DEVELOPMENT OF AN AIRBORNE DIGITAL SENSOR FOR PHOTOGRAMMETRIC AND REMOTE SENSING APPLICATIONS

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ABSTRACT

Even before the company was formally set up, LH Systems had begun work, jointly with the German Aerospace Centre (DLR), on the development of an airborne digital sensor. The production version is scheduled for launch at the XIXth International Congress of ISPRS in Amsterdam in July 2000. This development has involved several critical decisions in the quest to develop and manufacture a device capable of complementing the existing RC30 in photogrammetric applications and providing multispectral information too. One of these has been choosing between area array CCDs and three-line scanner approaches. The selection of the latter has led to further hardware and firmware decisions, for example lens design, layout of the focal plane and CCD specifications to give sufficient resolution, dynamic range and signal-to-noise ratio, and the selection of inertial and GPS sub-systems. The number and spectral responses of the multispectral lines has been a delicate response to user requirements. On the software side, aspects such as flight planning and feature collection are very similar to the existing products, but others have required considerable innovation and development. The latter include sensor model, data management, triangulation and DTM measurement as well as defining the different image product levels available from the new device.

INTRODUCTION

LH Systems' announced at the end of 1998 that an engineering model of their forthcoming airborne digital sensor had been flown successfully. A genuine alternative to the familiar aerial film camera is imminent! Except for stereoscopes, LH Systems and its predecessor Leica were never active in image interpretation. Yet this new sensor will have multispectral lines on the focal plane: it will be capable of generating precise, geometric information about the surface of the earth, but will also produce data amenable to proven remote sensing techniques. It will further blur the demarcation between photogrammetry and remote sensing and accelerate the decline of the photo laboratory, as digital image data can be transferred from the aircraft directly to the workstation.

The debate about airborne versus spaceborne imagery continues. The highest resolution applications, with ground pixel sizes in the one centimeter to one decimeter level, are likely to remain the province of the film camera. Yet there is a huge, pent up demand for top quality, multispectral information in the gap between this and the one meter and coarser resolutions available from satellites. Both spaceborne and airborne sensors have their advantages and the most likely scenario for the future will be an increased emphasis on data fusion as users select the sensors most likely to provide their information in each case and rely on their workstation software to combine the data. The two types of data will be complementary rather than competitive.

AIRBORNE DIGITAL SENSORS: REQUIREMENTS

To have any chance of an impact in a market accustomed to high performance film cameras, an airborne digital sensor must provide:

- large field of view and swath width
- high resolution and accuracy, both geometric and radiometric
- linear sensor response characteristics
- multispectral imagery
- stereo

The first requirement seems to rule out area CCD arrays: most models are 4Kx4K pixels or less, whereas a linear array of 12,000 pixels is readily available, requiring only one third as many flight lines. Considerable research in Germany since the 1970s has demonstrated the suitability of three panchromatic lines on the focal plane, with additional multispectral lines near the nadir. This obviates the need for multiple area arrays to provide a wide field of view and a multispectral capability (Figure 1). The left-hand diagram suggest how the focal plane could be populated using the three line principle: three panchromatic lines give the geometry and stereo, whilst additional lines, their sensitivity controlled by filters, give the multispectral information. In the right hand diagram, multiple area array CCDs and lenses are required to provide the same ground pixel size and multispectral range.

