

PERFORMANCE OF THE IMAGING SYSTEM IN THE LH SYSTEMS ADS40 AIRBORNE DIGITAL SENSOR

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ABSTRACT

The LH Systems ADS40 airborne digital sensor fulfils photogrammetric and remote sensing requirements. The new sensor is not only a camera to acquire attractive pictures: it is the next - fully digital - generation of measurement device for airborne photogrammetry and remote sensing. The accuracy of the lens and focal plane system under flight conditions (pressure and temperature) is described and a justification provided for the selection of the staggered CCD elements as the best choice for the customer. The electronics of the real-time data processing channel are introduced and the absolute signal-to-noise ratio (SNR) function of the sensor given.

A modular, customised concept is used and the first version of the sensor has four multispectral CCD lines, which are selected to support both photogrammetry and remote sensing applications. The principle of achieving good colour pixel matching is explained. After a short description of the digital sensor's function and the technical performance, some application examples are shown to demonstrate the main features of the digital sensor: wide angle, high radiometric dynamics, high signal-to-noise-ratio, in-track stereo capability and multispectral capability.

1 INTRODUCTION

Assessment of a project for the customised development of the first commercial airborne digital sensor started after the OEEPE workshop 1994 in Paris. The goal was a complete solution to meet the requirements of photogrammetry and remote sensing. The two parties to the project are LH Systems and the Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre, DLR), providing a strong combination of experience of both the needs of the market and the technological possibilities (Sandau and Eckardt, 1996; Sandau, 1998).

The whole development focussed on a solution that would provide final products automatically to the user. The project was split into four stages to ensure the quality of the digital sensor:

- (i) The functional model showed the principal SNR relations between the CCD sensor and the cost-optimised electronics.
- (ii) The engineering model - the first complete camera - delivered the first test results of SNR and photogrammetric accuracy. The results were presented at the DGPF meeting in Essen in 1999 (Reulke *et al.*, 1999).
- (iii) The prototype model, which incorporated the 24k CCD line, generated data sets with which to test the accuracy of the staggered CCD arrays.
- (iv) The series model is the final ADS40 product and incorporates the experience derived from the test results of the three previous models. This ensures that the customer will receive a fully tested and proven system.

LH Systems thus offers a measurement device, in which all known errors are restricted to less than a third of a pixel. The user will encounter few restrictions in the use of the digital system. The system itself monitors accuracy and compensates for motion, air pressure and temperature. The ADS40 can work in a fully automatic mode. All camera specific parameters are controlled such that the user has the best SNR at the data level. For some special applications the customer may use control commands via the man machine interface.

To ensure acceptance in the market it was also necessary to develop a cost-optimised solution for the mass memory system (MMS). LH Systems offers a ruggedised hard disk system with in-flight storage capacity between 200 and 500 GB, which is an airborne qualified solution for a small budget.

2 CCD SENSOR

The CCD sensor is a customised design, made to fit the requirements of both photogrammetry and remote sensing. All the parameters of the CCD, such as dimensions, flatness, conversion factor, electronic interfaces and linearity, fit the requirements of the total system. Figure 1 illustrates the triple sensor device, each sensor consisting of two staggered 12k CCD lines. Figure 2 shows the electrical structure of the CCD line – the solution of a dual output structure for the two 12k CCD lines.

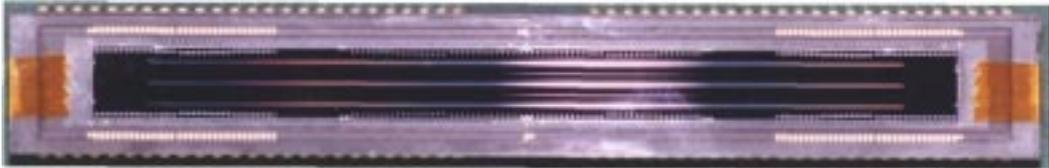


Figure 1. One of the five sections on the focal plane, showing three possible locations for a 24k CCD, consisting of two staggered 12k lines

