3D Perception for Robotics

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Joseph Schornak
Research Engineer
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Southwest Research Institute

- An independent, non-profit applied R&D organization founded in 1946.
- 2,600 staff across 11 technical divisions located on a 1,200-acre campus.

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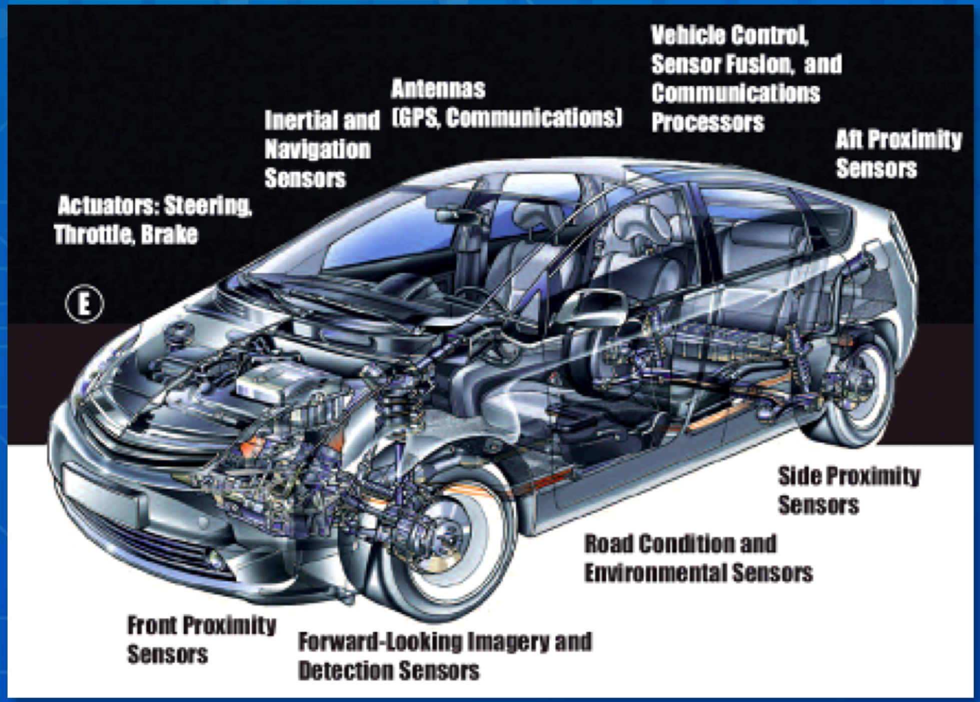
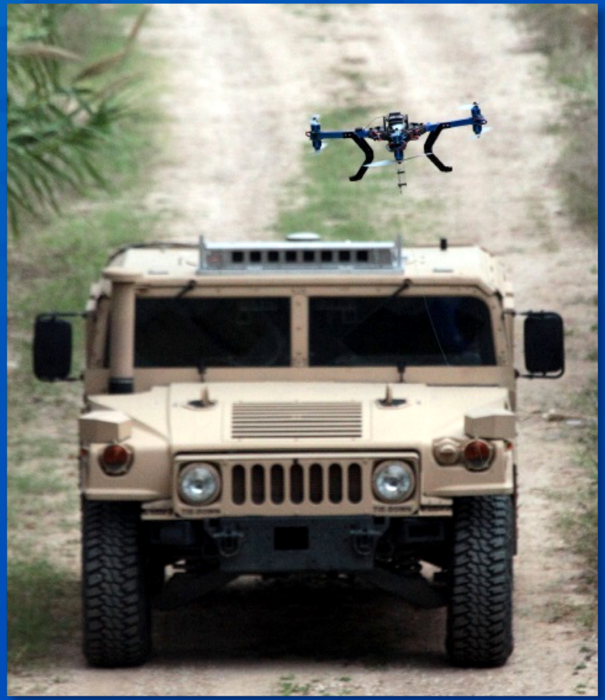
Intelligent Systems Division

- Autonomous vehicles
- High-reliability systems
- Traffic management systems
- Industrial automation





