CALIBRATION OF THE LH SYSTEMS ADS40 AIRBORNE DIGITAL SENSOR

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ABSTRACT

High performance photogrammetric cameras require high resolution geometric, spectral and radiometric calibration. Instruments to meet the stringent specifications exist at LH Systems and DLR. The underlying principles of operation are discussed with respect to the new LH Systems ADS40 airborne digital sensor, and the results of the first cross measurement are reported.

1 INTRODUCTION

The rapid progress of electronic sensors will undoubtedly lead to the substitution of film-based photogrammetric cameras by digital cameras. However, both analogue and digital cameras will be used in parallel by the photogrammetric community for at least one decade. With the advent of the ADS40, a joint project of LH Systems and Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre – DLR), the issues of sensor calibration must be addressed. This paper reviews the calibration equipment currently in use at both locations. While the DLR equipment is favoured owing to its great flexibility and the possibility of modifying geometric, radiometric and spectral measurements in the development phase, the LH Systems equipment is optimised to industrial needs, especially through fast and automatic measurement modes.

2 THE CALIBRATION-FACILITY AT DLR - EXAMPLES OF CALIBRATION RESULTS

The calibration facility located in the DLR Institute of Space Sensor Technology was originally developed for calibrating spaceborne sensors (Schuster, 1994) and was later extended to the infrared spectrum. The optical scheme of the calibration set up is shown in figure 1.

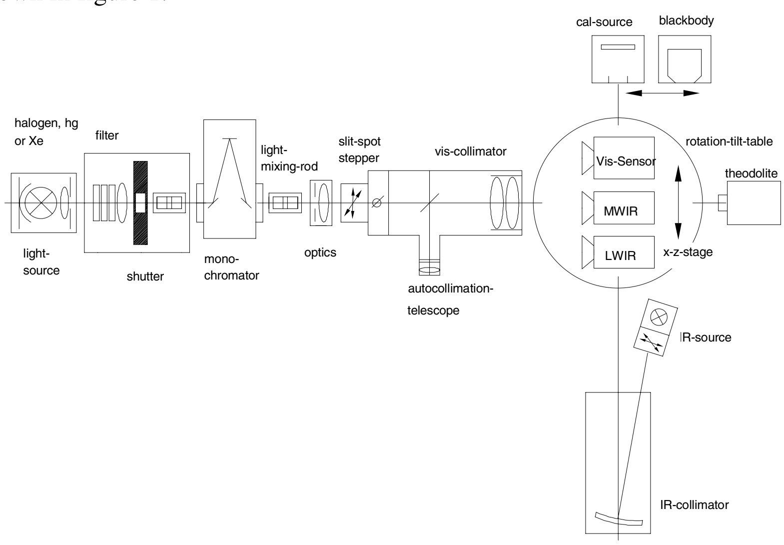

Figure 1. Calibration facility at DLR (optical scheme)

The DLR facility (figure 2) features:

- Clean room class 10000
- Lamps: halogen (150W), xenon (150W), mercury (200W)
- Collimator f=1200 mm, D=150 mm, apochromatic corrected 390-1013 nm, with autocollimation device, adjusting slit or spot: aperture ±25 mm, accuracy ±1 µm, resolution 0.1 µm
- Spectral resolution with grid-monochromator (350-800 nm, 700-1500 nm); $\Delta\lambda$ = 2...20 nm
- Two axis nodal bench azimuth axis 350°, elevation axis ±50°, accuracy ±2.5 arcsec, resolution 0.5 arcsec, load 50 kg
- PC-control of lamps, shutter, monochromator-drive, optical sensors, adjusting aperture and camera nodal bench
- Special software (MS Windows) for geometric and radiometric calibration tasks.

Figure 2. View of the calibration laboratory at DLR-Berlin

The main tasks for geometric calibration of a digital sensor are:

- Highly accurate measurement of the internal orientation of any active pixel for determination of the image co-ordinates
- Measurements of the system MTF for any pixel of the sensor.