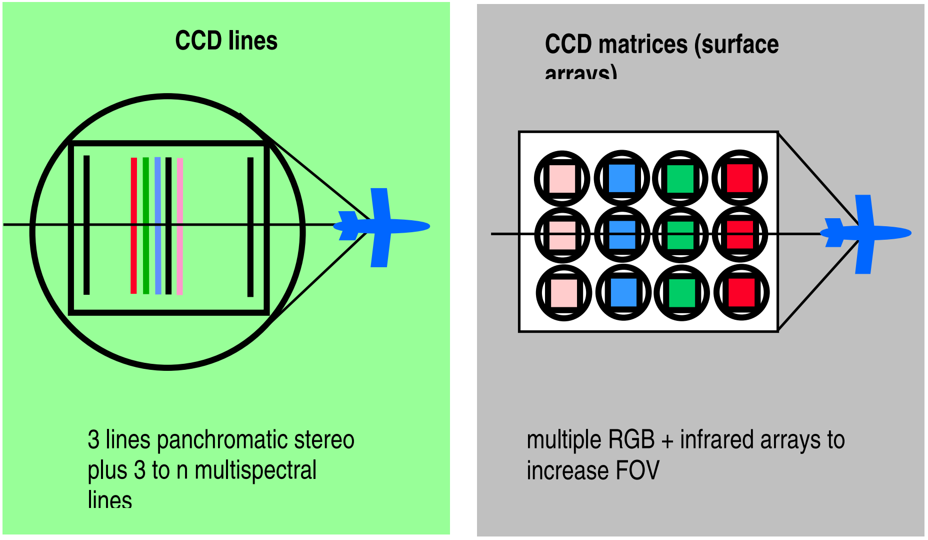

Figure 1. The alternatives: linear and area CCD arrays.

THREE-LINE SCANNER APPROACH

The three-line concept results in views forward from the aircraft, vertically down and looking backward (Figure 2). The imagery from each scan line is assembled into strips (Figure 3). The characteristics of relief displacement in the line perspective geometry of the strip approach *vis a vis* the conventional central perspective geometry are indicated in Figure 4, showing the line perspective geometry of the three-line imagery on the left and the familiar central perspective geometry of the film photograph on the right. The angles between the incoming information to the three lines are, of course, fixed. With three lines there are three possible pairings for stereoscopy – strips 1 and 2, 2 and 3, and 1 and 3. With film cameras, the parallactic angle is a function of principal distance and airbase. Moreover, every object appears on all three strips, whereas on film imagery only 60% of the area of any one photograph is in a triple overlap.

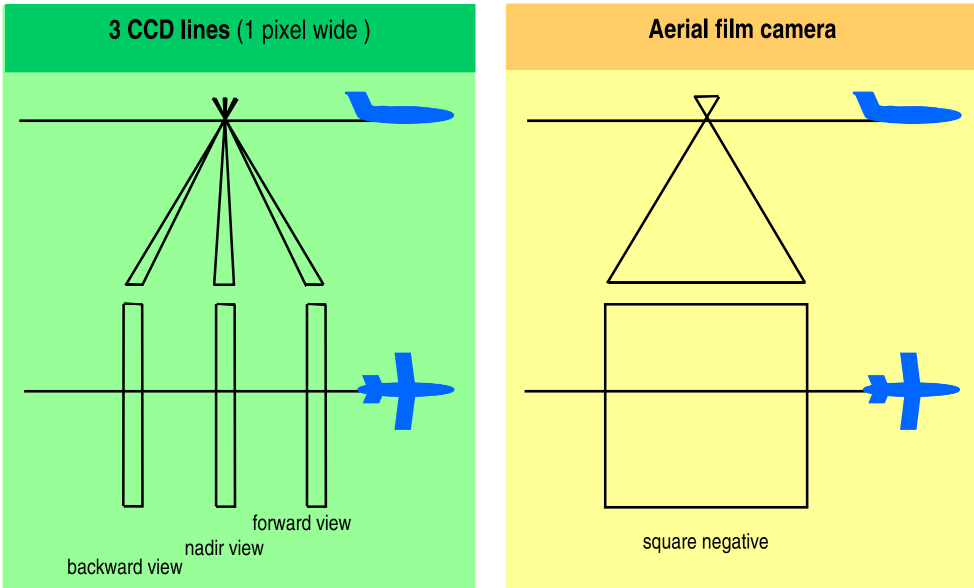

Figure 2. Basic geometric characteristics of three-line digital sensor and film camera.