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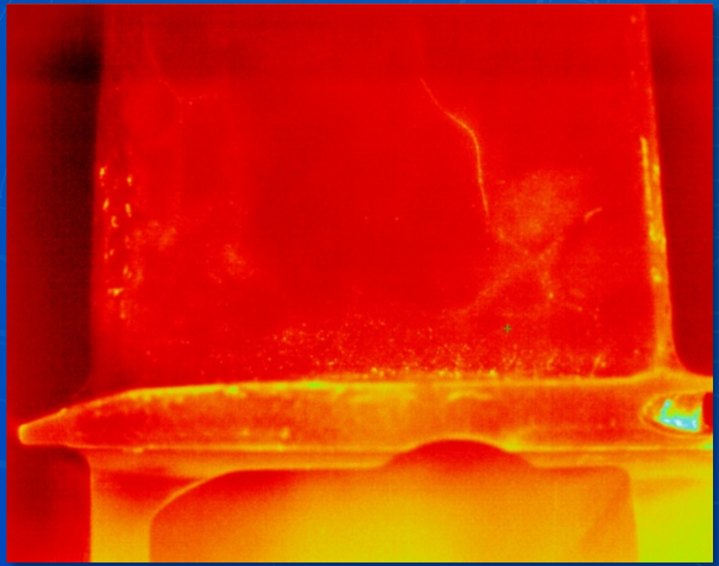
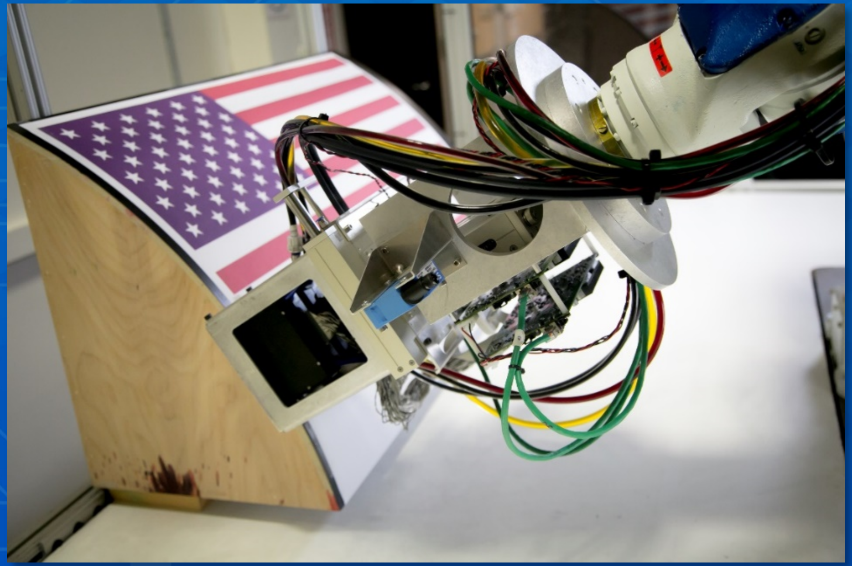
Manufacturing and Robotic Technologies Department

- Advanced perception and planning for robotic applications.
- Industrial automation and controls.
- Systems incorporating both custom and off-the-shelf hardware.





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ROS-Industrial

- Goal is to develop software within the Robot Operating System (ROS) ecosystem targeted towards industrial applications.
- Consortium of companies and research groups provides funding.
- Resulting projects released as open-source repositories.

rosindustrial.org
github.com/ros-industrial
github.com/ros-industrial-consortium

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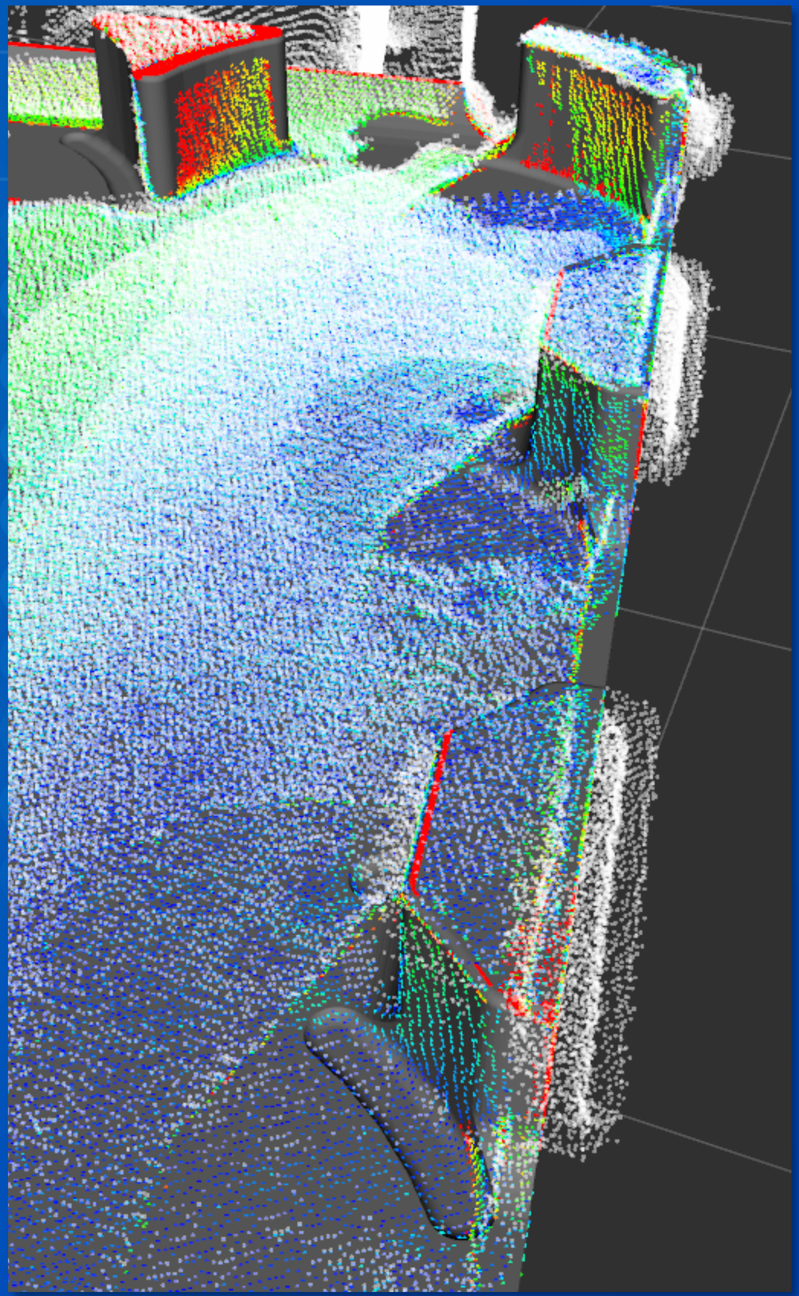
Scope of perception work in our group