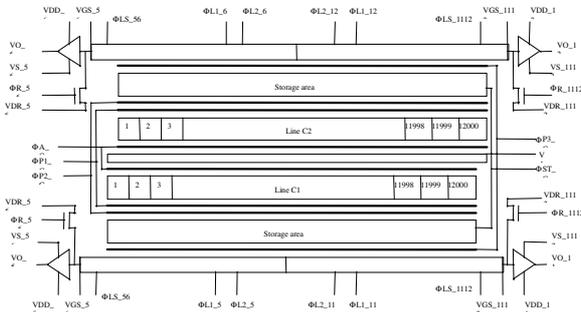


Figure 2. Electrical structure of the CCD line

3 OPTICS

High performance photogrammetric cameras need powerful optical systems. The lens system has to pick up, transfer and map the spatial, spectral and radiometric information from the ground to the sensor. The role of the optics is best described as an analogue-parallel processor, integrated into the whole processing concept. To meet the stringent flight mission specifications, the information must be recorded spatially, spectrally and radiometrically in a broad range with high resolution. These demands lead to the optical specifications in table 1 and the lens design in figure 3.

Spatial channel	Wide angular field of view (FoV) High spatial resolution over the whole FoV equally along and across track Telecentric on imaging side Large depth of focus
Radiometric channel	Fast lens (F-number 4) High transmission Homogenous irradiance distribution across the FoV Minimised optical crosstalk between pixels
Spectral channel	Panchromatic channel Narrow band spectral channels from blue (400 nm) to infrared (900 nm)
Further demands: Environmental Flight mode Mechanics	Insensitive to temperature and pressure variations Fast operability Rigid, but weight optimised construction

