PUSHBROOM SCANNERS PROVIDE HIGHEST RESOLUTION EARTH IMAGING INFORMATION IN MULTISPECTRAL BANDS

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ABSTRACT:

Airborne digital pushbroom scanners are currently the only commercial sensors capable of acquiring color and false color strip images at the same high resolution as the black and white stereo images. This high resolution of 12,000 pixels across the entire swath combined with 100% forward overlap in the three to six black/white image strips results in high quality DSM's, True Ortho's and at the same time allows unbiased remote sensing applications due to color strip images unchanged by pan-sharpening. The paper gives details on what the application range and the range of map scales is. It describes how a variety of mapping applications benefit from this sensor, a sensor type 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 mostly 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 user's 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 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.

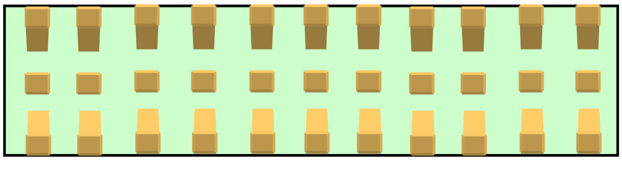

Fig. 1: Quasi orthogonal projection in the centre of the Nadir image strips

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

- Least amount of data to ensure least amount of occlusions in true-ortho maps
- Height/Base ratio which is unachievable by film frame cameras or digital frame cameras
- The pushbroom image acquisition principle is closer to true FMC (Forward Motion Compensation) than TDI (Time Delayed Integration), which erroneously is being confused with FMC.
- 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].

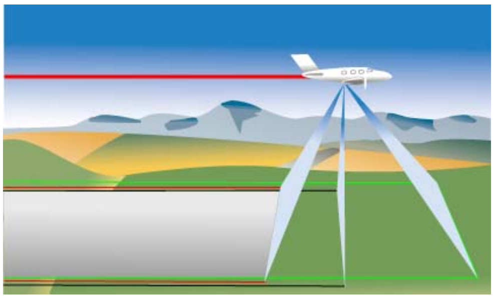

Fig.2: Stereo imagery with 100% overlap and inherent FMC

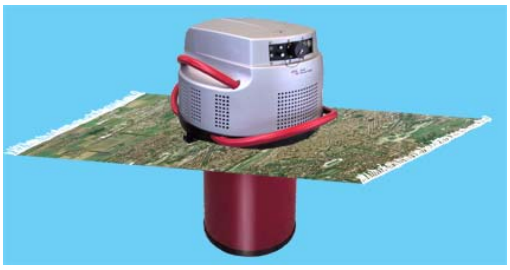

Fig.3: Nadir image with perfectly co-registered RGB pixel carpets

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 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.

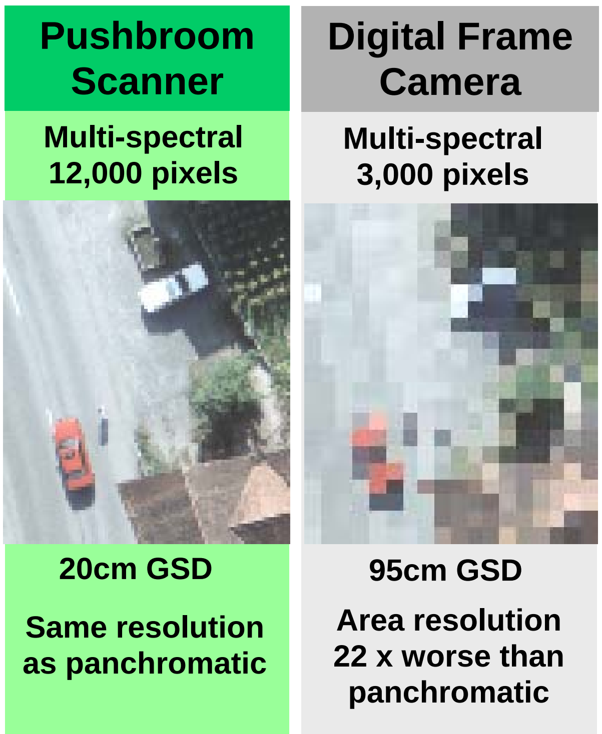

Fig.4: Comparison of direct resolution RGB images at equal flying heights (simulated images)

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 spectral 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.5: Example of a pan-sharpened image of a digital frame camera

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.