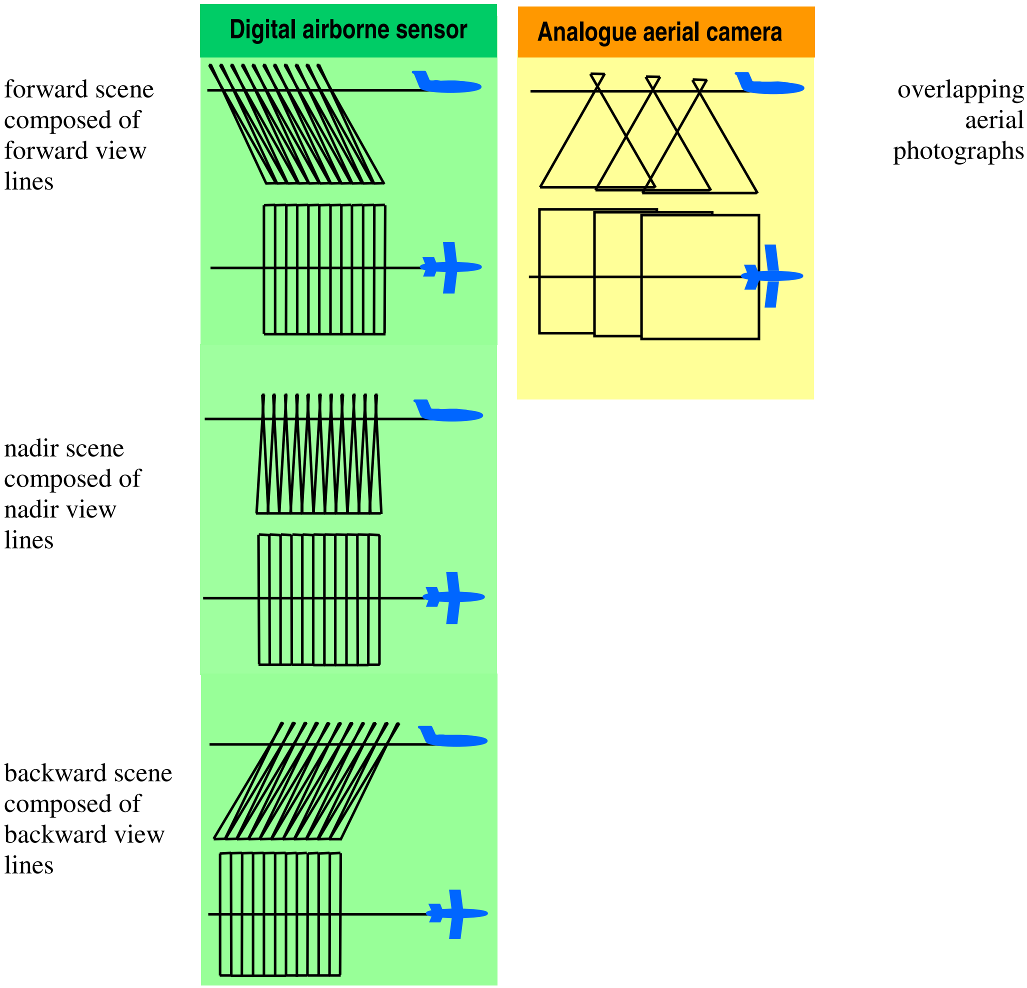

Figure 3. Comparison of the acquisition of scenes by three-line digital sensor and film camera.