Table 1. Optical specifications

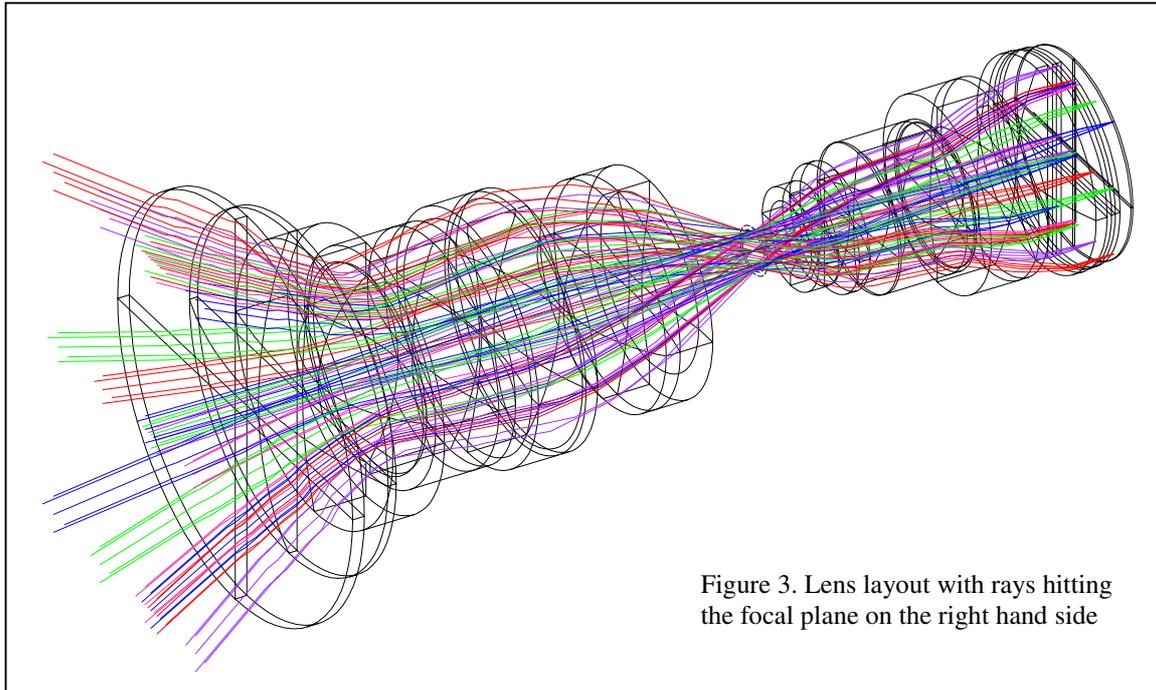


Figure 3. Lens layout with rays hitting the focal plane on the right hand side

4 FOCAL PLANE TECHNOLOGY

The focal plane technology development includes the accuracy of the CCD alignment, the temperature control of the CCD sensors and the interface between the optics, filters and the environment. Figure 4 shows the general solution of the focal plane structure. Each CCD has an individual insert, whose height is matched to the tolerances between the silicon surface and the bottom of the CCD housing. At the side of the insert are located hybrid layers to solder the pins of the CCD. The accuracy of the insert polishing is better than 1 μm . The result is a standard mechanical CCD chip interface. Only the accuracy of the chip gluing influences the tolerances. Figure 4 shows these dependencies.

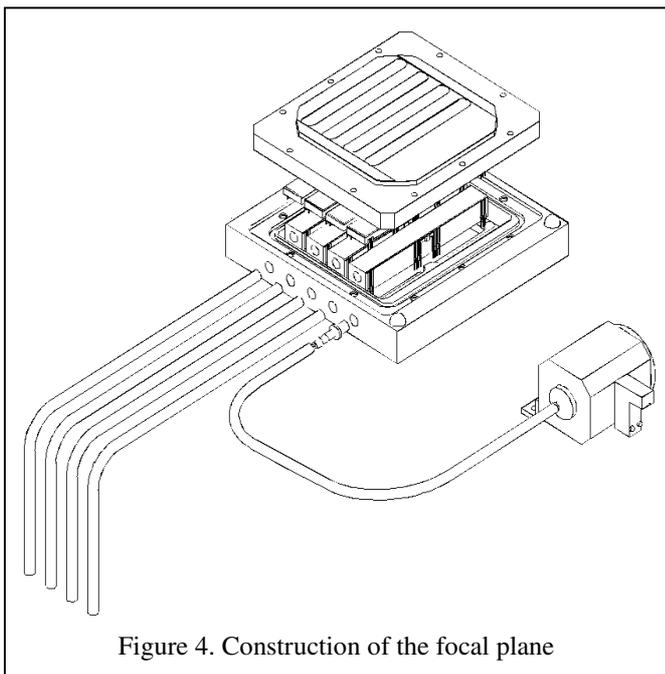


Figure 4. Construction of the focal plane

The excellent heating transfer of the insert ceramics is used to achieve an optimised heat pipe interface. The insert contains a length hole to fit the heat pipe diameter. Thus the temperature control unit can supply a constant temperature of all CCDs via a cooling system at the end of the heat pipes. The main ceramics have a very low heat transfer function so that the cooling system has better efficiency. The air filter and drying mechanism manages the pressure differences between different altitudes and the problems of water condensation on the CCD chips. The mechanism has a valve, which is opened if the sensor is switched on.

Figure 5 shows the result of the focal plane assembly. The flatness of the CCD chips themselves is shown by the top lines (dashed) and the results after the compensation, by the bottom lines (solid). The compensation accuracy is better than $\pm 10 \mu\text{m}$ after final assembly. This accuracy is necessary to fulfil the depth of focus requirements of the optics.

