# LOW LIGHT PANORAMIC CAMERA

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## ABSTRACT:

During the last years the department of Optical Information Systems (OS) at the German Aerospace Center (DLR) developed a considerable number of imaging sensor systems for a wide field of applications. Systems with a high geometric and radiometric resolution in dedicated spectral ranges of the electromagnetic spectrum were provided by developing and applying cutting-edge technologies. Designed for photogrammetry and remote sensing, such systems play an important role for photogrammetric tasks. Complete system solutions were implemented considering theoretical framework, hardware design and deployment, overall system tests, calibration, sensor operation and data processing. Outstanding results were achieved with the airborne digital sensor ADS40 and the micro satellite BIRD and its infrared camera payload. In the last years OS invested a lot of work to solve the 2D and 3D 360° panoramic image processing for photogrammetric applications. The simple CCD-line technology in combination with a 360° rotation table is the basis of the full frame panoramic technology. The LLPC principle (Low Light Panoramic Camera) is based on the same 360° rotation table technology in combination with the TDI-line sensors. This kind of sensor technology allows us a programmable SNR of the system. The technology origin is the high resolution satellite imagery. The electronics components are parts of the film scan technology of the DLR. The paper will introduce the new generation of the panoramic camera.

## MOTIVATION

The department Optical Information Systems (OS) of the German Aerospace Center (DLR) has more then six years experiences with the 360° panoramic technology. The used state of the art technology is an RGB CCD line behind a 6 cm standard optics with a 360° rotation table.

Under different environmental and illumination conditions the current technology includes a noise problem in dependency on the imaging time. The user of the system has to install a lot of auxiliary light sources for indoor applications to fulfil the colour and image quality requirements. The installation of the light source for indoor applications causes more work than the panoramic imaging itself. This exactly was the motivation to invest work in the next generation of this technology. The second generation of the panoramic sensor technology should be able to control the sensor parameters in dependency on the light conditions meaning that the sensor should have a possibility to control the SNR. This was the starting point of the LLPC project.

## THE LLPC PRINCIPLE

As you can see from the equation (1), the sensitivity of a quantum detector is direct proportional to the size of the detector area [A] and the integration time [ti]. The goal of the second generation of the panoramic senor as to control the sensitivity in dependency on the illumination conditions has a direct impact on the detector architecture and control.

The equation (1) shows also that the quantum efficiency [PL-number of photons which are reflected] also directly affects the numbers of photons [Nph].

$$N_{ph} = \frac{Pl \cdot A \cdot t_i \cdot \lambda}{h \cdot c} \tag{1}$$

$$s_i = t_i \cdot I_K \cdot \left( \frac{dV}{dN_e} \cdot A_S \right) \cdot \frac{\pi}{4} \cdot \left( \frac{1}{F} \right)^2 \int_{\Delta\lambda} \left( \frac{QE}{E_{ph}(\lambda)} \right) \cdot T_r(\lambda) \cdot Ld(\lambda) d\lambda + D_{Si} \tag{2}$$

The equation (2) gives a model of the relation between all of the parameters which have an influence on the sensitivity and the signal voltage [si]. It can be seen that optics with a lower F-number [F] and a spectral filter [dλ] with larger bandwidth gives a larger signal. The spectral bandwidths of the filters depend on the applications. In addition to these parameters the detector material has a direct effect on the signal. The quantum efficiency [QE] and the factor of the electron to voltage conversion dV/dNe are very important for the SNR of the sensor. What can be seen by the model is that the best case scenario can not fulfil the requirement for a sensitivity control.

The solution of the problem was to use a space borne technology known already more than 20 years. The Time Delay and Integration (TDI) technology allows us to collect more

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photons from the same object. Figure 1 shows the TDI architecture.

The TDI effect reduced the main important noise component - the photon noise by the increased number of photons coming from the sensor architecture and sensor controlling. The numbers of electrons which are generated by photons are moved in the next TDI stage in relation to the rotation table. In that case the next TDI stage will also collect electrons/photons from the same illuminated position. The numbers of TDI stages depend on the detector architecture. Behind the last TDI stage one or more shift registers are transferring the electrons to the output amplifiers.

