NEW CALIBRATION SCHEME FOR PANORAMIC LINE SCANNERS

S. Krüger[a], M. Scheele[b], R. Schuster[b]

[a]**HOLOEYE** Photonics AG, Albert-Einstein-Str. 14, 12489 Berlin, Germany
[b] German Aerospace Center (DLR), Optical Information Systems, Rutherfordstraße 2, 12489 Berlin, Germany

krug@holoeye.de, martin.scheele@dlr.de, reinhard.schuster@dlr.de

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ABSTRACT:

In the DLR department of optical information technology exists long experience and practical knowledge in geometrical calibration of opto-elctronical systems especially CCD-line scanners. An approved method is the single pixel illumination by collimated light. The accuracy of this method depends of the precision of the used goniometer and is in the order of 2 arcsec. The disadvantage of this method is the large amount of time.
A new method of geometrical calibration is the use of static Diffractive Optical Elements (DOE) in connection with a laser beam equipment. This method can be especially used for 2D-sensor array systems but is not suitable for line scanners. An advanced method using Spatial Light Modulator (SLM) of the Holoeye AG gives the possibility of geometrical calibration of line scanners.

1. INTRODUCTION

The procedure of geometrical calibration of camera systems can be divided in methods using test-fields and methods where test-fields are not necessary. In the case of stereo-analysis in connection with bundle-adjustment as well as methods with single-pixel illumination by collimator and goniometer arrangements no test-field are needed. The calibration procedure reported here is similar to that using test-fields, but the test pattern is produced by elements located directly in front of the camera.

2. THE CALIBRATION FACILITY OF DLR

The calibration facility located in the DLR-Department of Optical Information Technology was originally developed for calibrating space borne sensors in the visible range for geometrical, radiometrical and spectral calibration of optoelctronical systems [Schuster, R. 1995,2000 and 2002].

Fig. 1. - Calibration facility (optical scheme)

During the work on payloads for the small satellite BIRD the calibration facility was extended to the infrared spectrum. Now it is possible to calibrate sensors working in different spectral ranges together. In this way also the problem of copixelregistration between different sensors could be solved. The optical scheme of the calibration set up is shown in fig. 1
The main part of the Calibration facility is a high accuracy two-axis nodal bench which carries the sensors. The azimuth axis can move around 350° and the elevation axis ±50° with an accuracy of ±2.5 arcsec and resolution of 0.5 arcsec. Additionally the load can adjusted with a x-y translation stage of µm-stability.

The visible calibration part is build by a high corrected lens-collimator of f=1200 mm, D=150mm with autocollimation device. With an adjusting slit or spot of aperture = ±25mm, accuracy = ±1µm and resolution = 0.1µm PSF/MTF-measurements can be done.The collimator is apochromatic corrected between 390-1013 nm. Different lamps, halogen (150W), xenon (150W), mercury (200W) can be used. Spectral measurements can be made by different filters or with a grid-monochromator (350-800nm, 700-1500nm, $\Delta\lambda$ = 2....20 nm). Special software (MS Windows) helps for geometric, radiometric and spectral calibration of digital sensors or complete camera systems in the visible range.

The collimator for the infrared spectral range is an off-axis mirror collimator with f=1000mm and D=120mm. A spot-target is illuminated by an IR-source. This collimator was used for the geometrical calibration and PSF/MTF-measurements of the infrared sensors of BIRD. The two collimators are adjusted in the same plane and are perpendicular to azimuth- and elevation-axis of the nodal bench.
The main task for geometric calibration is the exact determination of the pixel orientation of each sensor. The pixel orientation is determined by measuring the two angles of the nodal bench during illumination of a single pixel. The calibration facility can be used for calibration of array as well as line sensor systems. A sufficient number of pixels in the

order of 50 for array sensors or 20 for a sensor line will be measured,

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

because it is not possible and also not necessary to measure more. The pixels between the measuring points will be interpolated mathematically. As the result of the geometrical calibration each pixel is signed with two angles which give the orientation and allows the exact correlation between the points of the scene and the image.
The disadvantage of the geometrical calibration with the collimator arrangement is single pixel measurement which requires a large amount of time. Therefore we looked for a more simple procedure which also can be used for field or in-flight calibration of sensor systems.