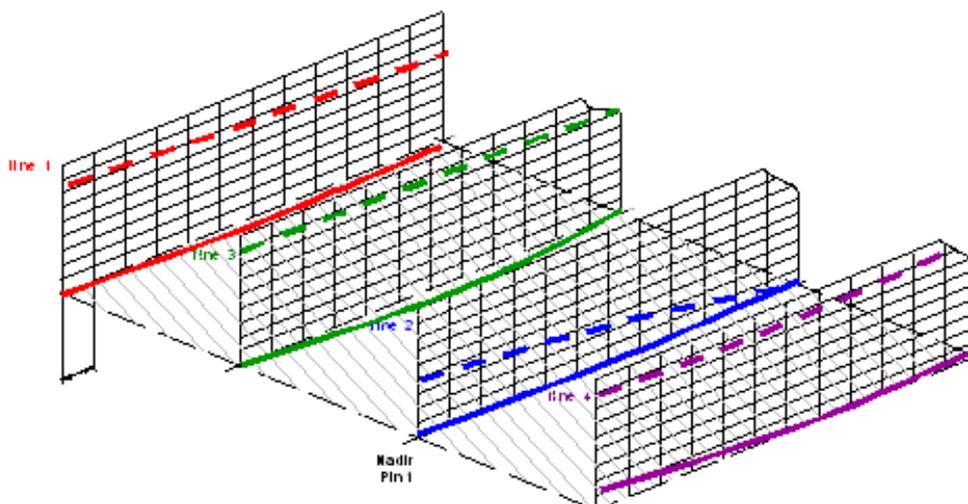


Figure 5. Accuracy of the CCD flatness: surface profiles of the CCD lines before and after assembly on the adapted focal plane inserts (relative heights)

5 THE SIGNAL PROCESSING ELECTRONICS

The CCD focal plane electronics are located at the back of the focal plane. The CCD drivers and amplifiers are a hybrid design at the back of the main ceramics of the focal plane. This design is very important to achieve a good SNR. The first driver amplification is useful for better impedance of the CCD signal. The Signal Processing Module (SPM) is the main processing unit in the camera head. Figure 6 shows the SPM with the hardware for real-time analogue signal processing including the error correction. Each CCD channel is assigned an analogue signal processor (ASP), which



Figure 6. PCB of the Signal Processing Module

contains a complete signal processing chain for correlated double sampling, offset correction, DSNU correction, PRNU correction and 12-bit A/D conversion. The SPM has a fibre input and output interface to the digital processing module.

The Poisson distribution of the incoming radiation mainly determines the SNR of photosensitive sensors. The parameters of the 24k CCD required that the expected total SNR be represented by the square root of the full well capacity. The real sensor application includes the RMS noise of the CCD, the A/D noise of the ASP and the analogue channel noise. The ADS40 has a real SNR of 8.9-bit in a dynamic range of 12-bit. All effects of quantisation and multiplication noise were considered and measured for this calculation.

For the real-time prediction of the integration time of the CCD, the Digital Processing Controller builds a histogram of the image. The DSP will predict from that information and from the knowledge of the sample time the best integration time for the application.

The good SNR of the CCD sensor combined with the geometrical resolution of the staggered pixels is the best solution to meet the requirements of all applications.

6 THE DIGITAL PROCESSING UNIT

The new generation digital sensor must have enough processing power to fulfil the required real-time algorithm calculation. The camera head fibre data link has a maximum data rate of 40 MB/s. The input pixel interface of the digital-processing unit builds block lines at the first memory of the board. The DSP has an input data rate of several

hundred MB/s and can read faster than the camera head interface can provide the data. The DSP now has the calculation power to normalise the data. The normalisation flow begins by searching the maximum and minimum. Then the DSP compares the differences (between maximum and minimum) with the 8-bit border. If the difference is lower than 256, all pixel values will be reduced by the minimum value. In the other case the DSP normalises the pixel values to 8-bit after the subtraction of the minimum, via a linear or non-linear look-up table. After the normalisation the DSP writes the data into the compression memory so that the data write access is faster than the data interface of the camera head. The next processing stage compresses the data in real-time via JPEG or lossless compression. The compression is performed by hardware. Figure 6 shows the PCI version of the digital processing unit of the ADS40.