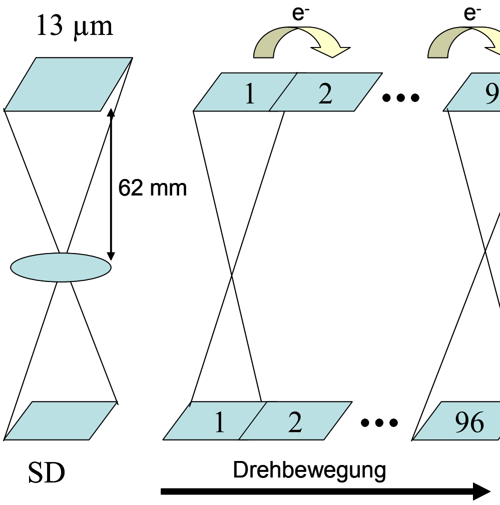

Figure 1 TDI-Principle

Equation (3) shows the influence of the TDI effect of the SNR of the sensor in dependency on the photon noise. It is like a larger aperture or a lower F-Number.

$$Photon\_SNR_{TDI} = Photon\_SNR * \sqrt{Nr\_TDI\_Steps} \tag{3}$$

This kind of technology has a typical problem of the mechanical stabilisation because of the numbers of integration steps (TDI-stages) of electrons in relation to the viewing position which generate a main mechanical accuracy requirement. Sometimes it makes sense to use this kind of technology for high speed applications because the mechanical system could be much more stable. Nevertheless, the mechanical stabilisation and the accuracy of the sensor controlling give an additional MTF component (see equation 4)

$$MFT = MTF_{Optics} * MTF_{Pixel} * MTF_{Chanel} * MTF_{smear[TDI]} . \tag{4}$$

The disadvantage of the mechanical stabilisation of the TDI technology is compensated by the advantage of the higher sensitivity. The better contrast of the image objects helps not only to reduce the noise of the image but helps also to increase the geometrical resolution. The relation between the radiometry and the geometry is given by the Rayleigh-Criterium (5).
The Rayleigh- Criteria gives a mathematical model when two objects could be discriminated from each other.

$$K_{\min} = \frac{MAX\{I\} - MIN\{I\}}{MAX\{I\}} = 25\% \tag{5}$$

The minimum contrast to be identified between two objects is described by the Rayleigh-equation. Therefore for the new generation of the panoramic camera, the Rayleigh-equation is the most important criteria to control the sensor. .

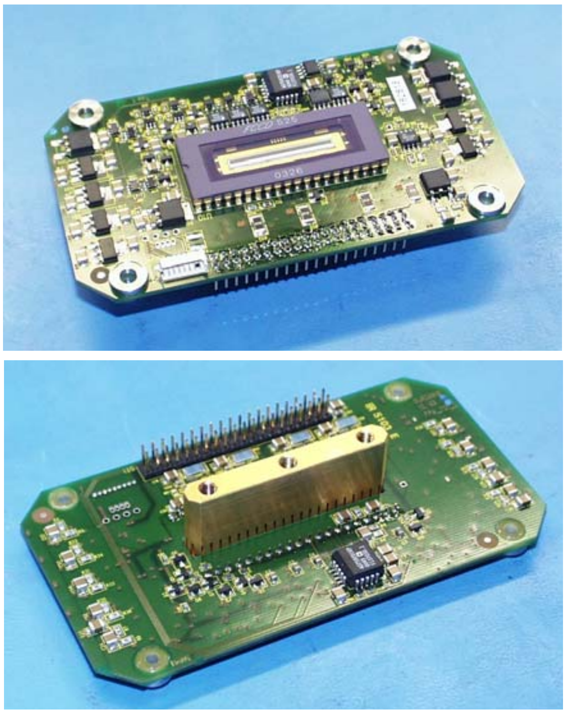

Figure 2 Focal Plate Module of the LLPC with 2k TDI line

## TECHNICAL CONCEPT

The imaging technology of the LLPC bases on a 360° rotation table using a vertical TDI-CCD line detector. The spectral information for the red, green, blue and NIR channels will be generated by a beam splitter with a viewing angle of 30°.
The concept is based on the optics and beam splitter component, the filters, the focal plate with electronics and the rotation table. Two spectral channels are using the same front end electronics. The front end electronics is directed via fibre optics and connected with the 64 Bit control PC for the camera control and data archiving.