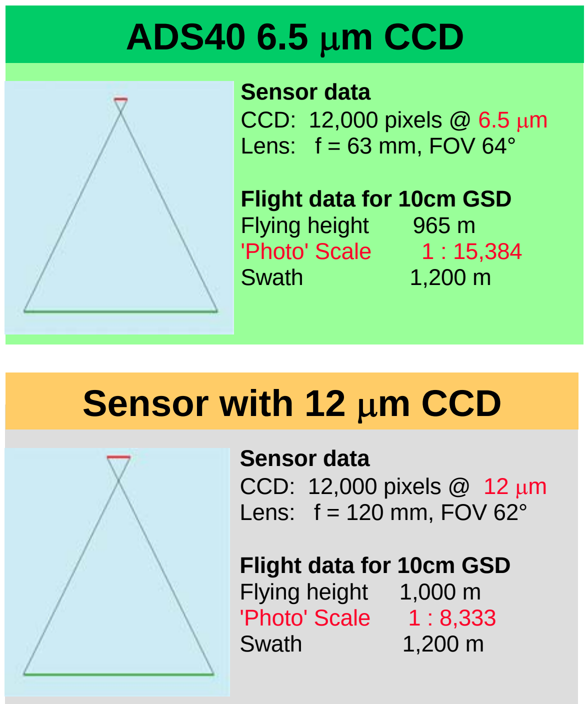

Fig.6: 'Photo Scale' is irrelevant and misleading to mapping from digital images.

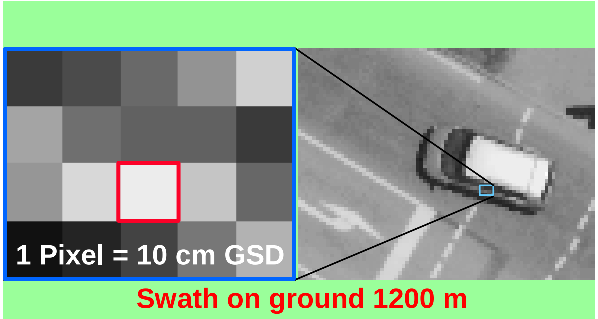

Fig.7: In the digital imaging world the relevant relation is that between GSD and Map Scale and not between the CCD dependent Photo Scale and Map Scale.

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	
		x-y accuracy RMSE	contour interval
5 - 10 cm	1 : 500	0.125 m	0.25 m
10 - 15 cm	1 : 1,000	0.25 m	0.5 m
15 - 20 cm	1 : 1,500	0.40 m	0.75 m
20 - 30 cm	1 : 2,000	0.50 m	1 m
25 - 35 cm	1 : 2,500	0.60 m	1.25 m
30 - 50 cm	1 : 5,000	1.25 m	2.5 m
40 - 60 cm	1 : 10,000	2.50 m	5 m
50 - 70 cm	1 : 20,000	5.00 m	10 m
50 - 80 cm	1 : 25,000	6.25 m	12.5 m
50 - 100 cm	1 : 50,000	12.5 m	20 m
50 - 100 cm	1 : 100,000	25 m	50 m

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

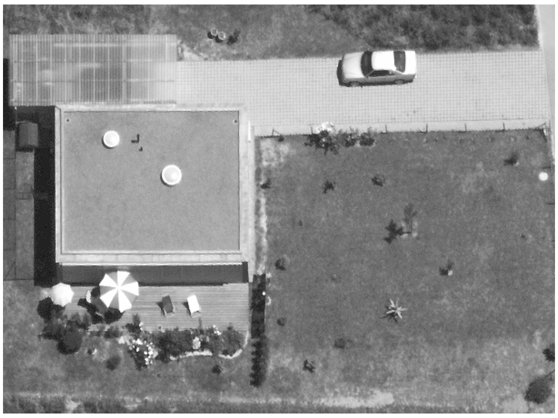

Fig.8: High resolution panchromatic image from ADS40 at 5cm GSD

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 height/base ratio in digital frame cameras. The favourable height/base 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].

Camera Type	Ratio	Accuracy		
	H / b	x,y cm	height (point) cm	height (terrain) cm
ADS40	1.26	20	12.6	24.2
DMC (Pan)	3.3	20	33	66
Ultracam (Pan)	3.7	20	37	74
DiMAC	4.7	20	47	94
Aerial photo (UAG, 15 cm)	1.66	20	16	32
Aerial photo (NAT, 30 cm)	3.32	20	32	64

Table 2: Theoretical Height/Base ratios of digital sensors and cameras based on the general stereo distance error formula.

