the ADS40 has been able to record panchromatic images 5 cm GSD and larger and RGB images 15 cm GSD and larger under normal lighting conditions. Above 15 cm GSD both panchromatic and RGB images are the same and of an equally high resolution.
The 5 cm GSD PAN capability was hardly used by customers because the ADS40's highest potential for return on investment is in large area coverage projects where the resolution is between 20 and 80 cm GSD. Proof of this exceptional area coverage capability is the 1 million sq. km flown in the NAIP project in the USA in 2004.

Commercial digital sensors or cameras flown in a fixed wing aircraft cannot achieve direct acquisition of RGB images at a GSD of 5 cm, whether it is a line sensor or frame sensor camera. The closest any airborne digital sensor or camera can get is the ADS40 with a direct resolution of 15cm GSD for RGB imagery. To collect 15 cm GSD RGB images directly with the a typical digital frame sensor camera it would have to be flown at about 350 m above ground and this is not feasible for security reasons. At the flying height of 1500 m above ground where the ADS40 collects a 15cm GSD RGB image a typical digital frame sensor camera collects an RGB image directly at a GSD of 70cm.

The so called high resolution RGB images from digital frame sensor cameras are in fact based on the technique of colorizing panchromatic images with a color pixel up to 22 times larger than the pan pixel. This pan-sharpening technique has been rejected in the USA by the USDA in the NAIP projects because the radiometric information content is distorted.

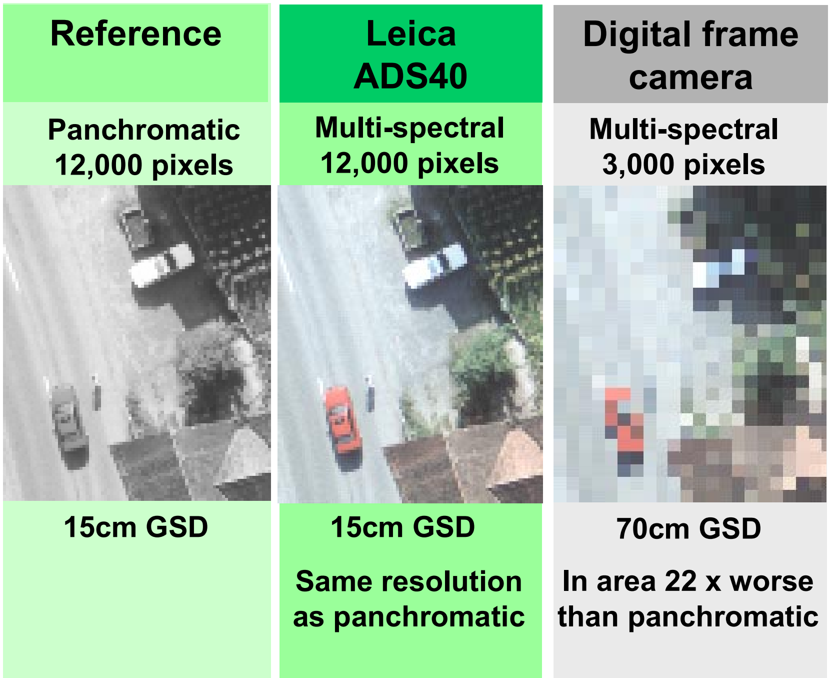

Fig.3: Comparison of direct resolution RGB images at equal flying heights (simulated images)

4. Image fusion techniques

Most methods focus on enhancing the appearance of a hybrid high-resolution image to facilitate visual image exploitation. [3]. There are various methods to fuse images. The most widely used method is the IHS method (intensity, hue, saturation). In the case of digital cameras with multiple frames the pan-sharpening process is essentially a fusion which involves merging data from different cameras in the same sensor with different resolutions thus attempting to improve the interpretability of the lower resolution images.

The pan image has been found to be roughly proportional to image brightness and is used to replace the intensity in the IHS image. The "high resolution" IHS image can then be back-transformed to the RGB space for display. This back-transformed image then appears to be a high-resolution three-band multispectral image. This process is also called the color-coded fused image (IHS to RGB). If the three input bands are not highly correlated, the substitution of the pan band for intensity can produce substantial changes in the radiometry of the hybrid scene. Unfortunately this way of pan-sharpening the low resolution RGB image is not focussed on preserving the radiometric integrity of the hybrid image and is therefore questionable for quantitative or machine exploitation.