- Generally use "raw" sensor output like 2D images and point clouds.
  - As opposed to "refined" output such as object positions and orientations.
  - Develop our own custom software to interpret sensor data.
- Use perception to plan complex processes on previously-unseen parts.
  - Contrast with traditional industrial robotics and turnkey commercial perception solutions, e.g. bin picking and item singulation.



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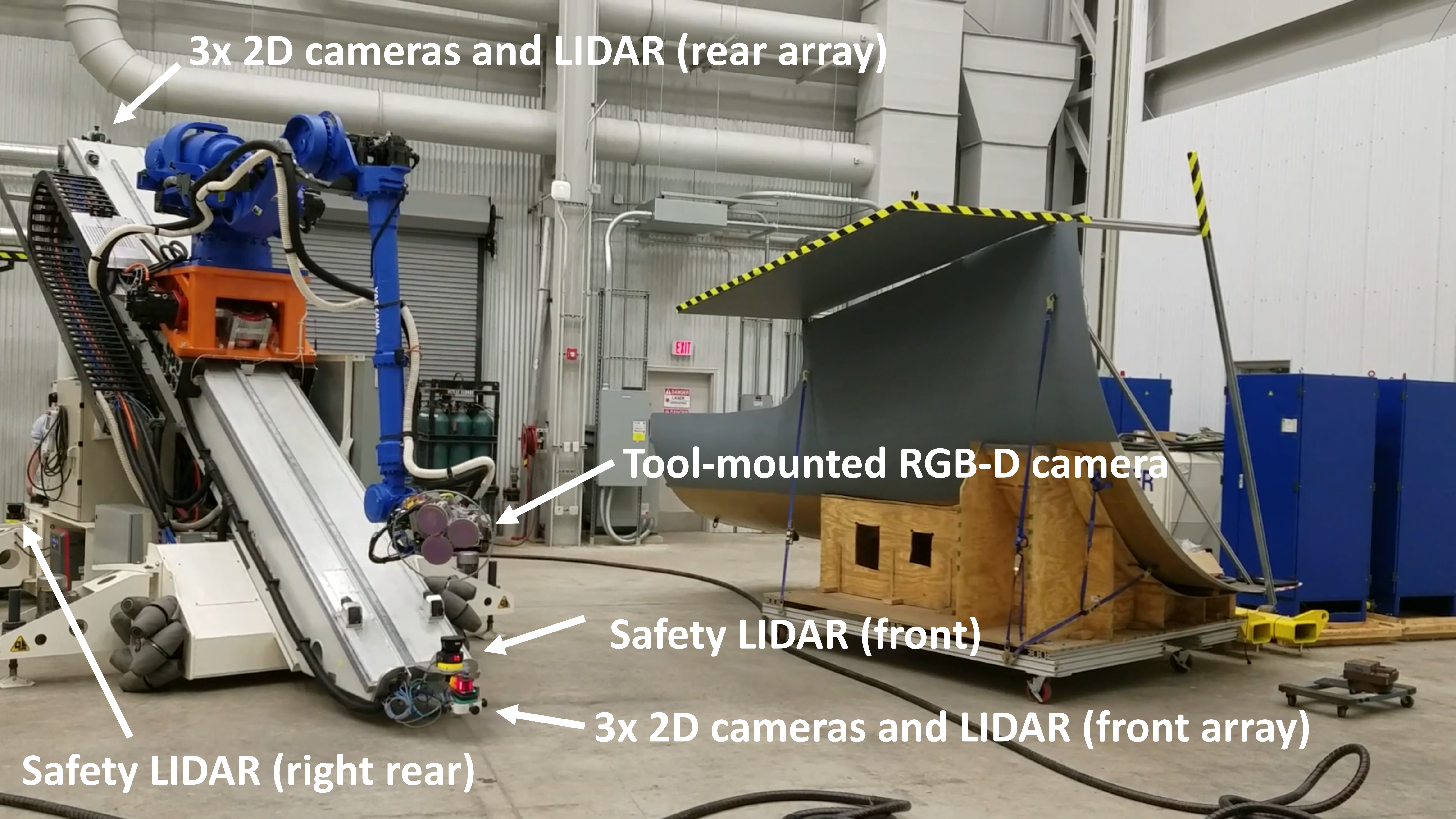
A5: Advanced Automation for Agile Aerospace Applications


