Calibrated High-Resolution Multi-Sensor Cameras for Image-Based 3D Reconstruction

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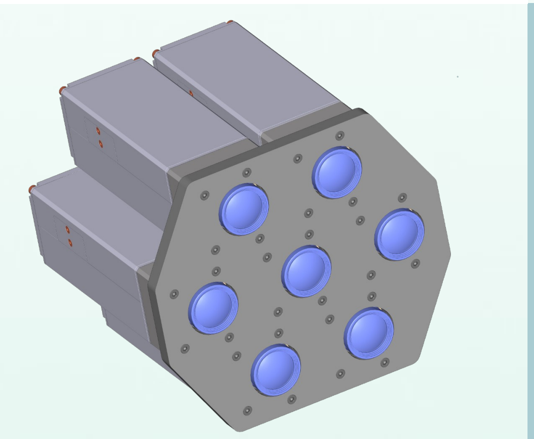
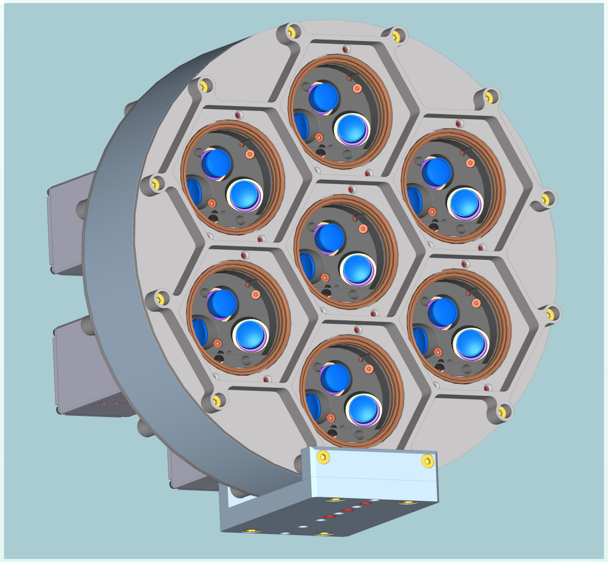
Multisensor cameras – why multisensor?

- Scalability in resolution
- Technology perfected by high volume applications (cellphones)
- Parallax – a handicap of the tiled arrays can be used for 3d capture
- Synthesized DoF
- HDR with heterogeneous sensors and optics