## SENSOR

The heart of the LLPC is the focal plate module with the TDI sensor line of the Fairchild Company which was developed for

space borne applications. Figure 2 shows the 2k TDI-CCD-line from Fairchild with the complete focal plate module. This module includes the TDI sensor and the detector electronics.
The thermal interface of the Sensor is shown on the back side of the module. This interface is also used for the mechanical alignment and optical positioning of the sensor. The expected thermal conditions of the module in the typical environment of the camera system allows a passive cooling concept of the module. The additional thermal heat of the detector electronics will be also passive cooled by a heat sink of the housing.

## OPTICS

For the LLPC project, a special telecentric lens with beam splitter was developed. The electromagnetic input spectrum will be splitted in red, green, blue and NIR. Each of the separated spectral channels is equipped with a focal plate module.

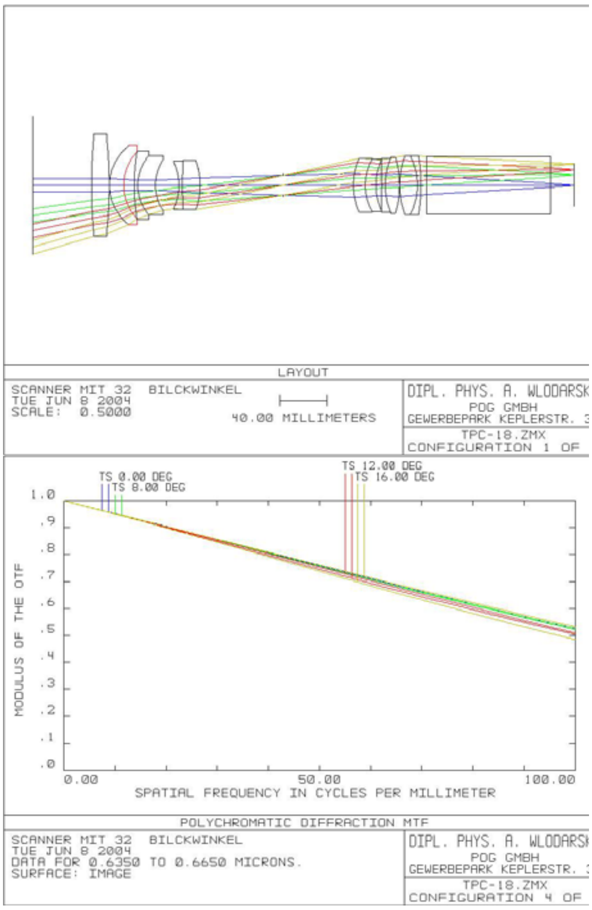

Figure. 3 LLPC-Optics design (Lay-Out and MTF for the red channel)

The design is shown in figure 3. One of the main design requirements was the low distortion over the different spectral bands and the chromatic focus for the mechanical pixel match of the focal plate modules. In that case the whole glass thickness of the beam splitter must be included in the optical design. The beam splitter concept is based on a classical Prismensynopter design. That means that the optical path through the prism will be divided in two 90° separated outputs. That allows us to split the incoming beam in four different parts.
The complex optics design with 12 lenses works nearly at the technological edge. The first measurements on the prototype of the optics in combination with the beam splitter are showing the quality of the design.

Figure 4 shows the MTF of the optics with a PSF measurement.

## MECHANICS

The main task of the mechanical structure of the optics and beam splitter design is the mechanical matching of the different spectral information. This design requirement can only be achieved by mechanical adjustment of each focal plate module by six degrees of freedom. After the prototyping and verification of the system the complexity could be reduced.

Figure 5 shows the optics and beam splitter alignment with the four focal plate module components. Inside the Housing you can see the beam splitter.

## CAMERA ELECTRONICS

The camera electronics beginning from the front end electronics over the AD-conversion up to the digital interface is mounted in one electronics box for two channels. The four-channel system is based on a two-box structure. Each of them has two flexible PCB’s to connect the focal plate modules. The electronics box includes one AD-board (FEE) and one interface board which is direct connected to a 64 Bit PCI frame grabber in a server PC.
The control PC initialised the scanning head and is responsible for the real time data storage. Figure 6 shows the electronics components.

The electronics of the LLPC is able to correct each systematic error in real time. The effects coming from the optics and sensor like dark signal non-uniformity, as well as the photo response non-uniformity are the first calculations at the digital processing.
After the real time RGB processing 48 TIF images will be generated. All auxiliary information of the images will be stored at the TIF header.