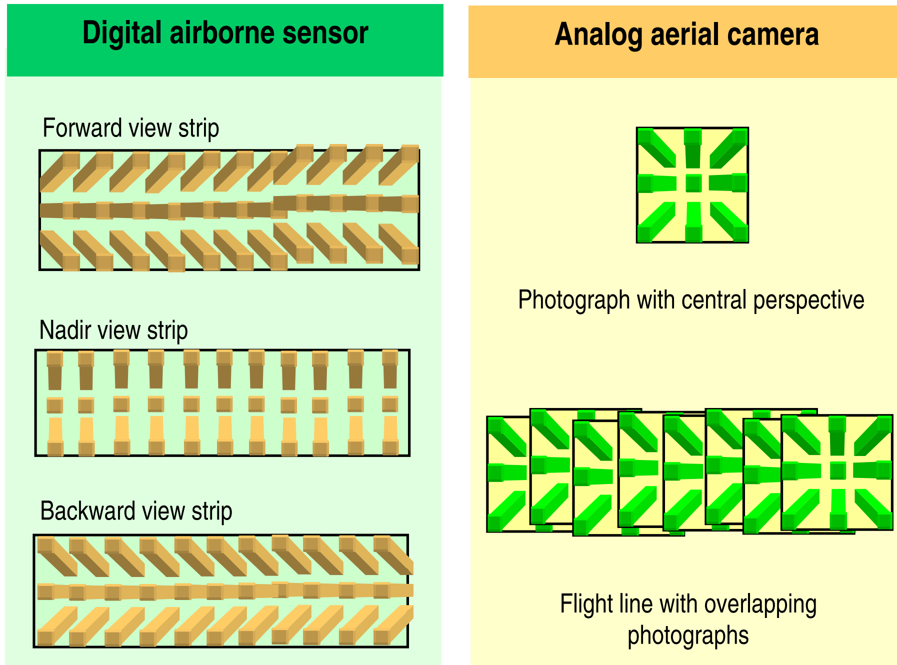

Figure 4. Effect of terrain relief on the imagery

RADIOMETRIC CONSIDERATIONS

The best possible signal to noise ratio (SNR) is a precondition for signal processing, digitizing, data compression and data transfer with little interference. In the new product, all sensor specific imperfections are corrected, for example photo-response non-uniformity (PRNU) and light fall-off, in order to achieve the maximum radiometric dynamics of 12 bit with a signal dependent SNR of better than 8 bit. The efficiency of the correction can be seen in Figure 5, which shows imagery of the Reichstag in Berlin, taken with the engineering model of the new sensor on 23 April 1999. The flying height was 3 km (10,000 feet) and the ground sample distance is 0.25 m. In the radiometrically zoomed-out image parts no noise can be seen.