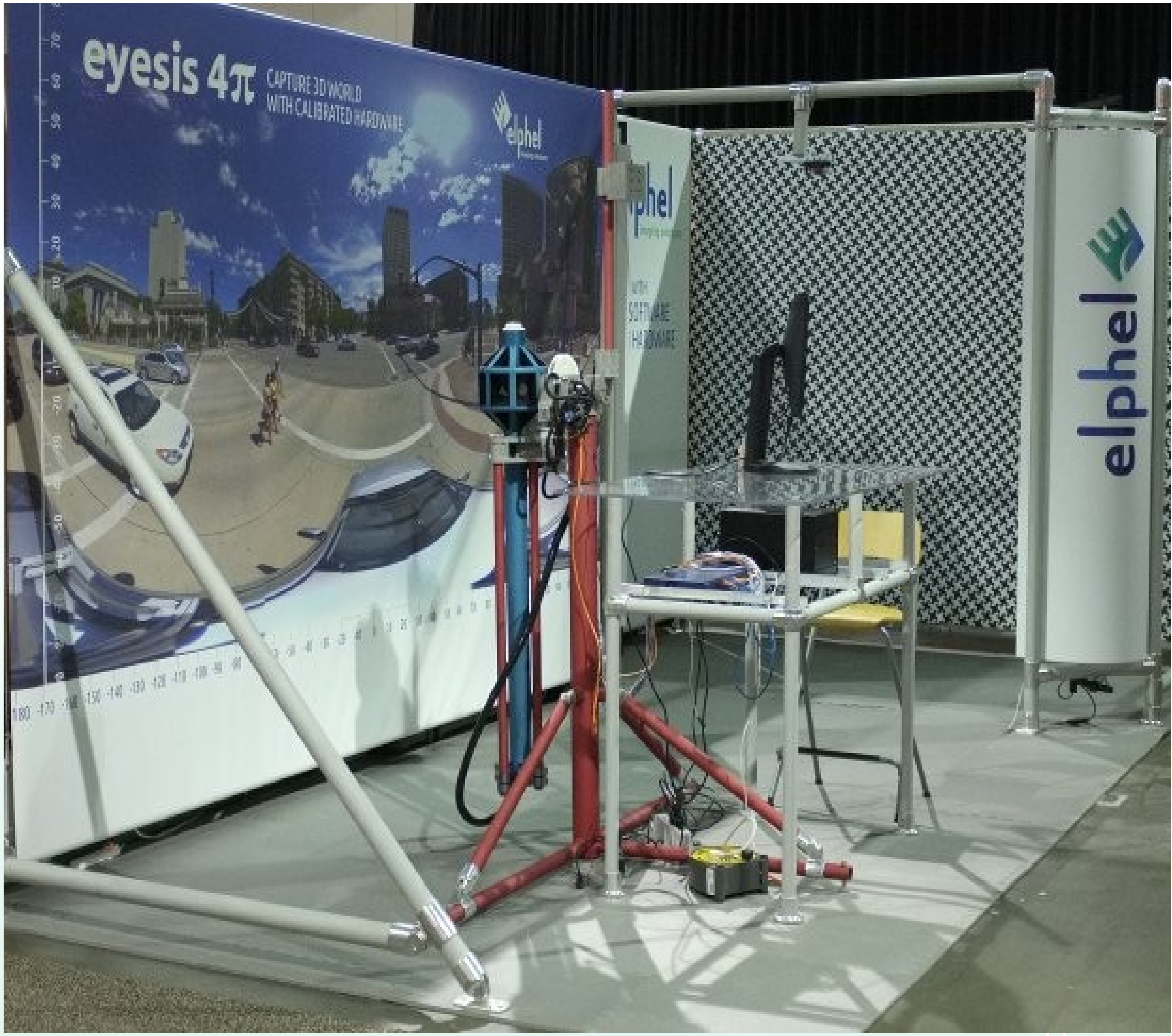




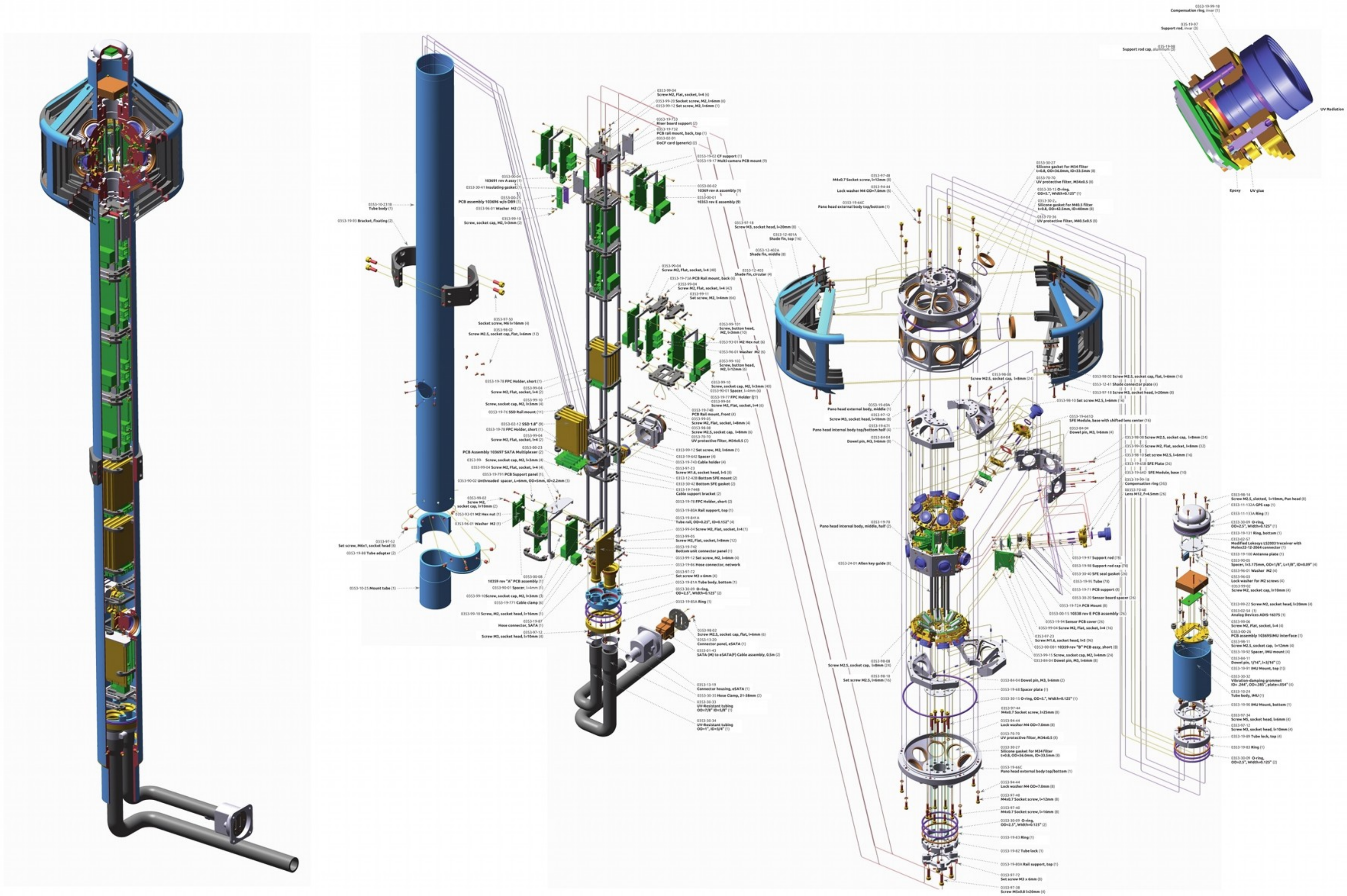
Eyesis 4π
26 sensor panoramic photogrammetric camera

- 4π (360x180) coverage
- 64 MPix after stitching
- Calibrated fixed lenses to compensate for the distortions and aberrations:
  10" (0.1 pix) in center 80% x 80% are
  30" (0.3 pix) max. error over the full FoV
  <0.03um/° thermal expansion

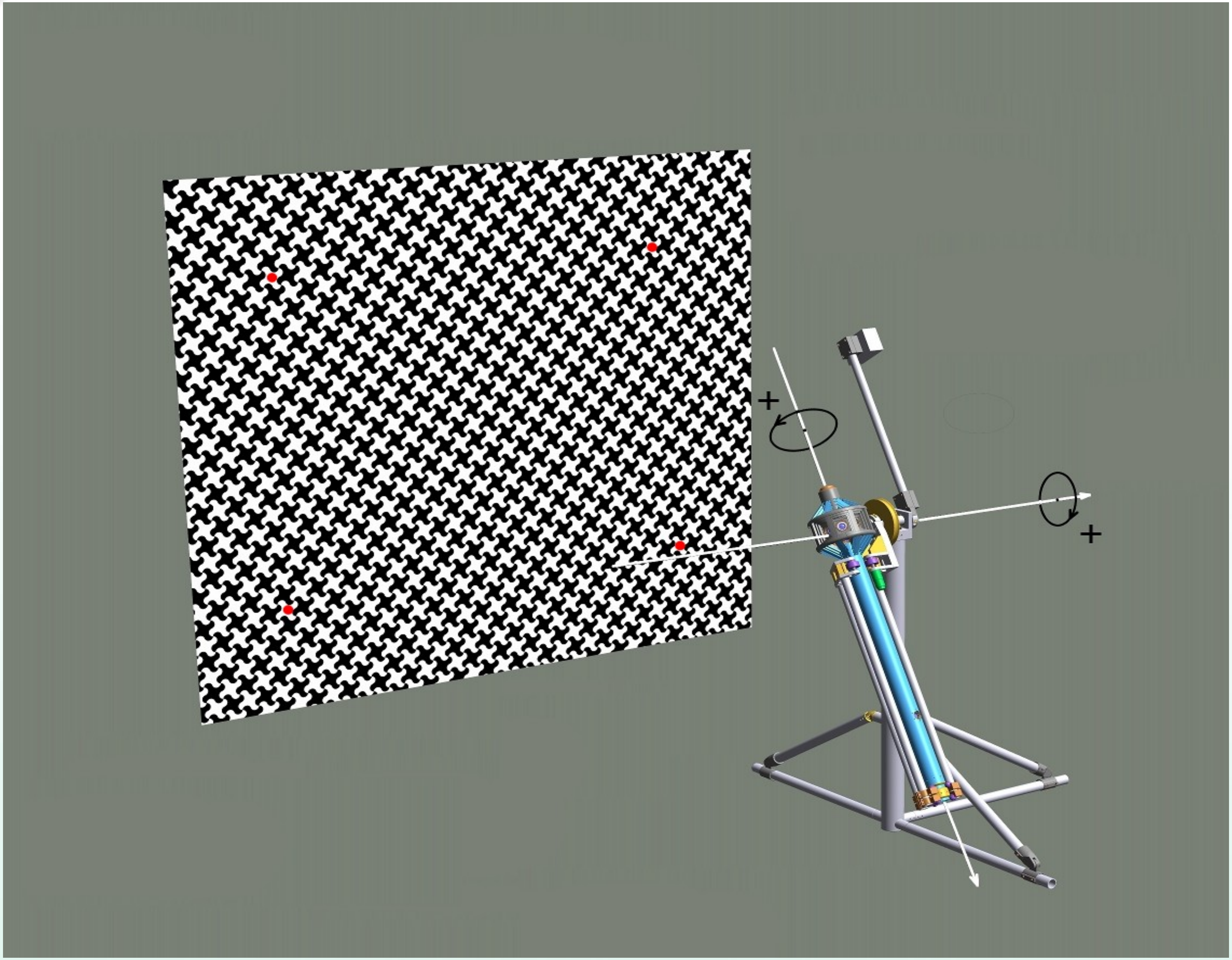
- Up to 5 FPS frame rate
- Integrated high-precision IMU and GPS
- Recording to internal SSDs
- Web Based GUI
- Free Software and Open Hardware