## SYSTEM SPECIFICATIONS

Table 1 shows the main important parameters of the system

| | |
|---|---|
| Focal length | 62 mm / F 5,6 |
| Pixel size | 13 µm |
| TDI CCD line | 2048 pixel |
| Programmable TDI steps | 24, 48, 64, 96 |
| Dynamic range | 14 bit |
| Radiometric resolution | 14 bit |
| TDI Line Rate [max] | 39.000 lines / s |
| Spectral channels<br>• Red<br>• Green<br>• Blue<br>• Near Infrared | <br>620 - 700 nm<br>510 - 560 nm<br>400 - 500 nm<br>780 - 1200 nm |

Table 1 Specification of the LLPC

## CONCLUSION NEXT STEPS

The conclusion of the paper is that the TDI technology allows us to fulfil the requirement to fit the SNR to the illumination conditions. Outside of buildings the LLPC can be operated with a very high frame rate of the 360° images under low light conditions.

The advantage of the concept is that all optical and electronic components are optimised for the LLPC to reduce the geometrical and radiometric errors. One of the important issues is the calibration of the four different focal plate modules.

The advantage of the higher SNR and contrast is one of the outstanding features of the LLPC.

Currently, the calibration and the stability test of the calibration parameters of the sensor are performed. The option of the programmable sensitivity of the sensor in relation to the illumination will be tested in the next couple of days.

After the validation of the system, a first project will be planned in June this year.