The first requirement is met by single pixel illumination along the CCD-line with a pinhole spot from the collimator focus. The direction of the illuminated pixel to the collimator axis is determined by the angles α (angle in line direction) and β (angle perpendicular to the line direction). These two angles can be exchanged in the case of horizontal mounting of the camera. For the transformation from the spatially fixed co-ordinate system (x,y,z) to the image co-ordinate system (x´,y´,z´) the simple transformation $x' = f \cdot \tan\alpha / \cos\beta$; $y' = f \cdot \tan\beta$; $z' = z$ (figure 3) must be applied (Ohlhof and Kornus, 1994). As example the result of calibration from the nadir-line of the first engineering model of the ADS40 (figure 4) is shown in figure 5 before and after transformation.

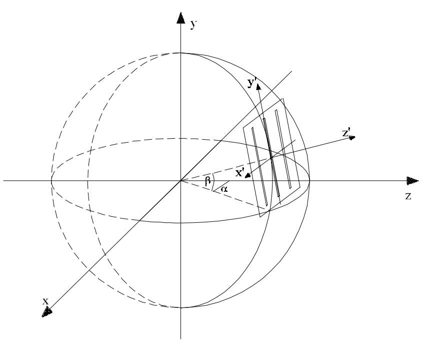

Figure 3. Transformation from (x,y,z) to (x′,y′,z′)

Figure 4. The engineering model of the ADS40 during the calibration procedure

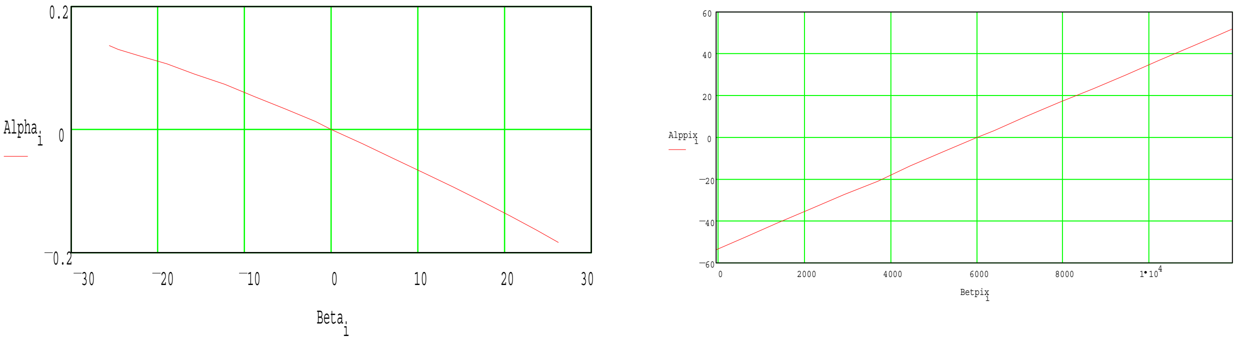

Figure 5. Result of geometric calibration in degree (1) before and
in units of pixel-size (2) after transformation

The second requirement is met by measurements of the Point Spread Function (PSF), from which the Modulation Transfer Function (MTF) can be calculated by a Fast Fourier Transform (FFT). It is useful to register at the same pixel the PSF and geometry. Because the PSF is a two-dimensional function, we measure in the two main directions corresponding to the flight direction and perpendicular in the line direction. From these measurements the MTF can be calculated at an arbitrary number of points along the line and used as input for the image post processing. Examples for PSF/MTF measurements with the engineering model of the ADS40 are shown in figure 6. The MTF curves characterise the optical performance of the digital camera system, which is mainly determined by the pixel size and the optics. The resolution always seems to be better in the flight direction than in the line-direction.