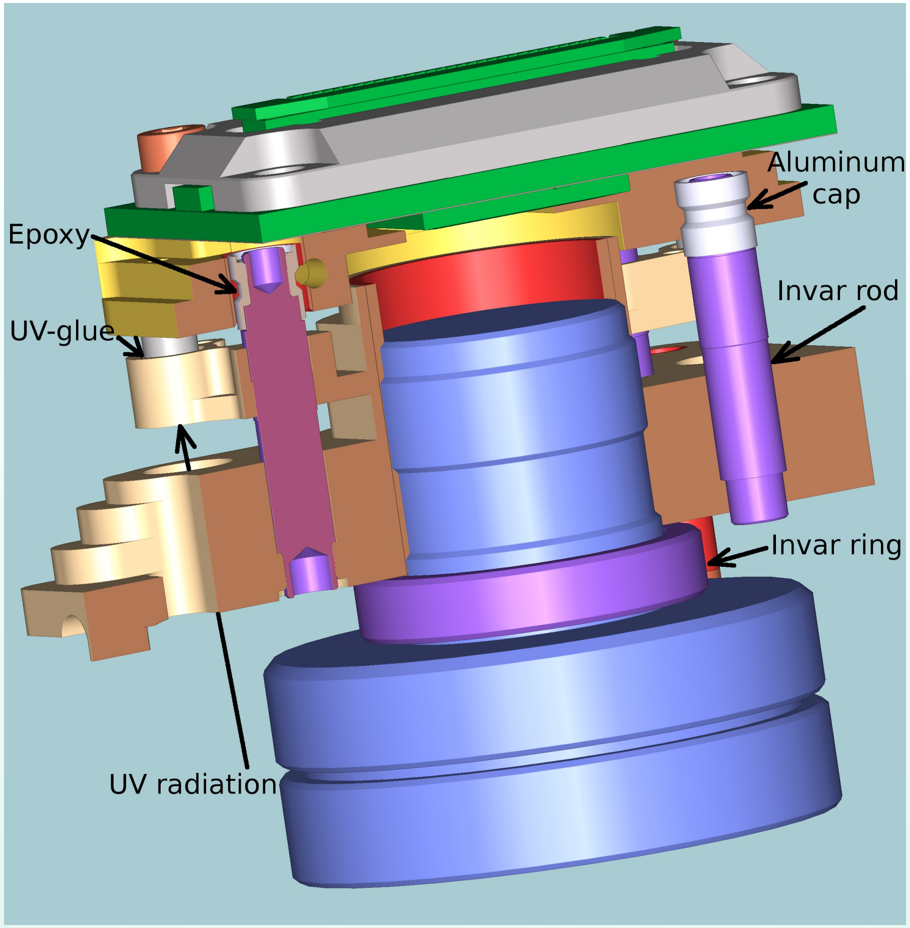
eyesis 4π ASSEMBLY DRAWING



Calibration setup



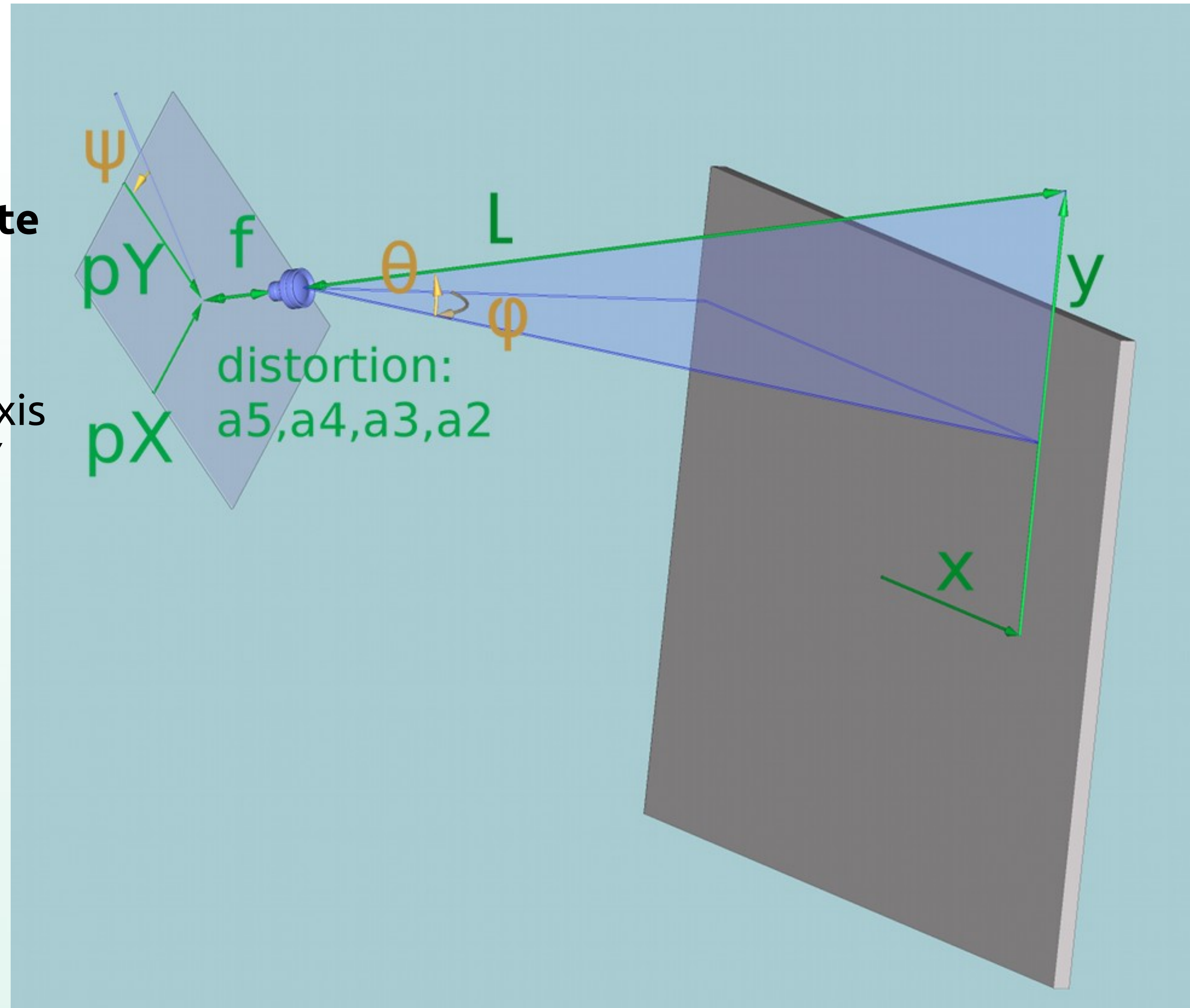
Thermally compensated Sensor-Lens Module