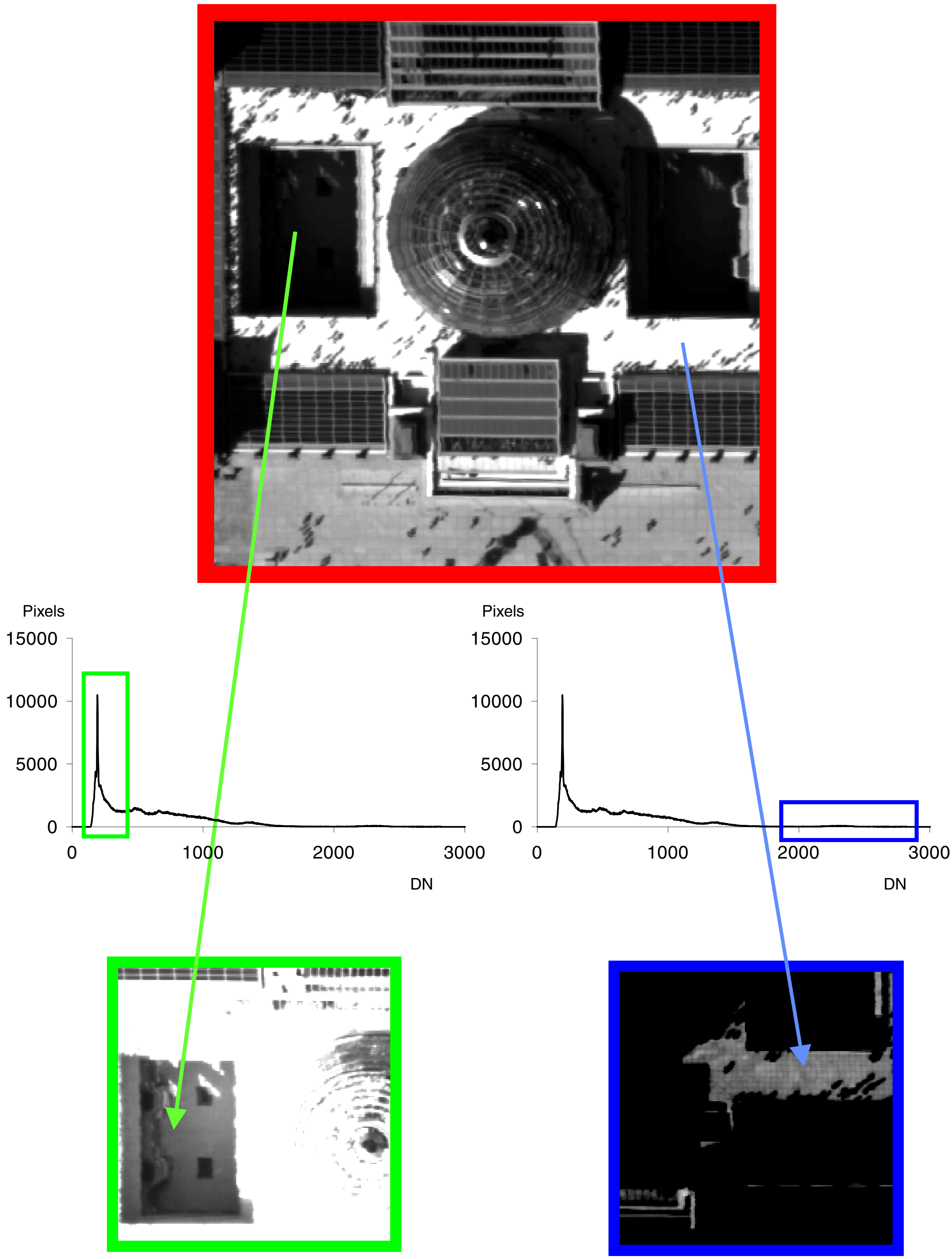

Figure 5. Imagery of Berlin, taken with the engineering model of the LH Systems airborne digital sensor.

MODULATION TRANSFER FUNCTION CONSIDERATIONS

The geometrical resolution of the camera system essentially depends on the MTF of the system optics and the CCD pixel. It describes the damping of the incoming radiation as a function of the spatial frequency. This may serve as a basis to define a contrast function.

With a MTF_{SYS} of $\approx 30\%$ at the Nyquist frequency:

$$k_{NY} = \frac{1}{2\Delta}$$

For Δ = 6.5 µm and k_{NY} = 77 lp/mm (line pairs per mm), the contrast potential and therefore the imaging quality of the sensor is satisfactory. This holds also for the non-nadir areas of the focal plane used by the nadir and stereo looking CCD lines, since the MTF_{SYS} does not deviate dramatically form the curve in figure 6, which gives a measured curve for the center of the stereo forward line (17° stereo angle) in comparison with the center of the nadir line.

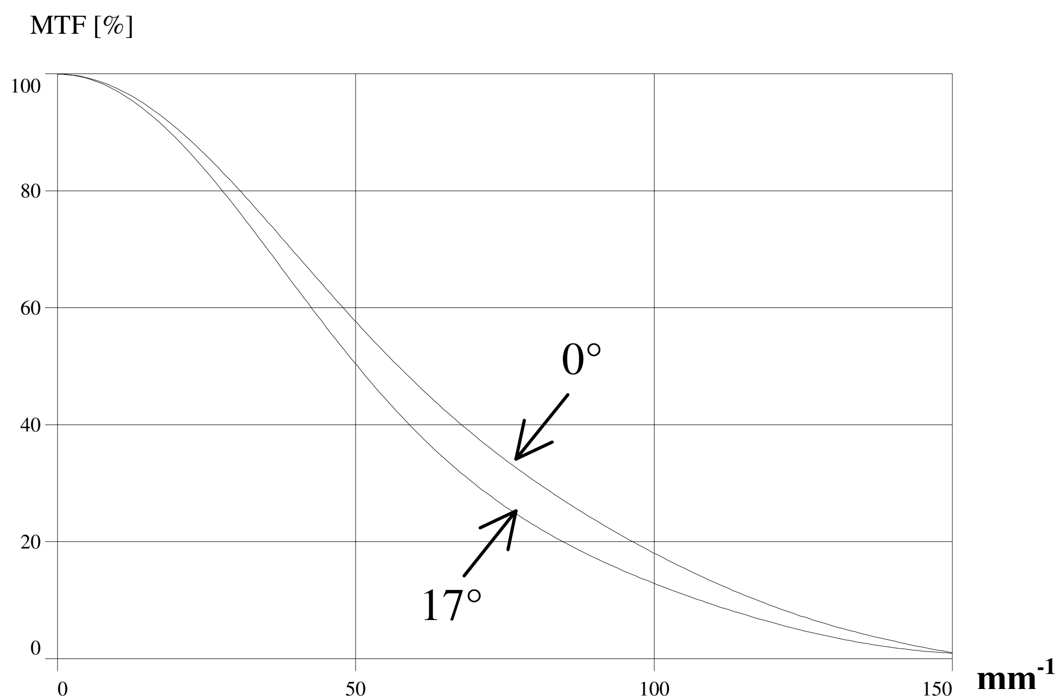

Figure 6. MTF of center of nadir line (0°) and center of forward stereo line (at 17° stereo angle)