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. For the case of the flying height of 1500 m above ground the 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 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. 8; DSM derived from 30 cm GSD ADS40 3-line image

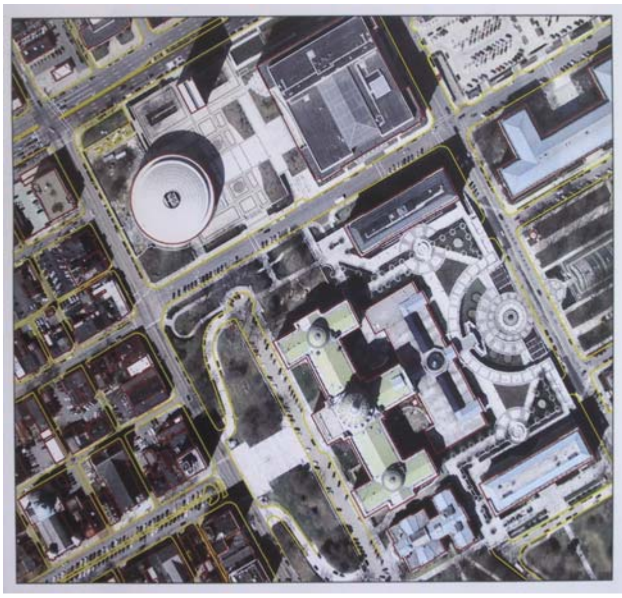

Fig. 9: True Ortho Map based on 30 cm GSD DSM

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.

Fig. 10: High Resolution RGB line sensor image

Fig. 11: Pan sharpened (colorized) digital frame sensor image

10. ADS40 as BRDF research tool in Remote Sensing

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.

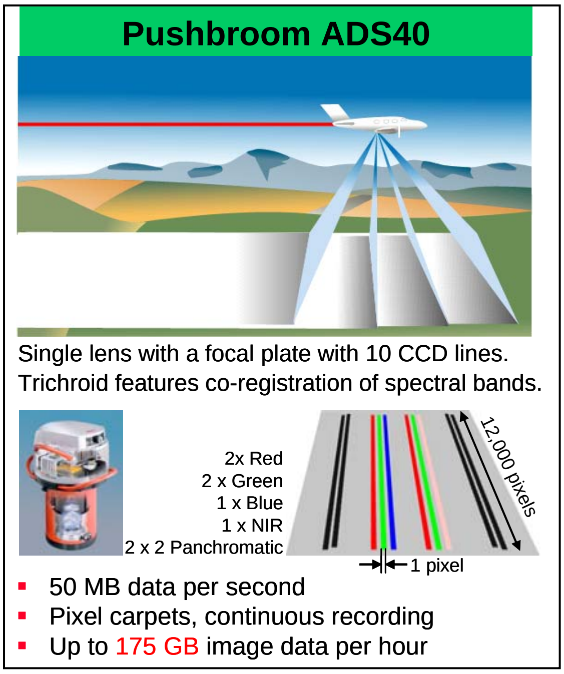

Fig. 12: Performance Specs of the ADS40 pushbroom sensor

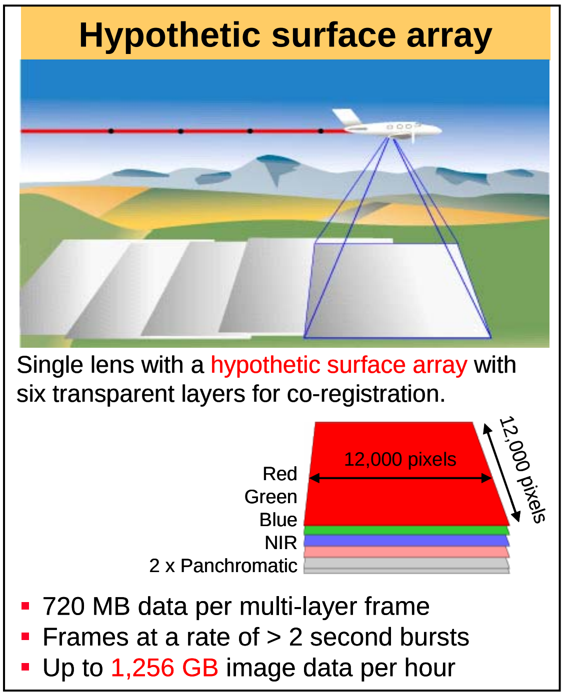

Fig.13: Hypothetical performance specs for a surface array camera to equal the ADS40 pushbroom sensor

Even if such a large surface array with 12,000 x 12,000 pixels and a pixel size of 6.5 microns would exist, it would also have to store a staggering 1,256 GB per hour if the images are taken approximately every 2 seconds to equal 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 real large format high resolution multispectral digital sensor.

12. References

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