3x 2D cameras and LIDAR (rear array)
Tool-mounted RGB-D camera
Safety LIDAR (front)
3x 2D cameras and LIDAR (front array)
Safety LIDAR (right rear)

Development of open-source calibration tools

- Intrinsic calibration
  - Calculate lens optical parameters and distortion coefficients
- Extrinsic calibration
  - Solve 3D transforms to relate sensor to the robot and its surroundings.
  - Camera-to-tool, camera-to-world, robot kinematics, etc.
- Industrial Calibration
  - https://github.com/ros-industrial/industrial_calibration
- robot_cal_tools
  - https://github.com/Jmeyer1292/robot_cal_tools

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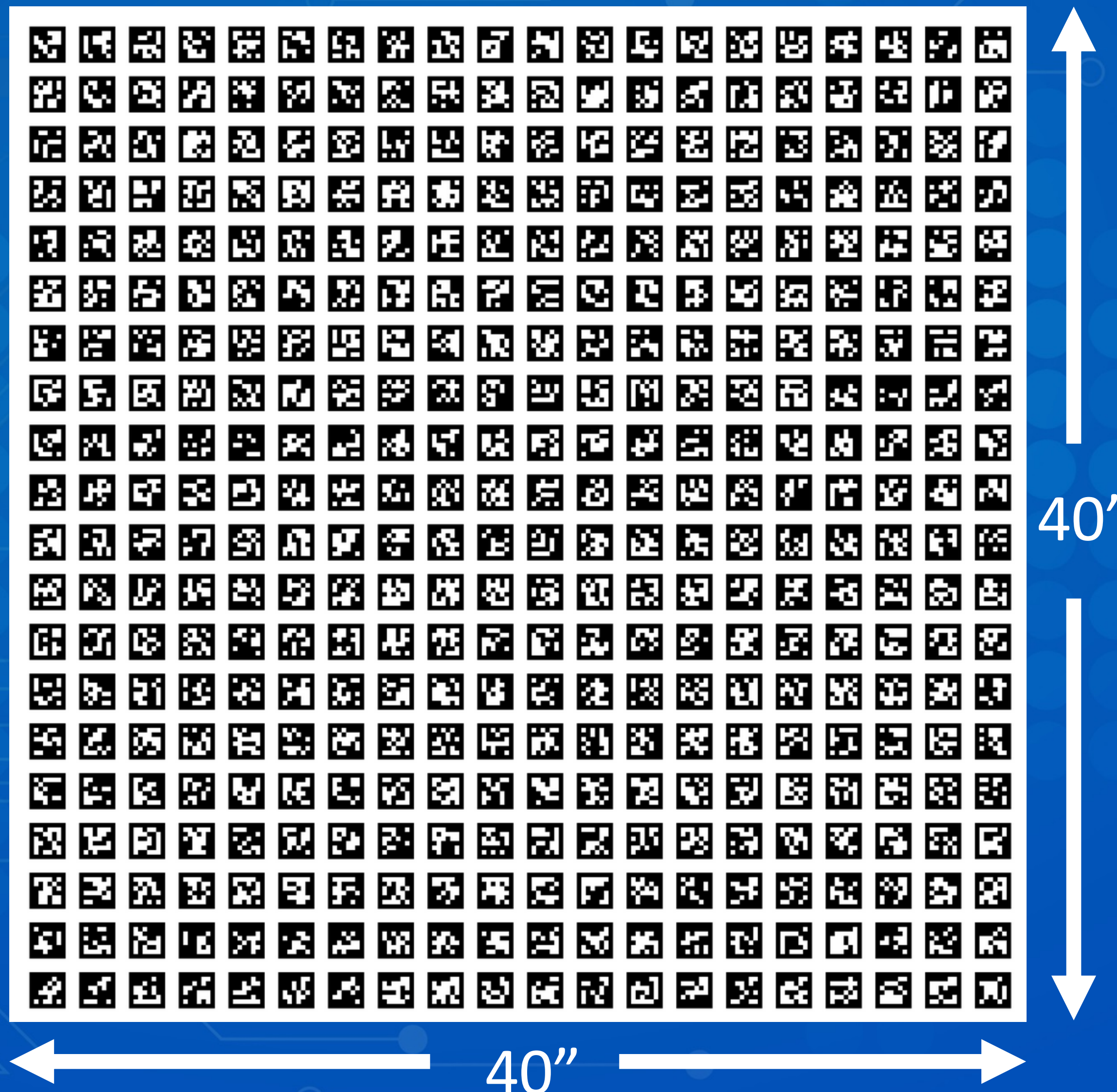
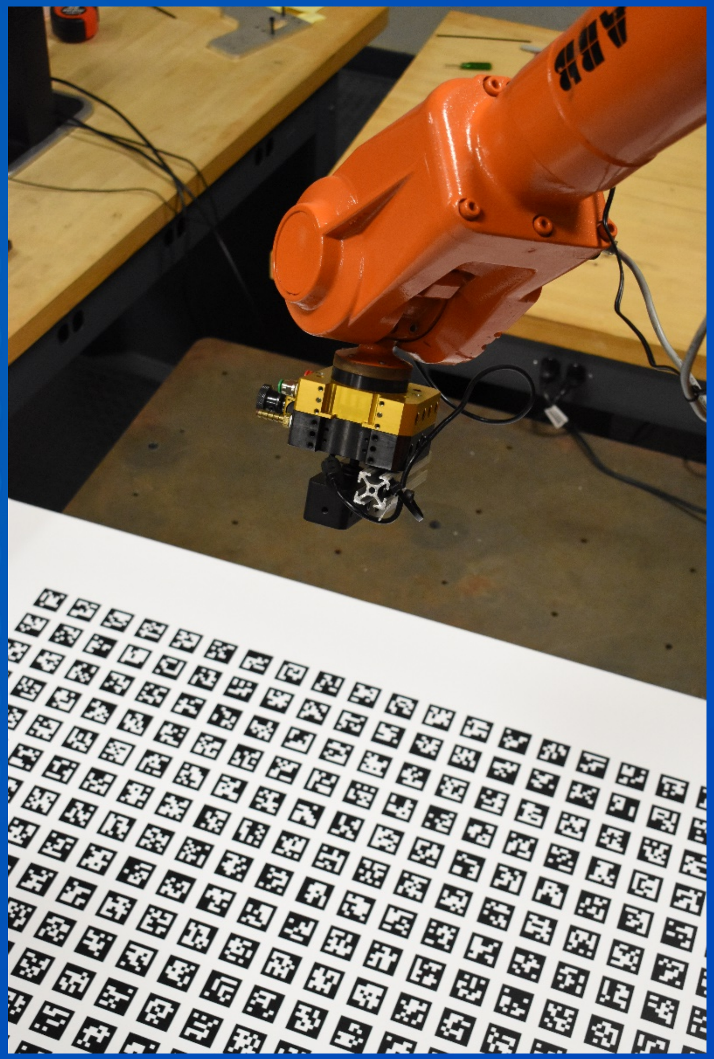
ArUco gridboard for calibrating in-hand sensors