flight-direction swath direction MTF

-10°

0°

+10°

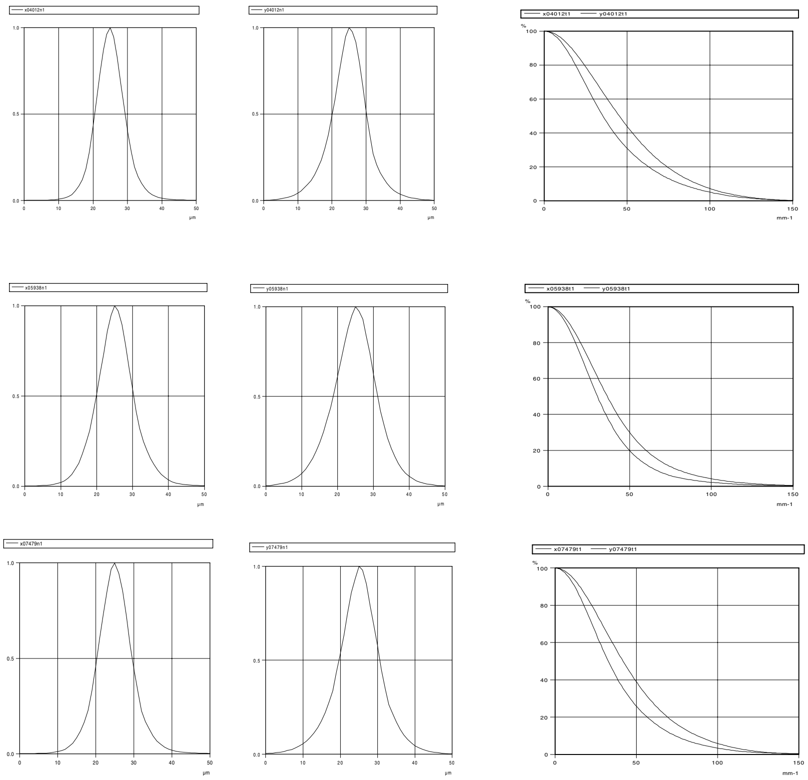

Figure 6. Examples of PSF/MTF measurements (nadir line of engineering model of the ADS40)

The use of modern digital sensors together with a flexible electronic read-out channel also leads to new possibilities for the radiometry. If the total field of view (FoV) of a line camera is illuminated homogeneously we get a line-signal similar to that in figure 7a. The shape of the curve reflects the intensity drop across the FoV, known as the $\cos^4$ law, but the high frequency variation is caused by the variation of responsivity (photo response non-uniformity - PRNU) of the line-pixels. It seems useful to correct the signals pixel-wise to obtain constant signals with homogenous illumination. The correction can be done very simply online by subtraction (dark signal) or multiplication (PRNU and limb shadowing) by the digital part of the electronics. An alternative solution would be off-line correction during the image processing work. In both cases it is necessary to determine the radiometric correction values in a separate calibration process. After this correction the line signal must be free from PRNU and limb shadowing (figure 7c).

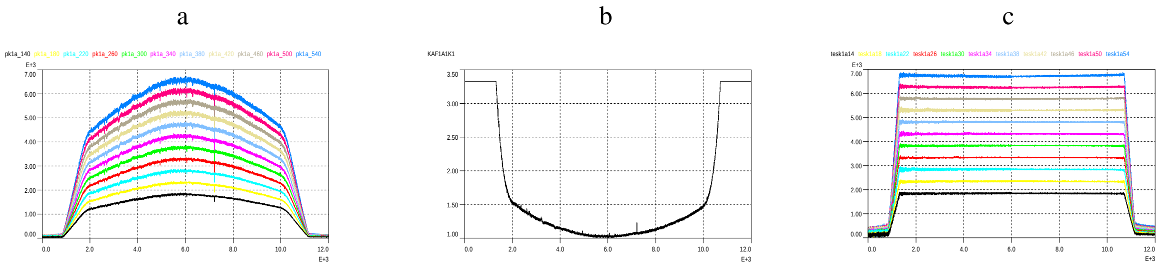

Figure 7. Line-signal: a-uncorrected, b-PRNU-correction values, c-corrected

Normally CCD camera systems are sensitive in a relatively wide spectral band. Therefore it is not possible to determine the spectral behaviour of radiance of an unknown source. Nevertheless the absolute calibration can be done to an averaged value given by the convolution of the normalised responsivity with the spectral characteristics of the source. This absolute calibration is a part of the calibration program of the DLR facility. To proceed the following steps are necessary:

1. Measurements of the irradiance in front of the camera optics with separate detector dependent on wavelength.
2. Measurement of the spectral responsivity of the pixels and normalisation with the spectral behaviour of the facility.
3. Measurement of an absolute calibrated source (radiometric sphere) covering the total FoV of the camera.
4. Calculation of the absolute radiometric correction values.