Fig.4: Example of a pan-sharpened image of a digital frame sensor

5. Map Scale and the line sensor

Experience with digital images in the last 3 years has dispelled uncertainties concerning the relation of GSD and Map Scale. For mapping from digital imagery a certain GSD is required for the x-y accuracy. Traditional terms like photo scale are misleading. The diagrams in Fig.5 and 6 show that both sensors produce the same pixel on the ground (GSD) even though they have different pixel sizes on the CCD and different Photo Scales.

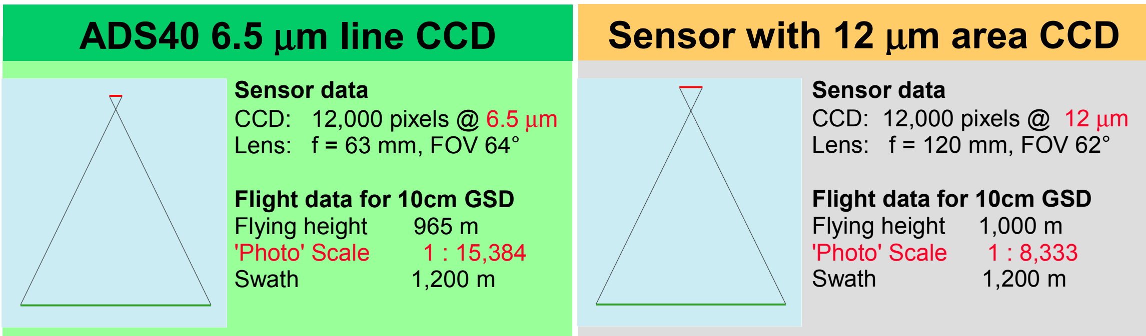

Fig.5: The term 'Photo Scale' is irrelevant and even misleading to mapping from digital images.

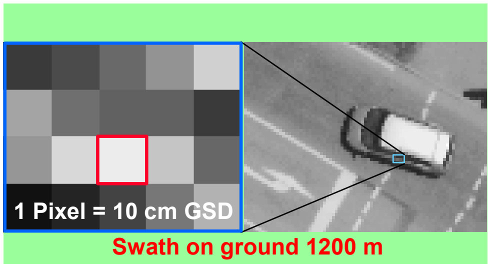

Fig.6: The relevant relation is that between GSD and Map Scale

Practice has shown that for data extraction from direct digital images, a GSD twice as large as that provided by digitized film imagery can be used to achieve the same positional accuracy as that which would be achieved with film based photogrammetry. An equivalent 10 cm GSD resolution from color film in practice corresponds to a 20 cm GSD from direct digital imagery.

Average GSD with ADS40	Map Scale	Map standard		Comparable film photographs	
		x-y accuracy RMSE	contour interval	photo scale	pixel size on ground of scanned film
5 - 10 cm	1 : 500	0.125 m	0.25 m	1 : 3,000 to 1 : 5,500	2.5 - 5 cm
10 - 15 cm	1 : 1,000	0.25 m	0.5 m	1 : 5,000 to 1 : 8,000	5 - 7.5 cm
15 - 20 cm	1 : 1,500	0.40 m	0.75 m	1 : 6,500 to 1 :10,000	7.5 - 10 cm
20 - 30 cm	1 : 2,000	0.50 m	1m	1 : 8,000 to 1 : 11,000	10 - 15 cm
25 - 35 cm	1 : 2,500	0.60 m	1.25 m	1 : 8,500 to 1 : 13,000	12.5 - 17.5 cm
30 - 50 cm	1 : 5,000	1.25 m	2.5 m	1 : 12,000 to 1 : 18,000	15 - 25 cm
40 - 60 cm	1 : 10,000	2.50 m	5m	1 : 17,000 to 1 : 27,000	20 - 30 cm
50 - 70 cm	1 : 20,000	5.00 m	10 m	1 : 25,000 to 1 : 35,000	25 - 35cm
50 - 80 cm	1 : 25,000	6.25 m	12.5 m	1: 28,000 to 1 : 42,000	25 - 40 cm
50 - 100 cm	1 : 50,000	12.5 m	20 m	1 : 40,000 to 1 : 60,000	25 - 50 cm
50 - 100 cm	1 : 100,000	25 m	50 m	1 : 60,000 to 1 : 90,000	25 - 50 cm