- 20x20 array of squares gives 1600 corner features per board.
- Unique marker IDs allow use of partial target views for camera calibration.
- Big target fills camera field of view at practical working distance.





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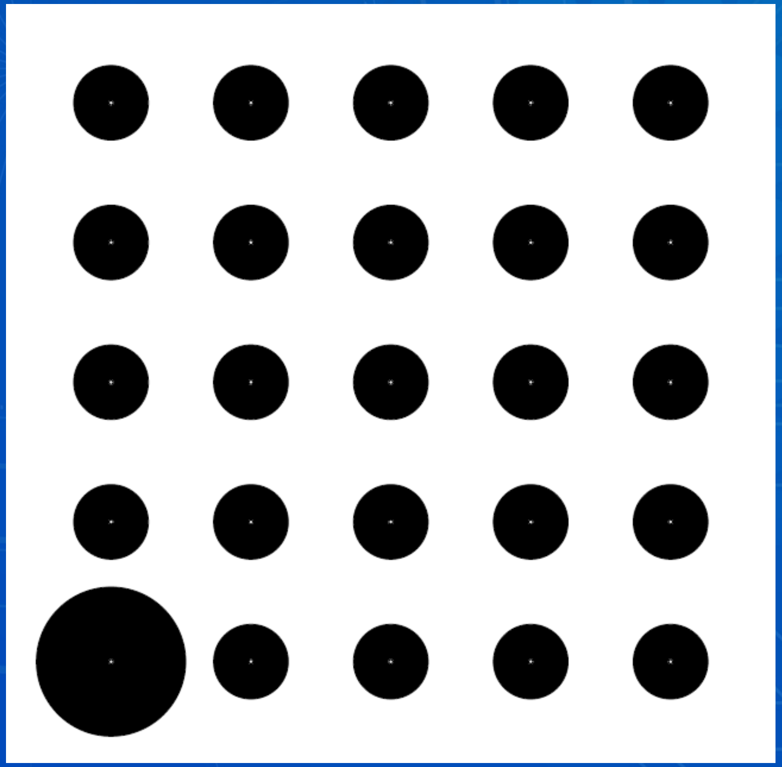
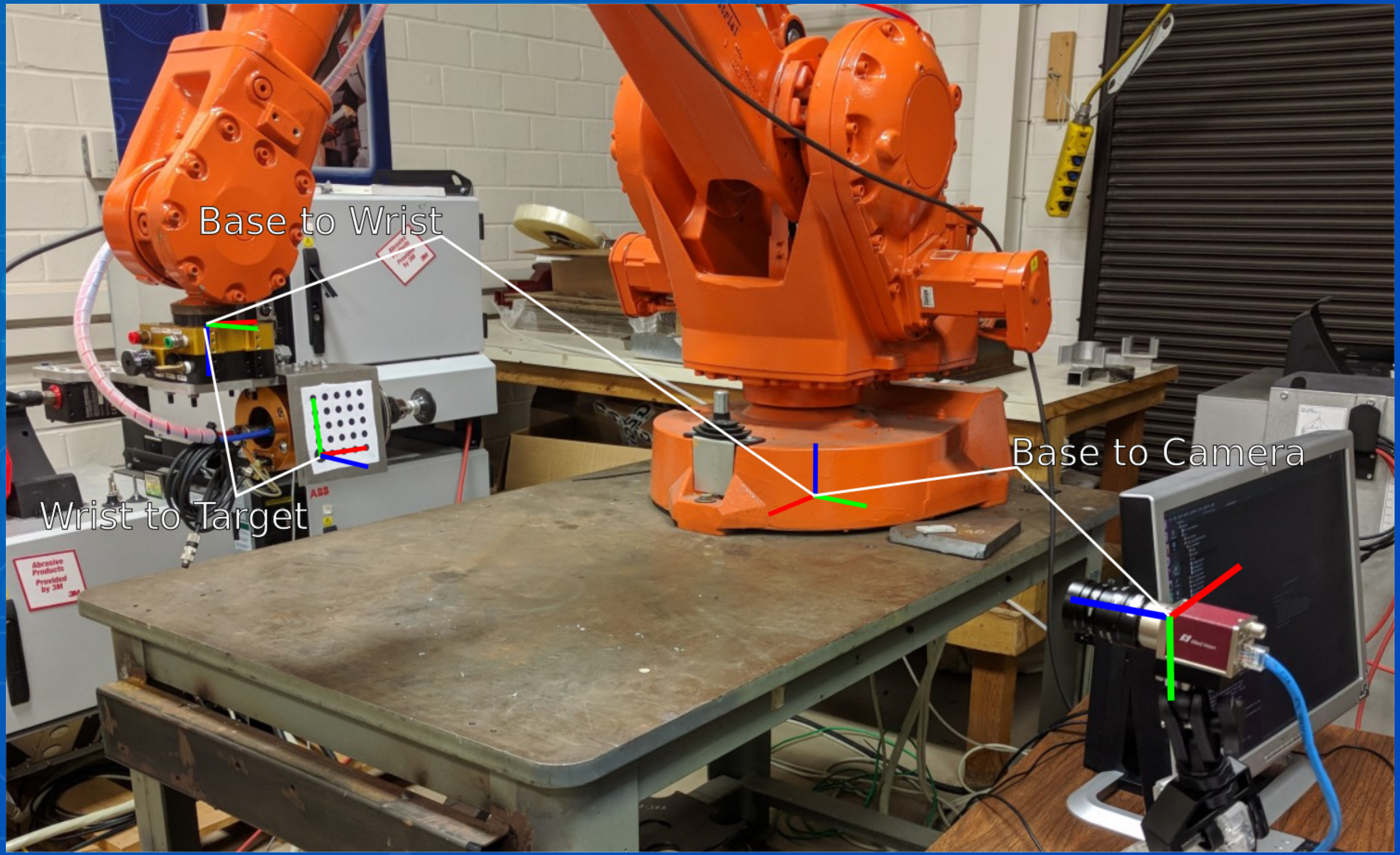
Modified OpenCV circle-grid target works too

- Circle centroids are more accurate than square corners.
- Large corner dot denotes origin.