Individual sensor front end (SFE) parameters (13)

6 extrinsic SFE parameters (relative to the target coordinate system):
- **X** – lens axis on target plane X
- **Y** – lens axis on target plane Y
- **L** – distance from target along axis
- **φ**– axis rotation around target Y
- **θ** – axis elevation from XZ plane
- **ψ** - camera roll around lens axis

7 intrinsic SFE parameters:
- **f** – lens focal length
- **pX** – pixel X of the lens axis
- **pY** – pixel Y of the lens axis
- **a2..a5** - four radial distortion model polynomial coefficients

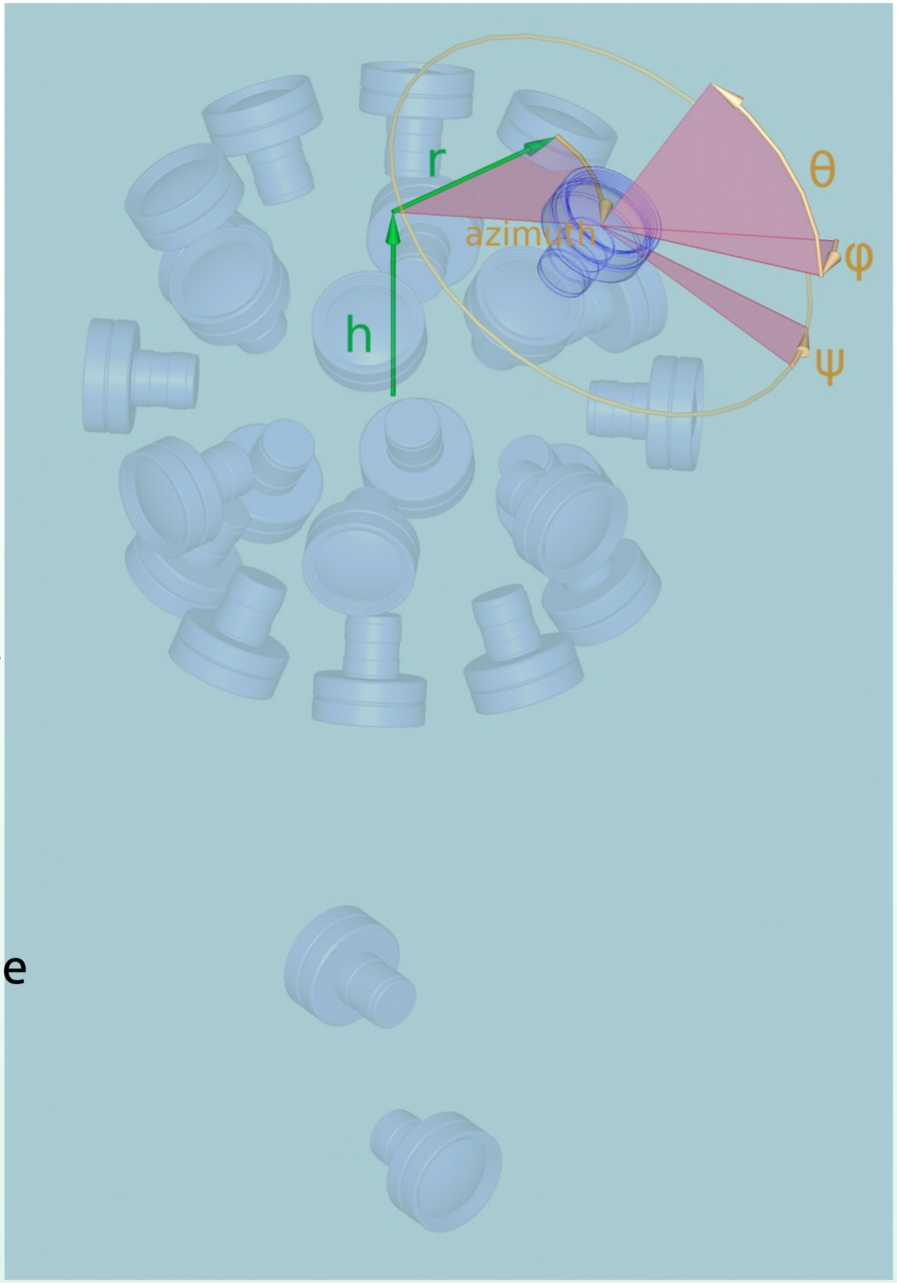


Sensor front end (SFE) location relative to the camera coordinate system

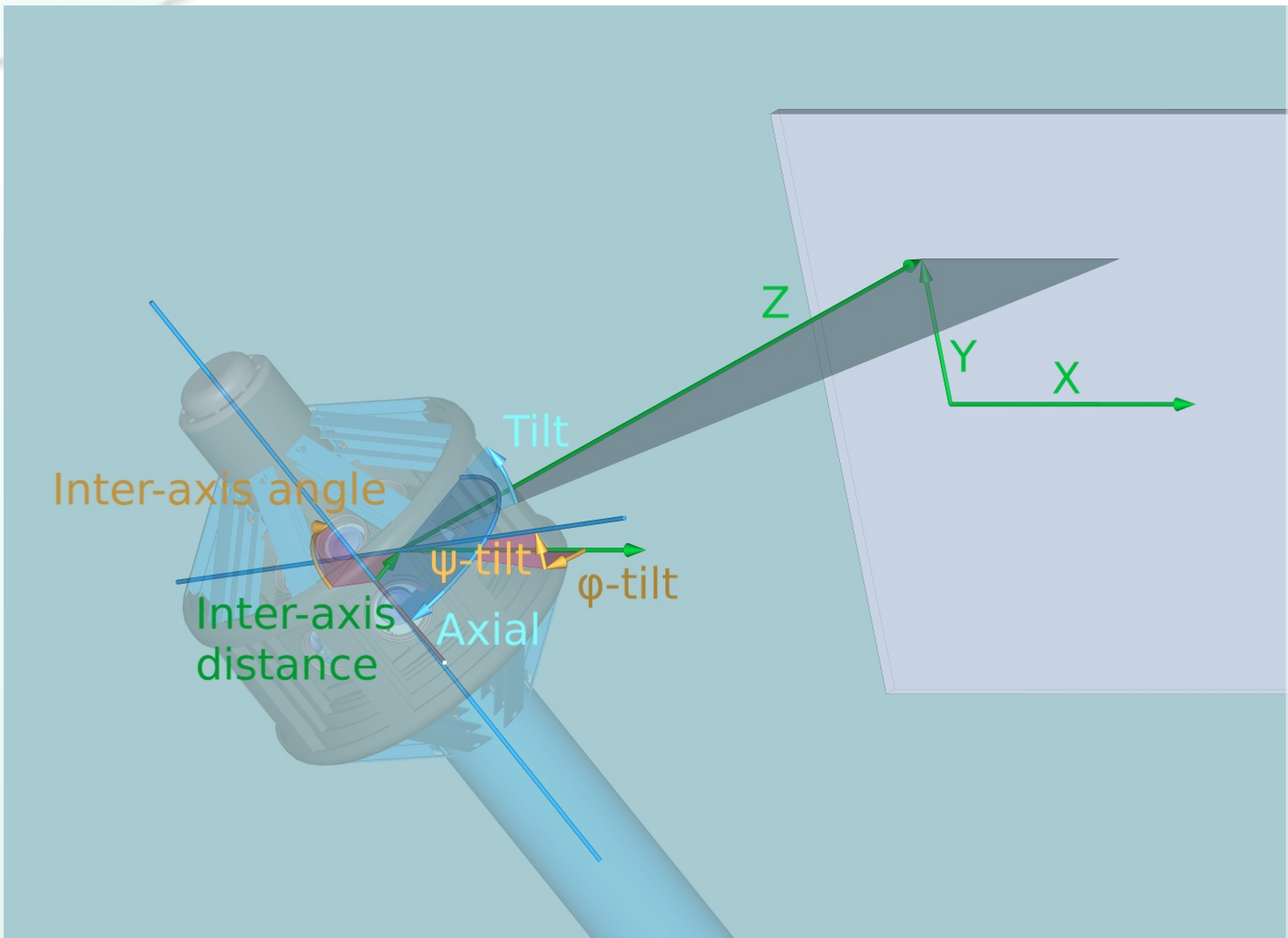
Camera has rotational symmetry around the vertical axis so cylindrical coordinates are convenient