IMAGE PROCESSING

The top image in Figure 7 has the familiar appearance of raw imagery from a line sensor because aircraft tilts and terrain relief cause the linear arrays to image widely varying strips of terrain. The flight direction was from left to right. The bottom image has been rectified, by adjusting each individual scan line for the attitude of the aircraft, using data from the airborne GPS and INS units carried on every fight, and looks similar to a conventional aerial photograph. Note the correspondence between the edges of the rectified image and the roll of the aircraft. An initial rectification using these data is essential even to view the imagery. Thereafter, operations such as triangulation, DTM measurement, orthophotos and feature extraction proceed in the usual way. Automated processes, such as point measurement for triangulation and DTM extraction, can be based on triplet matching using the three strips.

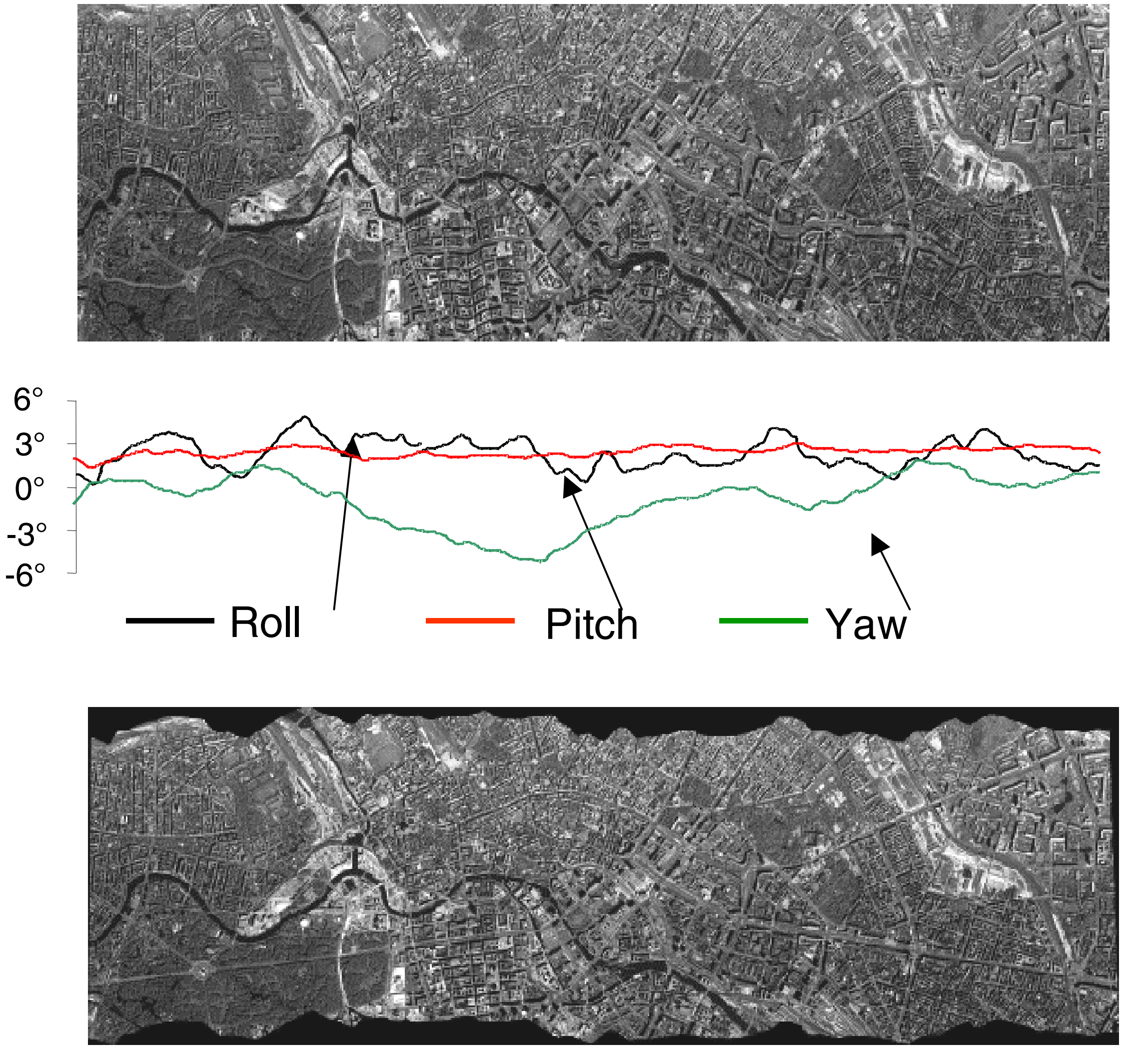

Figure 7. Imagery acquired by the new sensor over Berlin.

Owing to their positions on the focal plane, combined with the aircraft and terrain variations, the color lines image slightly different parts of the earth's surface. Thus full rectification is required, i.e. orthophotos are produced, before the color bands can be properly registered and transformed into color composite images suitable for analysis by conventional remote sensing packages.

IMU AND GPS INTEGRATION

