The new CMOS Tracking Camera used at the Zimmerwald observatory

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Tracking Cameras

- During the last years the use of tracking cameras for SLR observations became less important due to the high accuracy of the predicted orbits.
- Upcoming new targets like satellites in eccentric orbits and space debris objects, however, require tracking cameras again.
- Since a few months the interline CCD camera was replaced at the Zimmerwald Observatory with a so called scientific CMOS camera. This technology promises a better performance for this application than all kind of CCD cameras.
- After the comparison of the different technologies the focus will be on the integration in the Zimmerwald SLR system.
Zimmerwald Observatory
ZIMLAT – Zimmerwald Laser and Astronometry Telescope

- 1–m Ritchey Chrétien
- Altazimuth mount
- Derotator platform
- Dual use
  - SLR
  - Optical Obs.

- Nd:YAG Laser
- 1064 nm / 532 nm
- 90 – 110 Hz
- 58 ps Pulselength
- 9 mJ @ 532 nm
Derotator Platform

- Dichroic Mirror (DBS) allows for the use of tracking cameras simultaneously with SLR observations.
- Derotator Mirror (DM) allows for the use of 4 Corrector Lenses and cameras.
- Focal length varies between 1 m, 4 m and 8 m.
- 2 Tracking cameras
  - sCMOS: ≈10’ FOV
  - CCD: ≈30’ FOV
ANDOR NEO sCMOS Camera
SPECTRAL INSTRUMENTS CCD Camera
At the output amplifier(s) the photoelectrons are counted.

- **CCD**: photoelectrons of all pixels are counted in the same amplifier
- **CMOS**: number of amplifiers \(\Delta\) number of pixels
  - On-chip binning and on-chip stacking for increasing the sensitivity is not possible
  - Individual readnoise for each pixel
All photoelectrons are counted in the same output amplifier

- Interline CCD: every second column of the sensor is masked for storage
  - fill factor of the image area is dropped by a factor of 2
  - quantum efficiency is dropped by an equivalent amount
  - microlenses on the surface direct light away from the opaque region
  - no mechanical shutter necessary
  - shutter times less than a microsecond are possible
Read Noise Andor NEO

Distribution of the signal levels of two individual pixels / entire sensor

- The read noise varies considerably from pixel to pixel
- Some pixels show a double peaked distribution
- No Gaussian distribution of the read noise
- Read noise specification between CCD (mean value) and CMOS (median value) not comparable!
## Full-Frame CCD vs. Interline CCD vs. CMOS

<table>
<thead>
<tr>
<th></th>
<th>FF-CCD</th>
<th>IL-CCD</th>
<th>CMOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array Size</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>QE</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fast Exp.</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Readout Time</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>Binning</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Stacking</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Readnoise</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>PRNU</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
</tr>
</tbody>
</table>
## Camera specifications

<table>
<thead>
<tr>
<th></th>
<th>Full-frame CCD</th>
<th>Interline CCD</th>
<th>CMOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory</td>
<td>Spectral Instr.</td>
<td>PCO</td>
<td>Andor</td>
</tr>
<tr>
<td>Model</td>
<td>SI1100</td>
<td>Sensicam SVGA</td>
<td>NEO</td>
</tr>
<tr>
<td>Array Size (mm)</td>
<td>31 x 31</td>
<td>9 x 7</td>
<td>17 x 14</td>
</tr>
<tr>
<td>Number of Pixels</td>
<td>2048 x 2064</td>
<td>1280 x 1024</td>
<td>2560 x 2160</td>
</tr>
<tr>
<td>Pixel Size (µm)</td>
<td>15</td>
<td>6.7</td>
<td>5.5</td>
</tr>
<tr>
<td>Quantum Eff.</td>
<td>95 %</td>
<td>40 %</td>
<td>60 %</td>
</tr>
<tr>
<td>Full Well Cap.</td>
<td>150 000 e¯</td>
<td>25 000 e¯</td>
<td>30 000 e¯</td>
</tr>
<tr>
<td>Scan Rate</td>
<td>4 x 1 MHz</td>
<td>1 x 12.5 MHz</td>
<td>2 x 280 MHz</td>
</tr>
<tr>
<td>Readout Freq.</td>
<td>1 fps</td>
<td>8 fps</td>
<td>100 fps</td>
</tr>
<tr>
<td>Readout Noise</td>
<td>8 e¯</td>
<td>8 e¯</td>
<td>2 e¯</td>
</tr>
<tr>
<td>Cooling</td>
<td>Peltier / water</td>
<td>Peltier / air</td>
<td>Peltier / water,air</td>
</tr>
</tbody>
</table>
Concept of the CMOS Camera Integration

- Nd:YAG Laser with a pulse rate between 90 – 110 Hz
- The sensor will be exposed between the transmitted laser pulses.
- It is not possible to make use of the full time span of about 10 ms for chip exposure due to fluorescence effects in the dichroic mirror after transmitting a laser pulse.
Realization of the CMOS Camera Integration

- The FPGA card, responsible for the timing of the laser, transmits a pre-pulse with variable delay and pulse width.
- This pulse can be used for triggering the exposure of the camera and for controlling the exposure time.
Current Status of Work

• Mechanical and electrical integration of the tracking camera in our laser system has been completed
• First tests during some satellite passes have been carried out successfully
• The CMOS camera was used already during the ‘bistatic’ experiment in video mode (no triggering of the individual exposures) for the pointing correction of the telescope
• During above tests some problems have been identified that prevent to use the camera on a routine basis:
  • GUI is not user friendly
    • Default settings cannot be stored (more than 40 modes of operation available)
    • No continuous acquisition mode available
    • Contrast and brightness of the displayed images not flexible enough
    • No cross hairs available
    • Unknown rotation of the image w.r.t. zenith resp. moving direction of the satellite
  • No Autofocus function available
  • Point of highest echo rate is not stable on the image
Ajisai – No accumulation
Ajisai – accumulation of 10 images

Fixed-pattern noise
Glonass 107 – No accumulation
Glonass 107 – accumulation of 10 images

Fixed-pattern noise
Hy2A – No accumulation
Hy2A – Laser pulses
Saral – accumulation of 10 images