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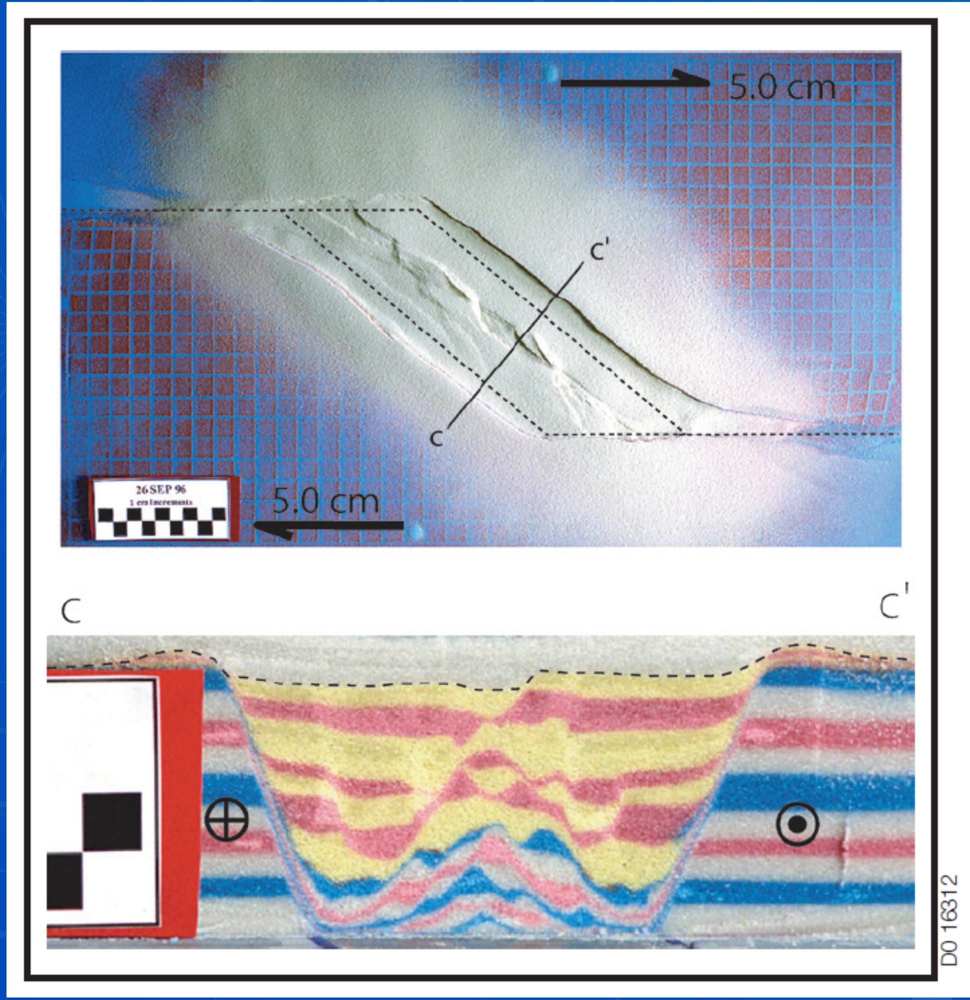