In order to reconstruct high-resolution images from line scanner data, the orientation data of each line has to be obtained. This can be done by using observations from image matching techniques only, as provided in modern aerotriangulation packages. But computation time for this indirect method is so large that direct observations from attitude and position sensors are seen as the easiest way to reduce processing time. Applying only the indirect method is time consuming, whereas applying only the direct method is capital intensive. The decision was made to find an optimal trade-off by including direct measurements from GPS and IMU sensors of only a certain accuracy into the triangulation techniques. The advantages of are:

- data processing time to rectify line scanner data is reduced significantly
- price/performance ratio of medium priced IMU sensors is likely to improve over time.

The tight integration (Figure 8) with the focal plane of a digital line sensor has a large potential for further reduction of ground control.

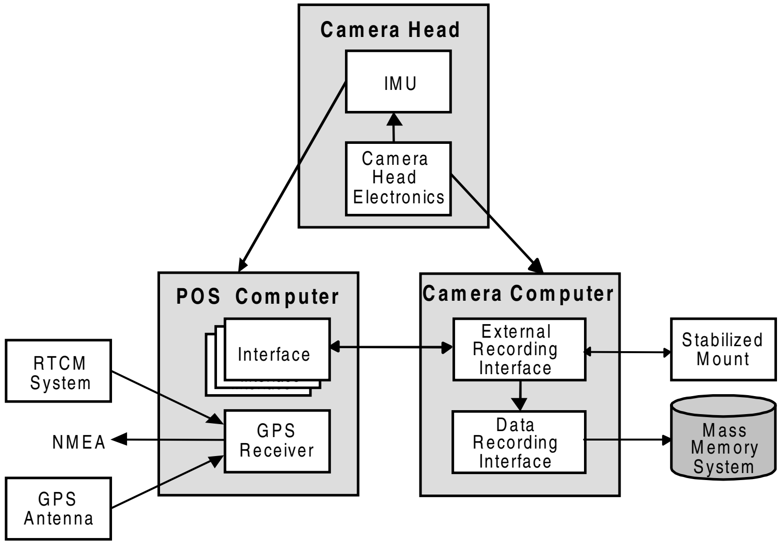

Figure 8. Main components of tight integration of IMU/GPS and a three line sensor camera.

In 1998 LH Systems and Applanix Corporation from Canada set up a working group to analyze the potential and propose solutions to achieve a tight integration between IMU, GPS and line sensors, within the scope of the co-operation agreement that LH Systems has with DLR. As one of the results, the engineering model of the airborne digital sensor is now being flown routinely including IMU and GPS sensors from Applanix Corporation.