•**h** – SFE (lens center) height from the camera center
•**r** –SFE distance from the camera vertical axis
•**azimuth** – SFE angular position
•**φ**– SFE optical axis rotation around the vertical camera axis from directly outwards
•**θ** – SFE optical axis elevation from the plane perpendicular to the camera axis
•**Ψ** – SFE roll angle

Total (6+7)*26-6=332 parameters to describe the composite camera



Parameters of the camera calibration machine



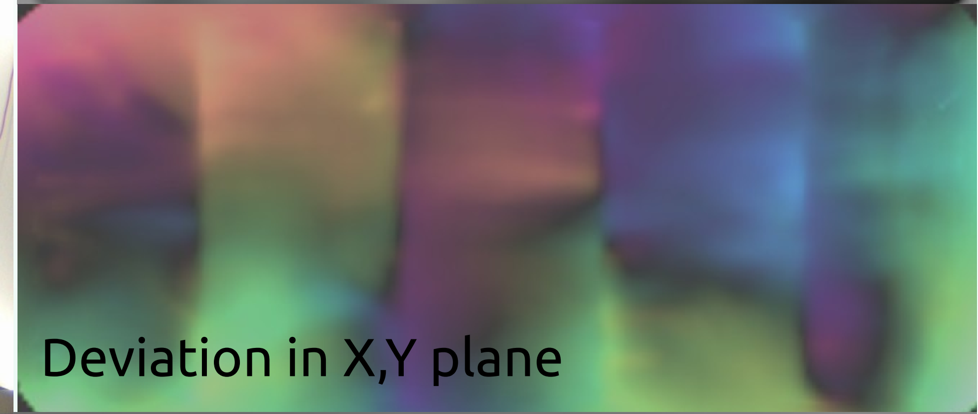
Camera parameters (9):
constant for each station (7):
X – camera center X
Y – camera center Y
Z – camera center Z
•**φ-tilt** – angle between the horizontal camera rotation axis and target X around target Y
•**Ψ** – angle between the horizontal camera rotation axis and target X around target Z
•**inter-axis distance** between rotational axes
•**inter-axis angle** between rotational axes
variable (2):
•**tilt** – rotation around horizontal axis
•**axial** – rotation around camera axis

Calibration procedure

•**Acquire image sets** from 3 different stations so each channel FOV is covered by the target pattern with 50% overlap (~400 sets from 7m distance and 150 sets from each of the “right” and “left” stations at 3 m from the target), recording the locations of visible subsets of 4 controlled laser pointers.
•**Process raw images**: identify pattern grid on the images, discard images with no grid; **extract grid nodes x,y pairs**; verify/filter detected pointers.
•**Run Levenberg-Marquardt algorithm (LMA) with default intrinsic parameters**, default pattern geomery, camera position common for each station and individual set orientation using only images with 2 or more matched pointers, remove outlayer images (if any).
•**Repeat LMA allowing intrinsic parameters adjustment,** calculate pattern correction (if uncalibrated pattern was used).
•**Add more images:** first with a single pointer, later with no pointers if the camera orientation can be determined by another channels, remove outlayers (mis-identified grids) and re-run LMA - about 1500-2500 parameters, 2500-4000 images (5-10 millions X/Y pairs).
•Freeze lens distortion parameters and **calculate residual X/Y distortion correction over the FOV**
•**Allow minor movements of the camera** caused by the building floor vibrations, adjusting the goal function that simultaneously minimizes assumed movements.

*Achieved reprojection errors RMS with only radial distortion model – **0.3 pix**, with additional distortion correction – **0.12 pix**, accounted for the floor vibrations – **0.06 – 0.08 pix***