The method of absolute calibration was tested with a spaceborne camera system and gave a Noise Equivalent Radiation (NER) of 30-70 10^4W/m³sr with a resolution of 7 10^4W/m³sr. The performance of the PRNU correction was better than 0.2%. Figure 8 shows some sample results.

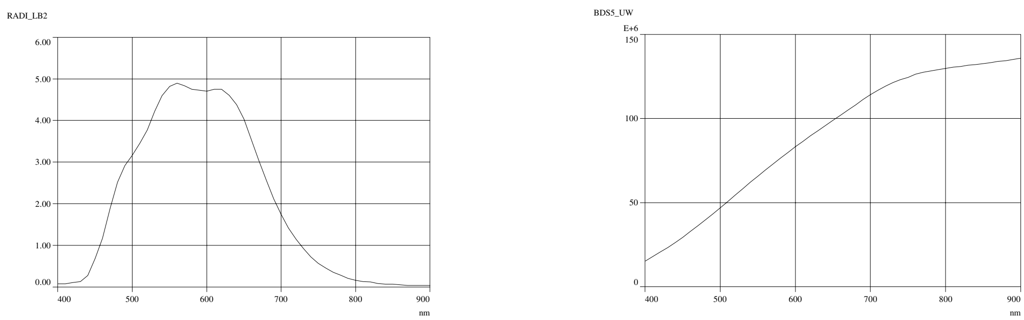

Figure 8. Spectral responsivity of (a) a pixel, (b) radiance of the radiometric W/m³sr

3 PHOTOGRAMMETRIC CALIBRATION FACILITIES AT LH SYSTEMS

The main optomechanical parts of the ADS40 are produced by LH Systems in Heerbrugg, Switzerland. Consequently, new instruments were developed for *dual use* at this location: to test lenses during the manufacturing process and to perform the final calibration of the integrated camera head at system level.

3.1 Geometric Calibration

Geometric calibration of the ADS40 includes the quantitative determination of the image quality and of the registration geometry. To speed up measurement, both criteria should be measured *simultaneously*. This is accomplished by a coded vertical goniometer (CVG). The test programs are run automatically and the results directly linked to the LH Systems databases.

3.2 CVG Hardware

The CVG was developed in 1998 by upgrading an existing vertical goniometer. Its main goal was the electronic testing of film-based analogue lenses under realistic operational conditions. Later, with the advent of digital cameras, hardware and software modifications were added to test the lenses together with the digital camera head (Pacey *et al.*, 1999).

Figure 9. Inserting optical systems into the CVG:
a) objective UAGS for testing the optics b) engineering model of the ADS40 for calibration

Figure 9 shows the installation of test lenses into the CVG, whereby the lens entrance pupil must coincide with the swivel axis of the goniometer. Inside the swivel arm an auxiliary optics images a small code pattern to infinity. The ADS40 lens under test refocuses the code pattern on to its digital sensors. Rotating the swivel performs a field scan along the CCD-line at nadir position. However, to address pixels outside the nadir line, a mirror scanner, moveable in the x-direction, is mounted on top of the goniometer arm. From the contrast of the transferred image we deduce values for the image quality; from the actual angles of swivel and x-scanner we gain the registration properties.

The code pattern consists of a series of stochastically arranged black and white bars of width 3 µm pointing in two orthogonal directions. The code is designed to be sensitive to small lateral displacements to increase the accuracy for the registration measurement, and to possess sufficient spatial bandwidth for the image quality tests.

3.3 Measurement of the Image Quality

As criteria for the image quality of a pixel the OTF (optical transfer function) across and along the CCD-lines is chosen. The OTF describes the complex variation of the transferred contrast through the optics with the spatial frequency. To ensure that the digital sensor lines are at best focus, the OTF must be measured at different depths of focus. This is easily accomplished by defocusing the small code pattern in the swivel arm.