Table 1: Ground Sampling Distance (GSD) and Map Scale

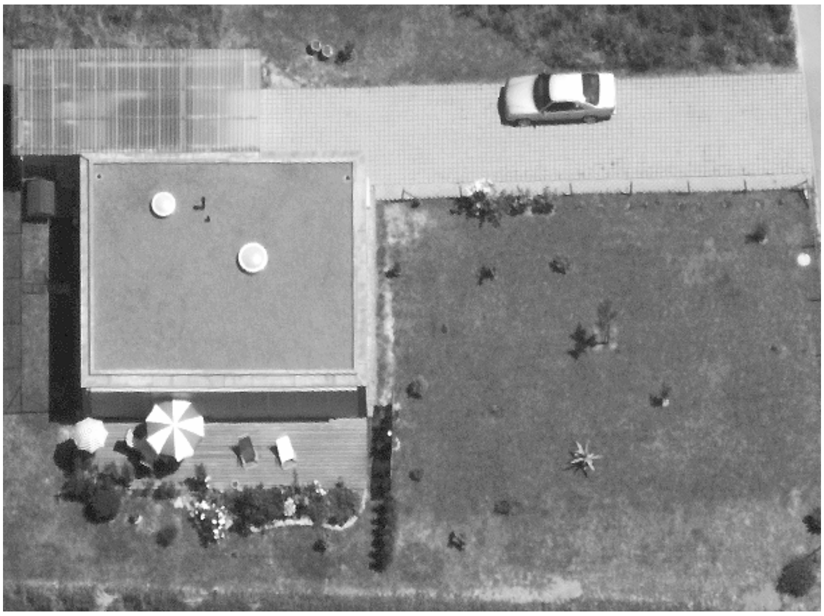

Fig.6: High resolution panchromatic image from ADS40 at 5cm GSD

6. Height accuracy of the line sensor

Based on the standard theoretical photogrammetric height accuracy formula, it is obvious that the line sensor in which the position of the line in the focal plane can be chosen optimally has a big advantage over digital frame cameras in which the dimension of the pixel array is rectangular in shape and smaller in the flight direction [1]. This results in a very weak base/height ration in digital frame cameras. The favorable base/height ratio of line sensors results in excellent height accuracy, which has recently been proven with flights over the Vaihingen test area by the University of Stuttgart [2].

	Comparison of Aerial Cameras				Comparison of Area coverage, and accuracy					
Camera Type	Individual camera parameters				Normalized to pixel of 10 um & 10 cm GSD (normalized photo scale 1:10,000)					
					Area coverage			Accuracy		
	Array (Pixels)	Pixel size um	Focal length mm	GSD @ 1000m cm	n.focal length mm	Area sq.km	h/b ratio	x,y cm	height (points) cm	height (terrain) cm
ADS40	12000 x 1	6.5	62.5	10.4	96	1.44	1.26	20	12.6	24.2
DMC (Pan)	13824 x 7680	12	120	10	100	1.06	3.3	20	33	66
UltraCam (Pan)	11500 x 7500	9	100	9	111	0.86	3.7	20	37	74
DIMAC	5440 x 4800	9	120	7.5	134	0.26	4.7	20	47	94
Aerial Photo (UAG)	15333 x 15333	15	153	9.8	103	2.35	1.66	20	16	32
Aerial photo (NAT)	15333 x 15333	15	305	4.9	204	2.35	3.32	20	32	64

Table 2: Comparison of Base/Height ratios of digital sensors and cameras

7. Geometric accuracy of the line sensor

In July 2004 the University of Stuttgart conducted a test flight with an ADS40 fitted with three different IMU's simultaneously. Flying height was 1500 m above ground and pixel size on the ground was 15cm GSD. 4 flight lines with two cross strips were flown. A total of 12 ground control points where used for the block adjustment. Absolute accuracy was tested against 198 check points established in the test area. The tests also had the objective to further investigate the feasibility of improving image resolution using staggered line images. Further results will be published by the University of Stuttgart in due course.