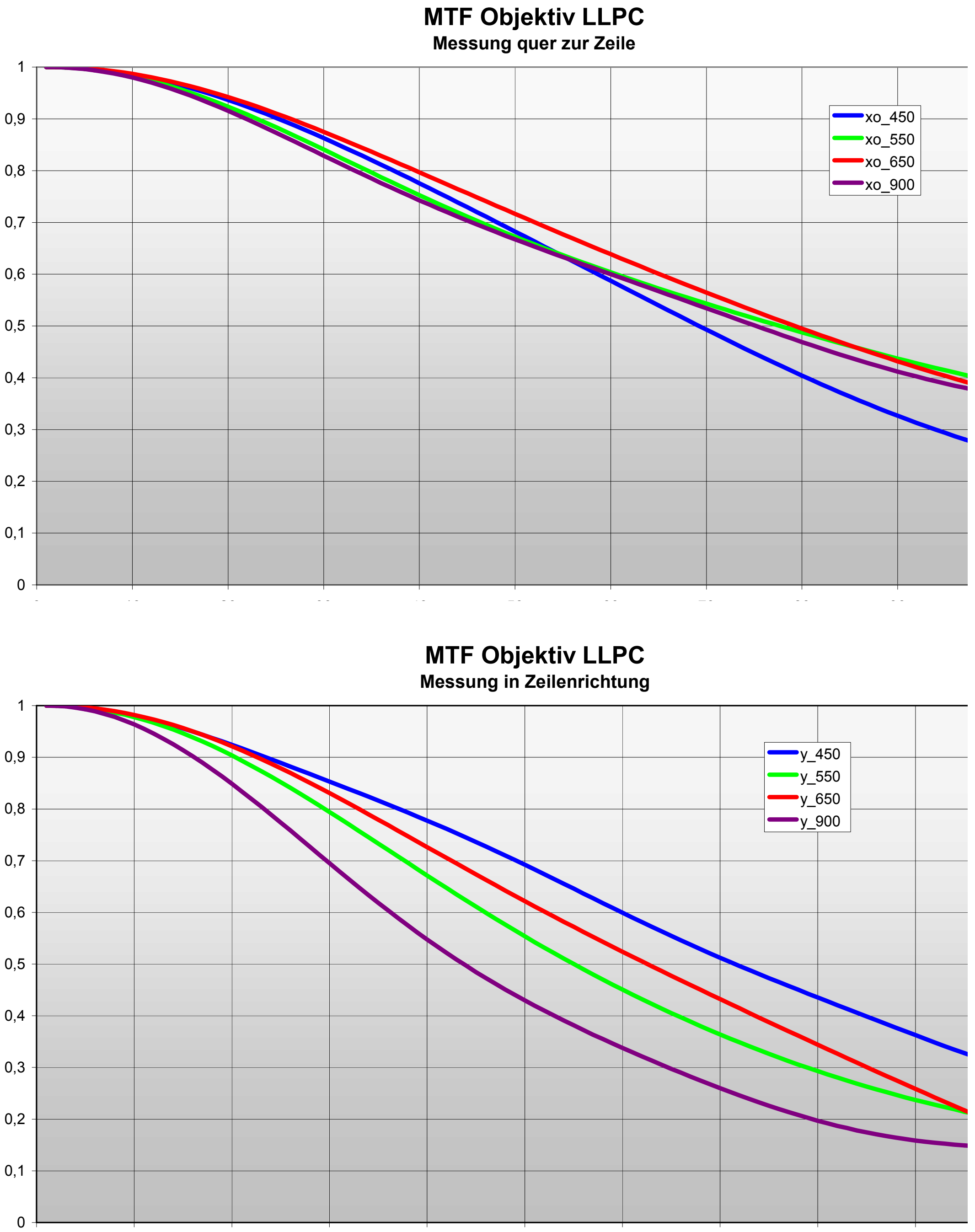

Figure 4 MTF of the Optics of the LLPC Prototype

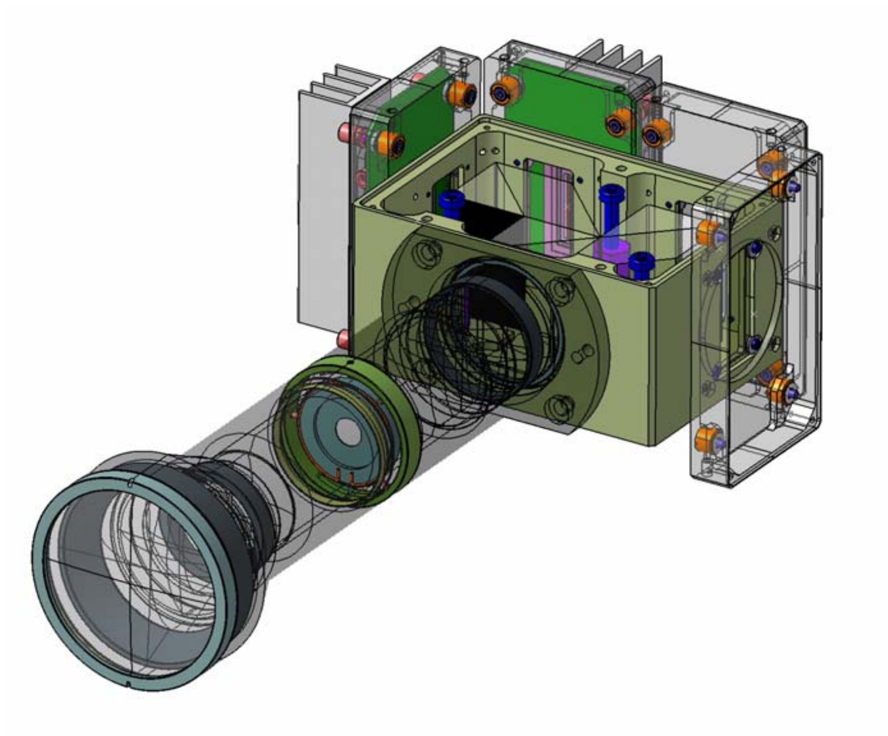

Figure 5 LLPC- Scanning Head

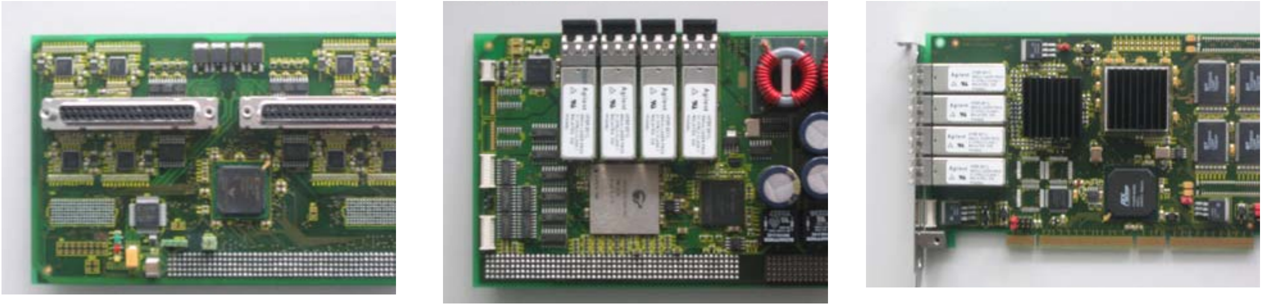

Figure 6 LLPC Electronics Components AD-Board, Interface-board und 64Bit Frame-Grabber

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