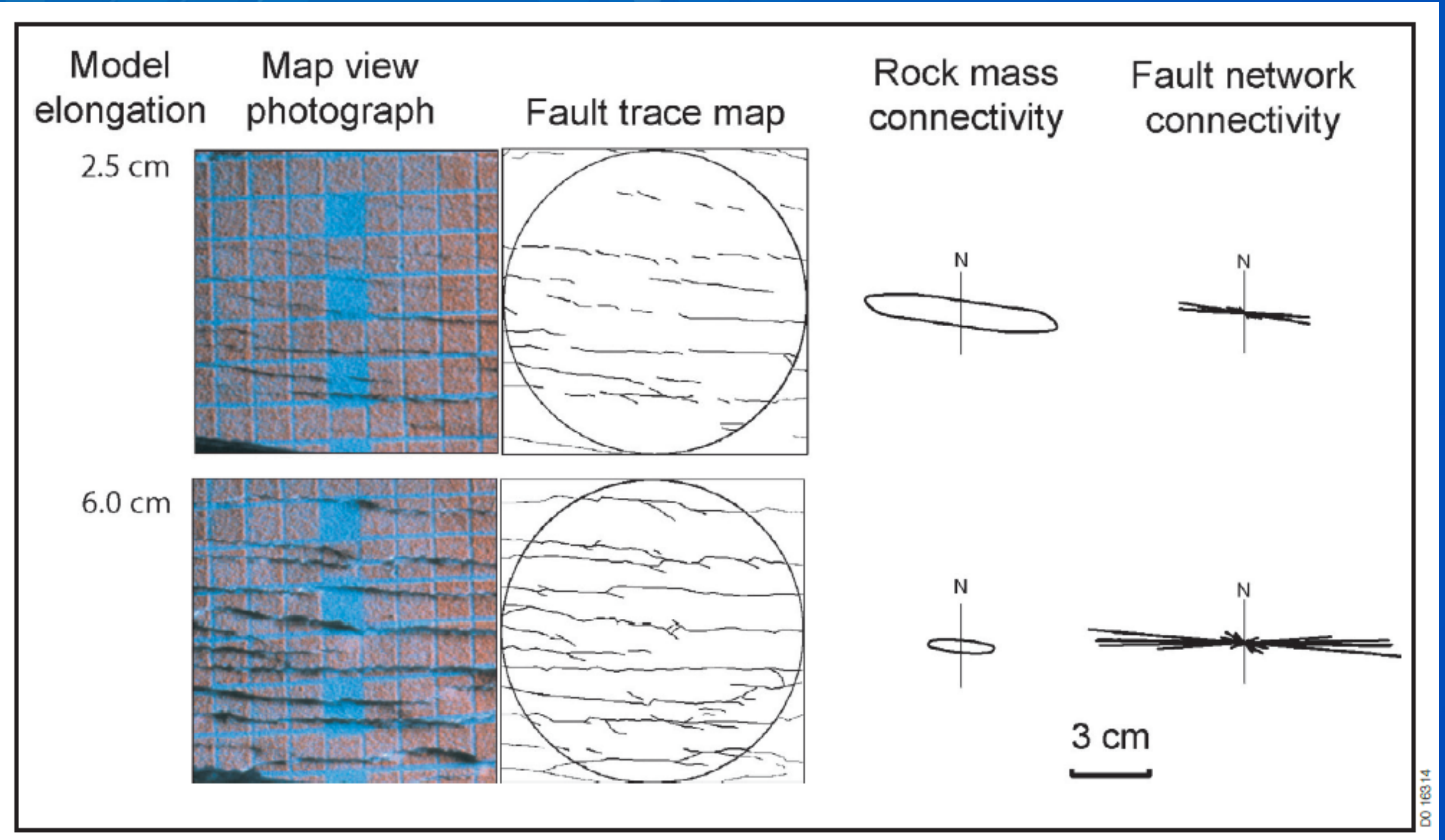
3D scans for physical analog geology simulation