	East	North	Vertical
RMS [m]	0.052	0.054	0.077
Mean [m]	0.000	-0.022	0.045
Max. [m]	0.133	0.188	0.242

Table 3: Geometric accuracy results using an LN200 IMU at a flying height of 1500m above ground

8. Digital Surface Models and the line sensor

The ADS40 is an excellent tool for true-orthophoto production ~~unit~~ when used with post-processing software that calculates a reliable DSM (Digital Surface Model) based on multiple image matching. Laser-scanning (LIDAR) produces a point cloud with a limited density. Up to now the only way to make a good 3D city model is to actually vectorize the outlines of the buildings (rooftops). At the same swath coverage, the ADS40 imagery has approximately a 10x higher point density which results in accurate building edges. In other words the ADS40 is a serious competitor to the laser scanner with respect to the creation of DSM's.
The DSM's are also better than those derived from aerial photography because imagery from three or more viewing angles can be used to match points. This has been proven both by DLR using HRSC data and by the ISTAR Company using ADS40 data. The DSM that ISTAR derives from three line imagery is about 10 times as dense as a LIDAR DSM and because of the oblique viewing angles it is possible to eliminate occlusions, which is difficult with LIDAR. The examples in Fig. 7 and 8 show a DSM and a True Ortho derived from ADS40 imagery by Earthdata using the ISTAR software.

Fig.7: DSM derived from 30cm GSD ADS40 three line imagery

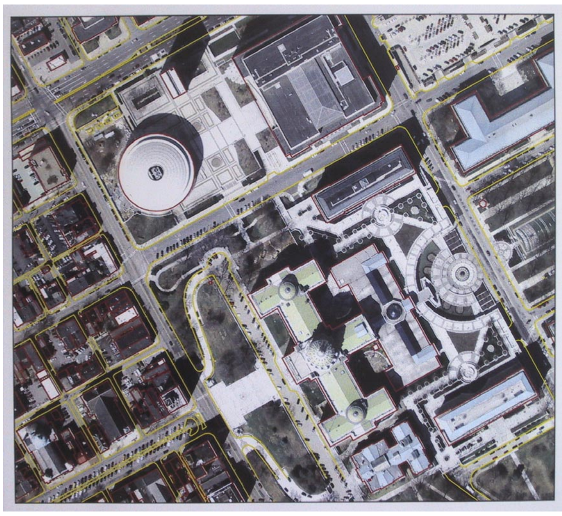

Fig.8: True Ortho Map based on a 30cm GSD DSM

9. Radiometric resolution of the line sensor

The non-overlapping spectral bands of the ADS40 were designed specifically to satisfy the needs of photo interpreters and remote sensing applications concerned with vegetation classification. The main advantage of the ADS40 lies in the fact that the resolutions of the RGB images are the same as those of the panchromatic image. Thus no pan-sharpening techniques are required to produce a high resolution RGB composite.

The RGB composites of digital frame cameras are produced by colorizing about 22 PAN pixels with the color information coming from one single color pixel. In forest areas for instance this results in dull images with little differentiation between different types of trees.

Leica ADS40

Fig.9: High resolution line sensor image

Digital Frame Camera

Fig.10: Pan-sharpened frame sensor

10. Remote Sensing and the line sensor as BRDF research tool

Digital airborne surveys have become an integral part of forestland management, precision agriculture, environmental change detection and urban planning in large part replacing extensive field surveys. With current digital mapping capabilities, acquiring fast, accurate imagery is now not only essential, but also cost effective. Whatever the user's needs he faces the challenge of choosing the best technology for his investment.

Precision techniques yielding high-resolution, geo-referenced, airborne digital imagery are designed to enhance human interpretation, classification and quantification techniques and to make trouble spots apparent at very short notice or well before any damage occurs.

With the introduction of the airborne multiple line, high-resolution push broom scanner with its forward, nadir and backward looking scenes of the same area a new tool has emerged which allows research in reflection properties of vegetation and soil – the so called BRDF (bi-directional reflectance distribution function). [4]

11. Conclusions

Only a large format surface array of 12,000 x 12,000 pixels having 5 transparent layers sensitive in the spectral bands red, green, blue, near-infrared and panchromatic could compete with the technology provided by the ADS40 equipped with multiple 12,000 pixel line sensors. Because such a surface array does not exist, manufacturers of surface array cameras are forced to use multi-lens systems and patch the images together.

Even if such a large surface array with 12,000 x 12,000 pixels and a pixel size of 6.5µm would exist, it would also have to have to be able to store a staggering 720 Mega pixels per image taken approximately every 2 seconds to compete with the ADS40's performance.

The 10 image strips acquired simultaneously at the same high resolution both in panchromatic and RGB spectral bands makes the ADS40 the only true large format high resolution multispectral digital sensor.

12. References

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