Figure 10a shows the results of a measurement: The ideal code pattern (red) has contrast one, while the measured code signals (blue) show smaller contrast values. The OTF is mathematically deduced from both functions. Its amplitude function MTF (modulation transfer function, upper curve in figure 10b, is already visible in the measured signals in figure 10a, where code sequences with low frequencies exhibit a larger contrast than those with high frequencies. Note further that the OTF's phase function PTF (lower curve in figure 10b) is nearly zero over the full frequency range, thus indicating a perfect, coma-free test lens. Again, this is nicely visualised in figure 10a, where the shape of all measured code elements is highly symmetric.

3.4 Measurement of the Geometric Registration

The purpose of the registration calibration is to assign to each sensor pixel the angular position of its *seen* ground pixel element.

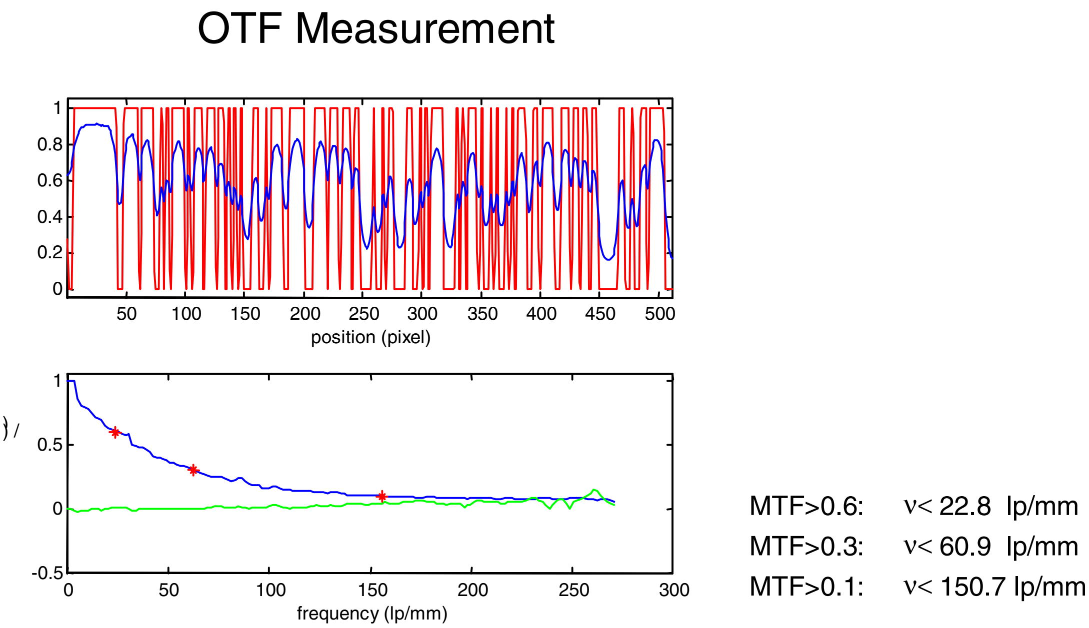

Figure 10. (a) code pattern before (red) and after (blue) imaging through a test lens
(b) transfer functions MTF (blue) and PTF (green) deduced from (a)

Unlike film cameras, where film shrinking requires the need of artificial fiducial marks, the situation is much easier for the digital camera. Each CCD-pixels is a fiducial *per se*. This allows to reduce the calibration task to assign to each pixel the value of its 'down to ground looking' direction vector $\underline{a}$, mostly expressed by two polar angles, relative to a lens based co-ordinate system.

Owing to the stringent accuracy requirements of 1 arcsec for both angles, special electro-optical means are foreseen in the CVG to control mechanical motions of swivel and x-scanner in real time. Powerful algorithms, specially adapted to the stochastic properties of the code structure, allow determination of the actual position of the code at the CCD-lines with sub-µm resolution.

3.5 Radiometric Calibration

The radiometric calibration is done with a large Ulbricht sphere, located directly beside the CVG. The test bench is still under construction, but operates very similarly to the DLR equipment. At the time of writing the first test runs with the engineering model of the ADS40 are complete.