PRACTICAL CONCLUSIONS

The features of the film and digital approaches are compared in Table 1. LH Systems has chosen the three-line scanner approach for the reasons given above. The engineering and the prototype model have both been flown (Figure 9, Figure 10 and Table 2) and work is proceeding towards the production model, which will have the equivalent of 24,000 pixels per line, fast integration times and multispectral bands. This is on schedule for launch at the ISPRS Congress in Amsterdam.

Photogrammetrists will be able to share data with the remote sensing community and for the first time create deliverables with both the depth of information resulting from image understanding of multispectral images and the geometric precision of photogrammetry. In the standard version of the new sensor the multispectral images will be derived from the data captured with four CCD sensors equipped with appropriate filters in the RGB and NIR bands. These data will be used to produce true-color and false-color composites based on the orthophotos derived from the panchromatic three-line CCD sensors.

It is LH Systems' intention to make the image data format accessible to all third party remote sensing software packages used for image enhancement and image analysis. SOCET SET® software will provide basic image enhancement functions.

Characteristic	Aerial film camera	Airborne digital sensor
Flying time	80%	100%
Photo lab	Yes	Unnecessary
12-bit in-flight sensing	No	Yes
8/10-bit scanning	Yes	Unnecessary
Data volume	80-50%	100%
Pre-processing	No	Yes
GPS	Yes (optional)	Very useful
INS	Unusual	Very useful
Projection centers	Interpolated (few)	Interpolated (many)
Ground control points	Yes, but few when using GPS	Yes, but fewer with INS/ GPS
Tie point matching	Few – between images	Many

Table 1. Features of aerial film camera and airborne digital sensor

ENGINEERING AND PROTOTYPE MODELS

The complexity and cost of developing and manufacturing a novel airborne digital sensor ruled out "going it alone". In early 1997, shortly before LH Systems was formed, Leica Geosystems reached a technology agreement with Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German Aerospace Centre in Berlin. This provided for long term co-operation, with joint development by both parties and assembly by Leica Geosystems. DLR's experience in this area is unparalleled. Amongst a host of intricate and impressive achievements in both airborne and spaceborne technology, it made historic progress with sensors based on the three-line approach, for example the WAOSS (Wide Angle Optical Stereo Sensor, built for the Mars-96 mission) (Sandau and Bärwald, 1994), WAAC (Wide Angle Airborne Camera) (Sandau and Eckardt, 1996) and HRSC (High Resolution Stereo Camera) (Albertz *et al.*, 1996). DLR's expertise complemented well SwissOptics' abilities in optics, mechanics and electronics, together with its deep appreciation of customers' requirements acquired through decades of producing aerial film cameras. It was natural that the agreement between the parties be transferred to LH Systems quite soon after its formation. The technical co-operation between the organizations has resulted in the engineering model, which was flown in late 1998, and the prototype model, flown in January 2000

Figure 9. The engineering model of LH Systems' airborne digital sensor, successfully flown in late 1998.

Figure 10. The prototype model of LH Systems' airborne digital sensor, successfully flown in January 2000.

General	
Principle	three-line CCD stereo sensor
Pixels per CCD Line	12,000 (EM) / 2 x 12000 (PM)
Pixel size	6.5 µm
Dynamic range	12 bit (raw data mode)
Radiometric resolution	8 bit
Normalisation mode	8 bit linear or non-linear
FOV (across track)	52° (EM) / 80° (PM)
Focal length	80 mm (EM) / 47mm (PM)
EM Swath at 10,000' flying height (3,100 m)	3,000m (1.9 miles) and 25 cm ground pixel size
PM Swath at 6,000' flying height (1,800 m)	3,000m (1.9 miles) and 25 cm ground pixel size
Stereo angles	17°, 25°, 42° (EM) / 19°, 36°, 54° (PM)
Recording interval per line	2.4 ms (EM) / 1.2 ms (PM)
Filter range (at λ50)	Panchromatic, 465nm – 680nm

Power	
Input voltage	28 VDC or 220 VAC/50 Hz
Power consumption: average /(peak)	600 W /(1000 W)
	Mass memory: 600 W /(600 W)
	ASCOT: 80 W /(180 W)

Table 2. Specifications of the engineering (EM) and prototype (PM) models.

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