3. GEOMETRICAL CALIBRATION WITH DOE

Diffractive Optical Elements (DOE) are able to bias the incoming light wave in a well defined way. The diffraction pattern will be calculated and written in chrom coating on silica by photolithographic procedure. For the first calibration experiment we used a DOE which works like a 7x7 beam splitter of 40x40 mm size. The DOE was calculated and produced by HoloEye Photonics AG. If such an element will be illuminated by parallel laser light 7x7 sharp light spots occur in the image plane of a lens (see Fig. 3). The angle difference between the spot is known with highest accuracy depending of the laser wavelength and the photolithographic process.

Fig. 3 Reconstruction of DOE-pattern by laser light

The principle scheme for calibration purpose of camera systems is shown in Fig4. The DOE will be illuminated by a wide laser beam and is located directly in front of the camera optics. The camera is connected with a PC for camera control, data acquisition and analysis [Jahn H.,Scheele M.,Schuster R.,2004].

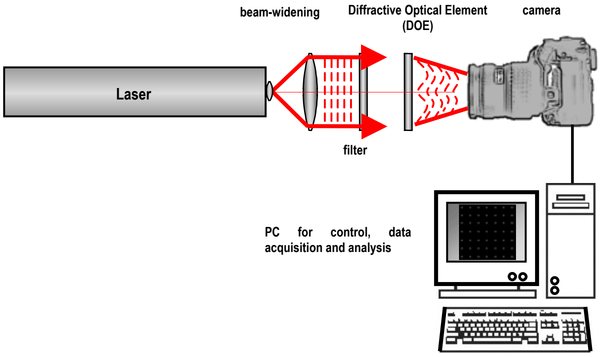

Fig. 4. Scheme of camera calibration with DOE

The advantage of the calibration using DOE is to get the whole information with one measurement instead of al large number of pictures with the single pixel illumination. The compact assembly and robustness is predestined for using the equipment under field condition and in-flight calibration tasks.
In Fig 5 a calibration measurement is shown taken in a bright environment. The calibration spots occur as sharp points in a blurred environment. This is very essential for long focus cameras where test fields because of the size and necessary distance cannot be used. Another point is the absolute stability of position of the spots against lateral displacement.

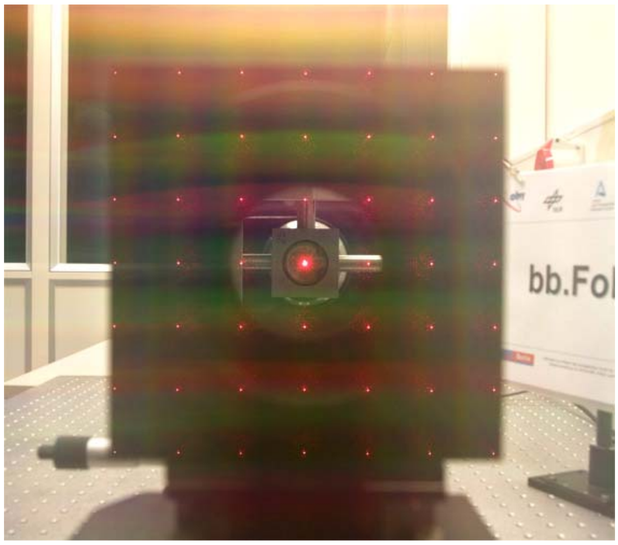

Fig. 5 Calibration recording in bright environment

The results of geometrical calibration of a 5 Mpix reflex-camera (Olympus E1) with the DOE arrangement was compared with the collimator single pixel method and the photogrametric test-

panel The accuracy of the different methods was nearly the same. The comparison is summarized in Table 1.
The calibration of line scanner systems with DOE is more difficult then matrix sensors and needs other kind of pattern

	Collimator-calibration-method	**DOE-calibration-method**	**Photogrammetric test-panel**
mean absolut error (horizontal)	**0.33 pix**	**0.24 pix**	**0.35 pix**
mean absolut error (vertical)	**0.32 pix**	**0.50 pix**	**0.39 pix**
standard deviation	**0.58 pix**	**0.55 pix**	**0.53 pix**

Table 1 Comparison of the different calibration-procedures

distribution. In the following chapter a new type of controllable elements is described. These elements shall be used for calibration of line scanner systems in connection with static DOE.