Properties of the Target Pattern



Reprojection error remaining after the radial distortion model

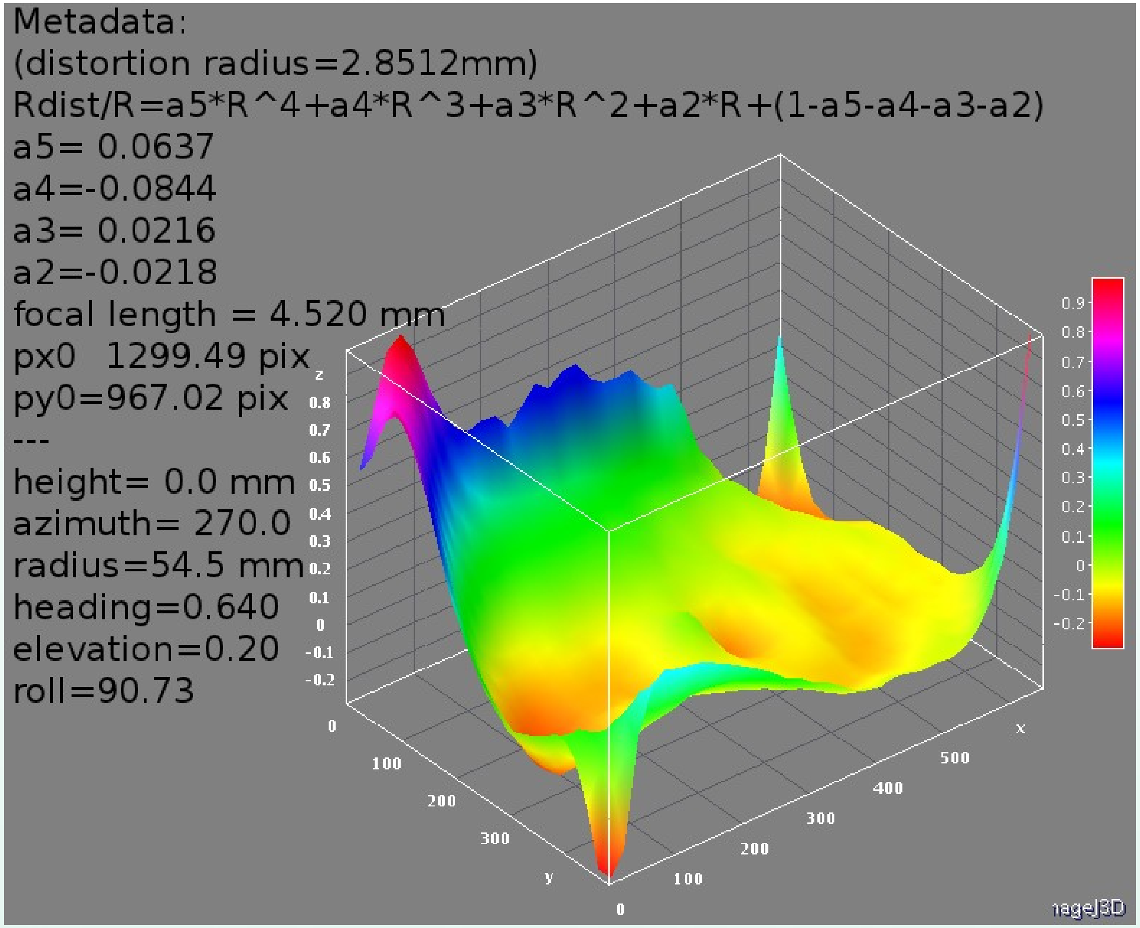
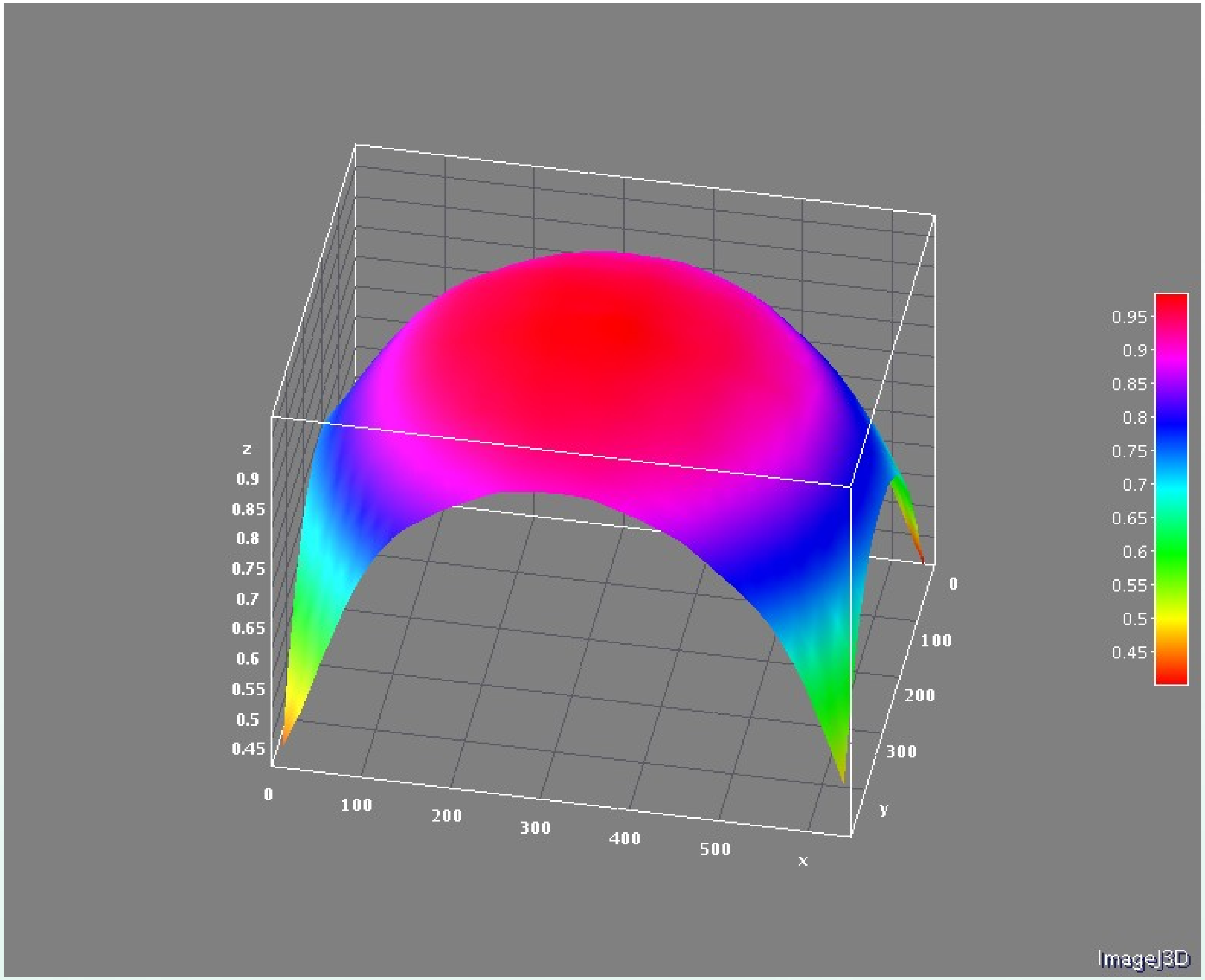
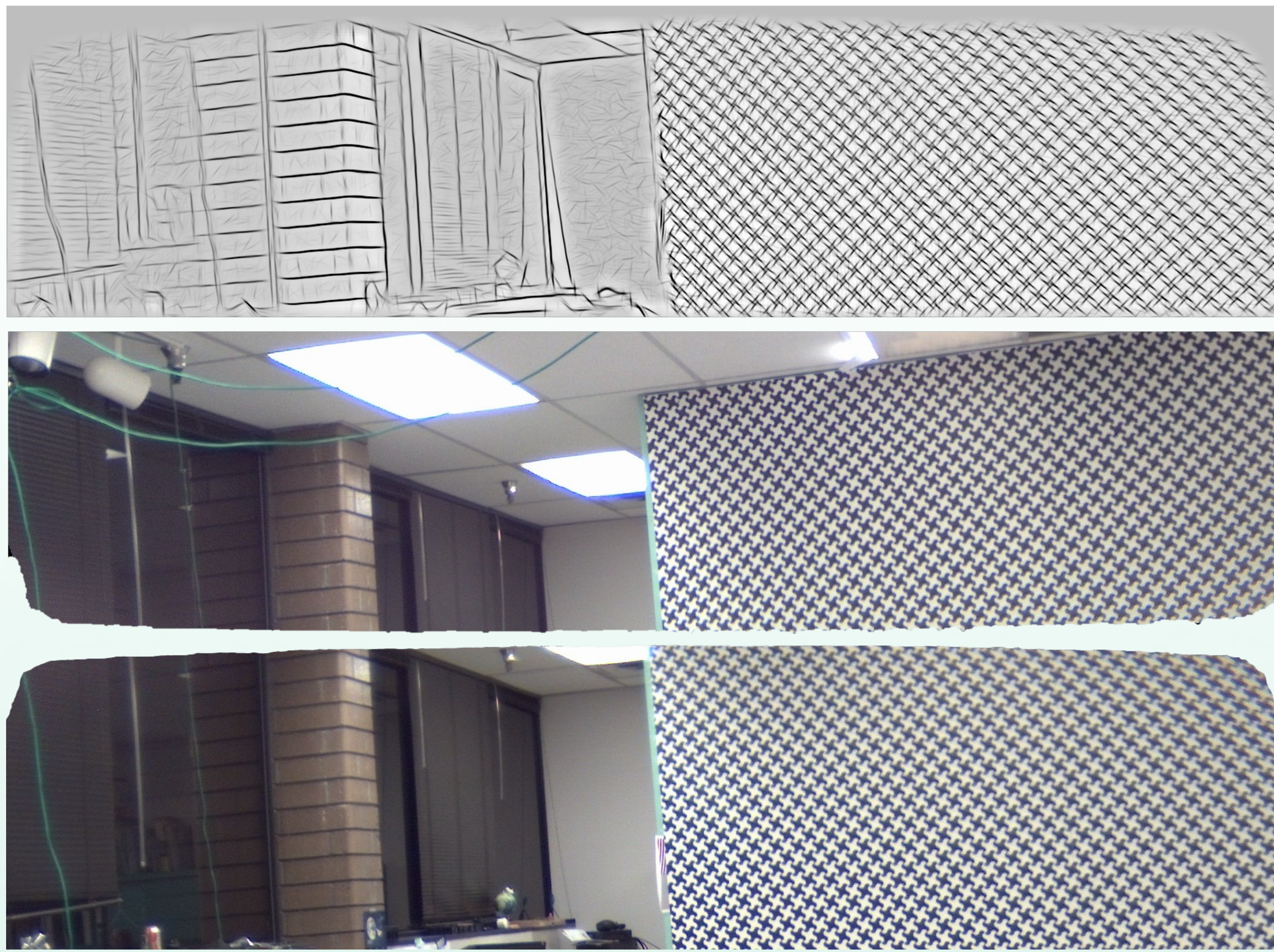