4 COMPARISON OF THE GEOMETRIC CALIBRATION MEASUREMENTS

Photogrammetric cameras must be geometrically calibrated with an accuracy of parts of one pixel. Therefore very precise angular measurements are necessary to meet the stringent requirements. Using the first working ADS40 model, the engineering model, geometrical calibration was performed at both calibration facilities of DLR and LH Systems for the purpose of comparison. The outputs of the geometrical calibration process are two polar angular co-ordinates, assigned to each measured pixel. The first results indicate that it is sufficient to measure pixels every 2-5 degrees within the field of view, depending on the length of the CCD-line and on the focal length of the camera. The angular co-ordinates for pixels in between are interpolated numerically. The geometrical calibration results can be presented in different forms and units, e.g. in multiples of a pixel. The conversion to conventional units e.g. SI units, is then a simple multiplication with the pixel size.

In the preceding chapters we outlined the different measurement modes at both locations. At DLR in Berlin the ADS40 is mounted horizontally on a rotation-tilt stage and the direction of the pixel through the optics to the fixed collimator axis is measured by moving the camera around two perpendicular axes. At LH Systems in Switzerland the camera is fixed in the vertical direction and the illumination device moves within the FoV of the camera. The direct comparison of the results for the nadir line of the engineering model at different times and places is presented in figure 11. The measured angles are converted to distortion values, expressed in pixel units. The difference between both curves is less than one pixel over the whole line of 12,000 pixels. This impressive result indicates the high level of precision and the high reliability of both devices.

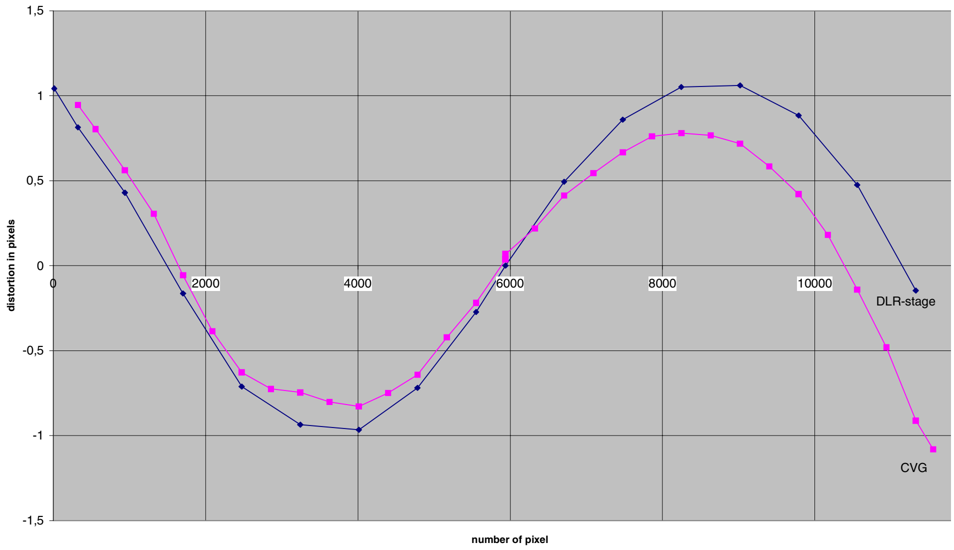

Figure 11. Comparison of the calibration results at DLR and LH Systems for the nadir line of the engineering model

REFERENCES

Ohlhof, T., Kornus, W., 1994. Geometric calibration of digital three-line CCD cameras. International Archives of Photogrammetry and Remote Sensing, Vol. 30, Part 1, Como, Italy, pp. 71-81.

Pacey, R.E., Walker, A.S, Scheidt, M., 1999. Calibration of analog and digital airborne sensors at LH Systems. Proceedings of the 1999 ASPRS Annual Conference, Portland, Oregon, pp. 950-956.

Schuster, R., 1994: Sensor calibration and geometric calibration of a three line stereo camera. International Archives of Photogrammetry and Remote Sensing, Vol. 30, Part 1, Como, Italy, pp. 265-271.