4. SPATIAL LIGHT MODULATORS

Spatial Light Modulators (SLMs) became very important components in optical systems [S. Krüger 2001; G. Wernicke 2002]. Beside shutter and display applications, also the possibility of phase modulation is more and more subject of current research. SLMs using two-dimensional arrays of phase-modulating pixels are the basis of many new system proposals in adaptive optics, image processing and optical switching. One challenge is the implementation in diffractive optics in order to realize high-resolution phase functions. With increased resolution and performance they could also compete with micro-lithographic fabricated diffractive elements. So, a wider range of application fields can open up. Here, one can mention laser beam splitting and beam shaping for projection and material processing application.

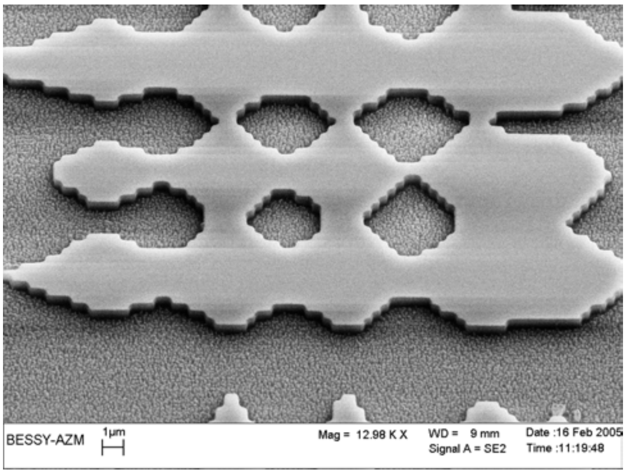

Figure 6: SEM-image of a 2-level diffractive structure (Source BESSY-AZM, Daniel Schondelmaier)
The LCD technology turned from transmissive TFT LCDs with pixel sizes down to 15 µm to reflective LCOS displays, which can realize pixels smaller than 10 µm with an enormous fill factor of >90%. So, especially the liquid-crystal-on-silicon technology is very promising to deliver displays with high resolution, small pixels, and a high light efficiency. See the panels of the LCoS system LC-R 2500 in Figure 7. There is still the tendency to realize displays with smaller pixels and higher pixel number. The new HDTV standard will bring 2.3 Megapixels soon to the state of the art. But the digital cinema is the mother of all higher resolutions - JVC is proposing a device of 3K x 4K pixels. They're a few public financed projects for higher resolution displays. So, the pixel number will increase up to 5 Megapixel in the next few years.

Figure 7: 0,97" XGA LCoS Display – HoloEye LC-R 2500 System

The micro-structured diffractive elements realize the phase shift by a surface profile in fused silica (see Figure 6).
Since one can make use of the phase modulation properties of the LC material, the SLM is able to act as a addressable phase diffraction grating. This leads to the ability to create a certain set of well defined diffraction patterns in a series. The same approach of chapter 3 becomes one more degree of freedom: time. A two-dimensional detector array, such as a CCD-camera can be calibrated with a static diffractive element, because of the two-dimensional reference laser pattern and the two-

dimensional CCD-array. This is not the case for line scanner cameras, where we loose one degree of freedom. Here, a set of diffraction patterns can determine all the necessary parameters for line scan camera calibration, in terms of global position of the CCD-line and the actual deformation or alignment of the CCD-line.

So, a set of lines generated as diffraction pattern, rotated by the addressable SLM can lead to the coordinates of the principal point of the optical system. The intersections of the CCD-line and the diffraction patterns are known, so the x- and y-coordinates can be determined. A similar procedure leads to the information of the inclination.

The higher the resolution of the SLM device the higher is the resolution of the diffraction pattern. The accuracy of the diffraction order depends only on the exact position of the display pixels, which are fabricated with lithographical exactness.

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