Image vignetting measured for green channel

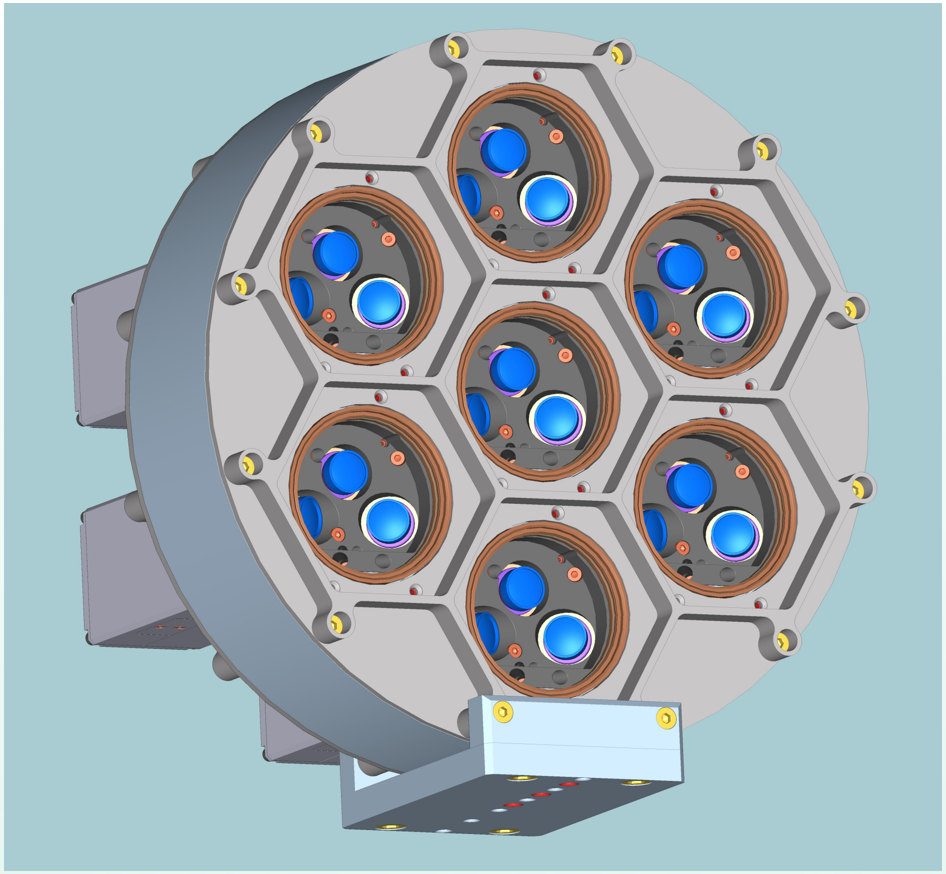


Overlapping view areas of the 2 subcameras and frequency-domain linear features extraction