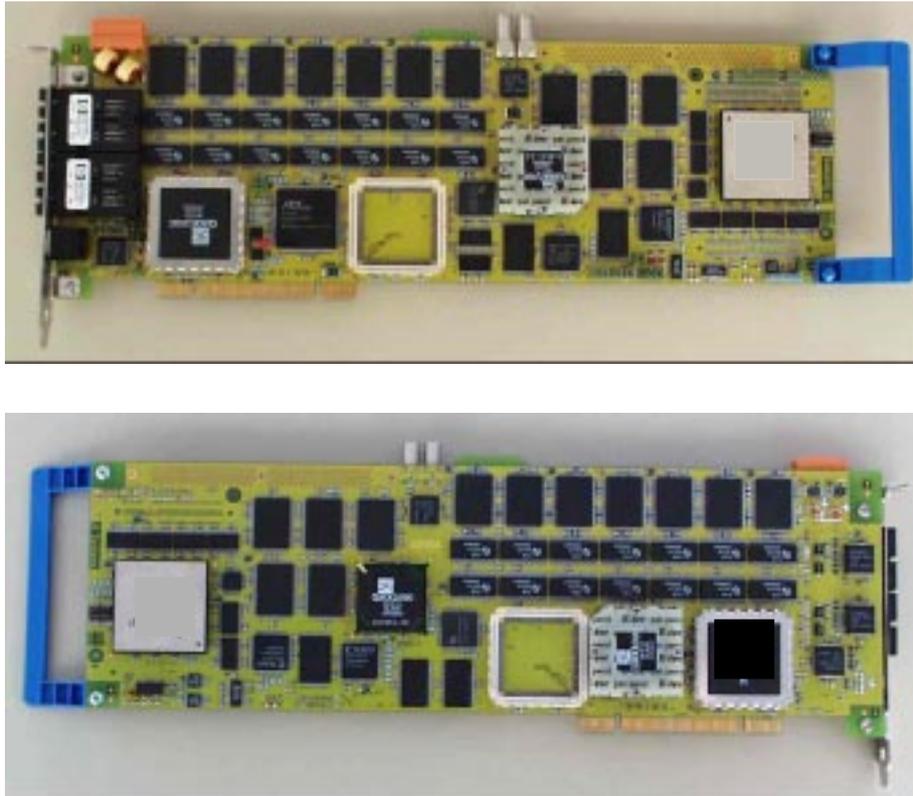


Figure 6. Front and rear views of the digital processing board

The user can select in which of the following data formats the ADS40 will operate:

- Lossless compressed
- JPEG compressed.

7 CONCLUSIONS

It has been shown that the LH Systems ADS40 airborne digital sensor is much more than a camera capable of acquiring attractive pictures. This new generation of airborne digital sensor system fulfils all requirements of a measurement device. The most important features are:

- Pressure stabilised optics
- Temperature stabilisation/compensation (CCD and optics)
- Compensation for condensation
- Accuracy observation
- Geometric accuracy better than 1/3 pixel
- Radiometric accuracy 8-bit
- Dynamic range 12-bit
- Real-time compensation of fixed pattern noise PRNU/DSNU
- Customised data format
- Electronic environmental control
- Fully automatic camera control
- Multivalent sensor arrangement.

A significant advantage of the ADS40 concept is to reduce dramatically the number of ground control points. The overall accuracy depends on the accuracy of data from the inertial measurement unit (IMU), which is a customised development by the Applanix Corporation.

All the above twelve features of the ADS40 have been implemented and proven by test and calibration facilities. The pressure and temperature conditions were tested in May 2000 in the vacuum chamber of DLR and the results demonstrated that the sensor contains all features of an airborne qualified measurement system.

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