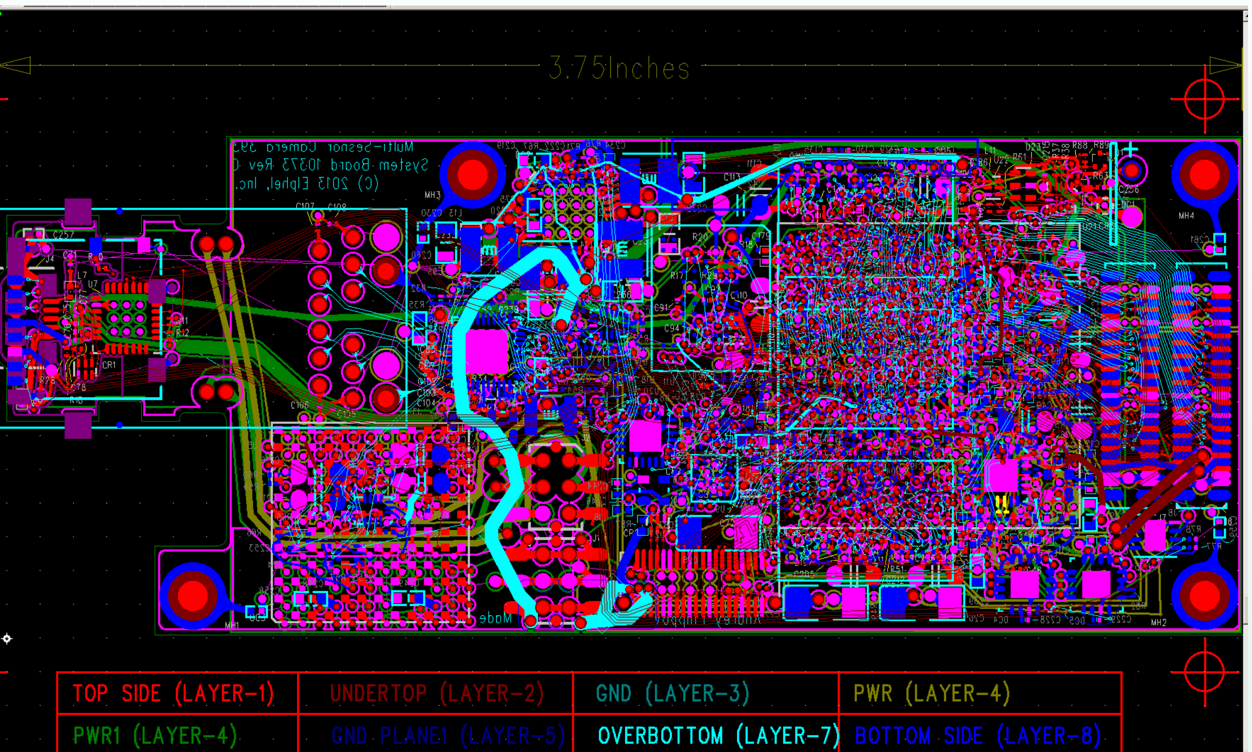
Multi-camera setups

3 sensors, overlapping FOV



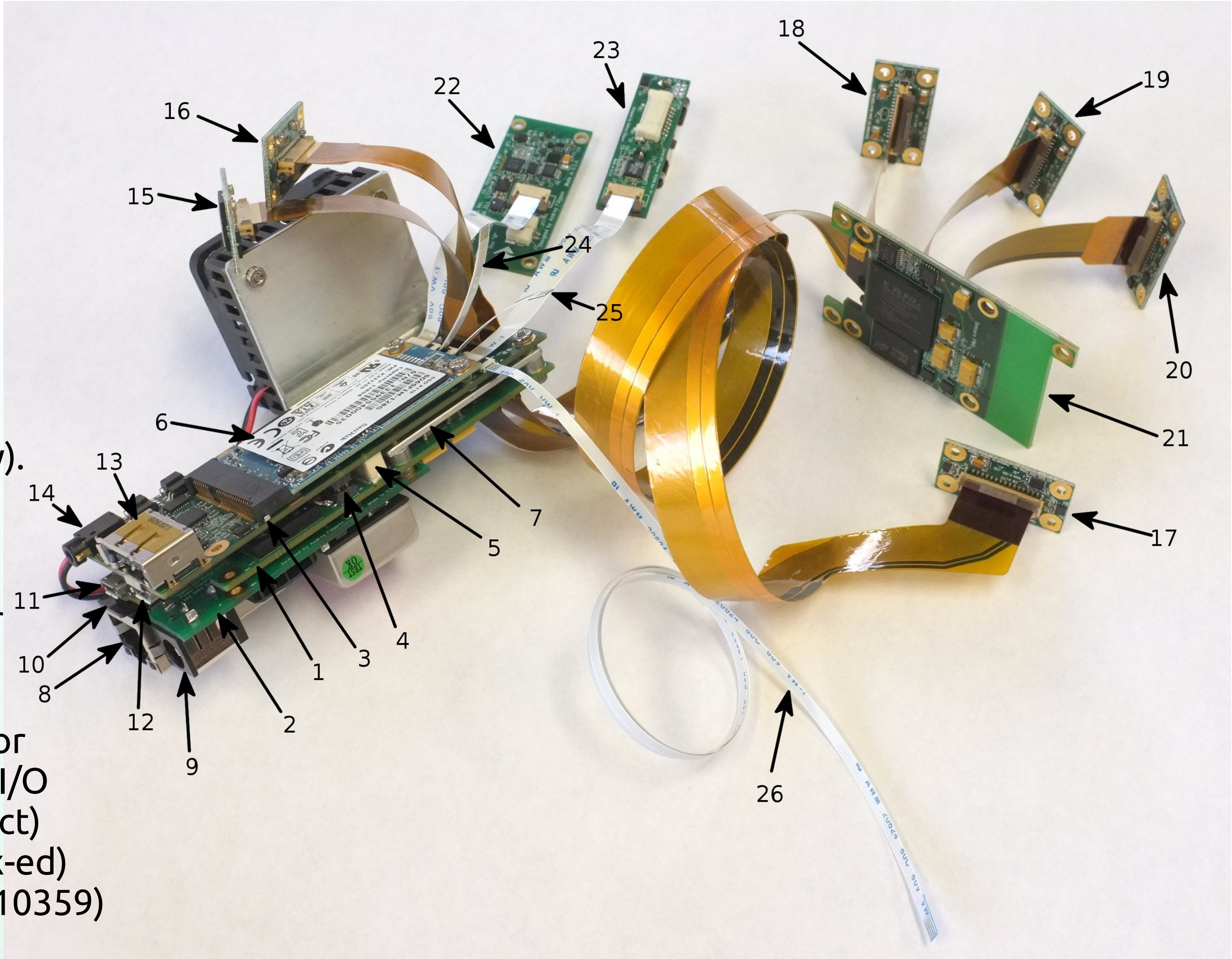
7 overlapping groups of 3 sensors with tiled FOV

NC393 Multisensor Camera



- 4 sensor ports: parallel or 8-lane (plus clock) serial differential
- With multiplexer – up to 12 sensors
- Xilinx Zinq SoC – dual core ARM with high performance FPGA
- 1GB DDR3 system memory
- 512 MB DDR3 dedicated to FPGA
- Dual 512 MB NAND flash/MMC boot
- GigE, mSATA SSD, eSATA, multiport USB2 host, separate inter-board and inter-camera synchronization I/O
- Aplications: multi-sensor camera arrays

NC393 camera sample configuration with existent modules



1) Camera system board (10393)
2) Power supply board (10385)
3) Interface board (10389)
4) Power distribution connector
5) Inter-board signal connector
6) mSATA SSD card
7) Processor heat sink (temporary).
8) Ethernet (GigE) port
9) DC power input
10) Memory card
11) Micro USB B device connector for system serial console
12) Micro USB A host connector
13) USB A/eSATA combo connector
14) Inter-camera synchronization I/O
15,16,17) Sensor front ends (direct)
18,19,20) Sensor front ends (mux-ed)
21) Sensor multiplexer/memory (10359)
22) IMU adapter board (103695)
23) Serial GPS adapter board (103696)
24,25,26) Inter-module synchronization