- Enhance current analysis methods with dense, spatially-accurate structured light scans.





Analysis of two deformation stages from extensional fault system development illustrating evolution of rock mass connectivity and fault network connectivity. These are essential elements in quantifying permeability anisotropy in fractured and faulted reservoirs.

Figures from https://www.swri.org/physical-analog-modeling

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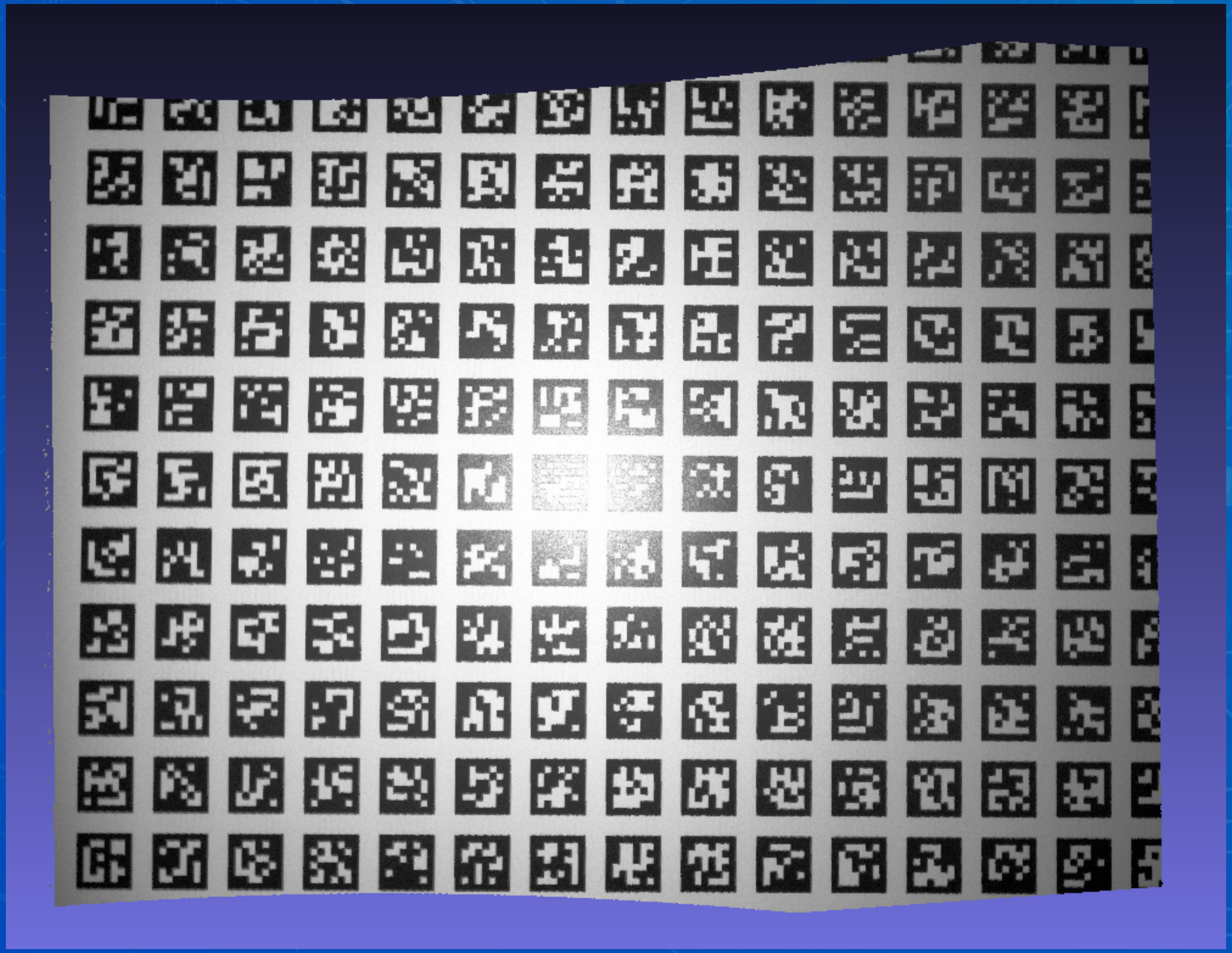
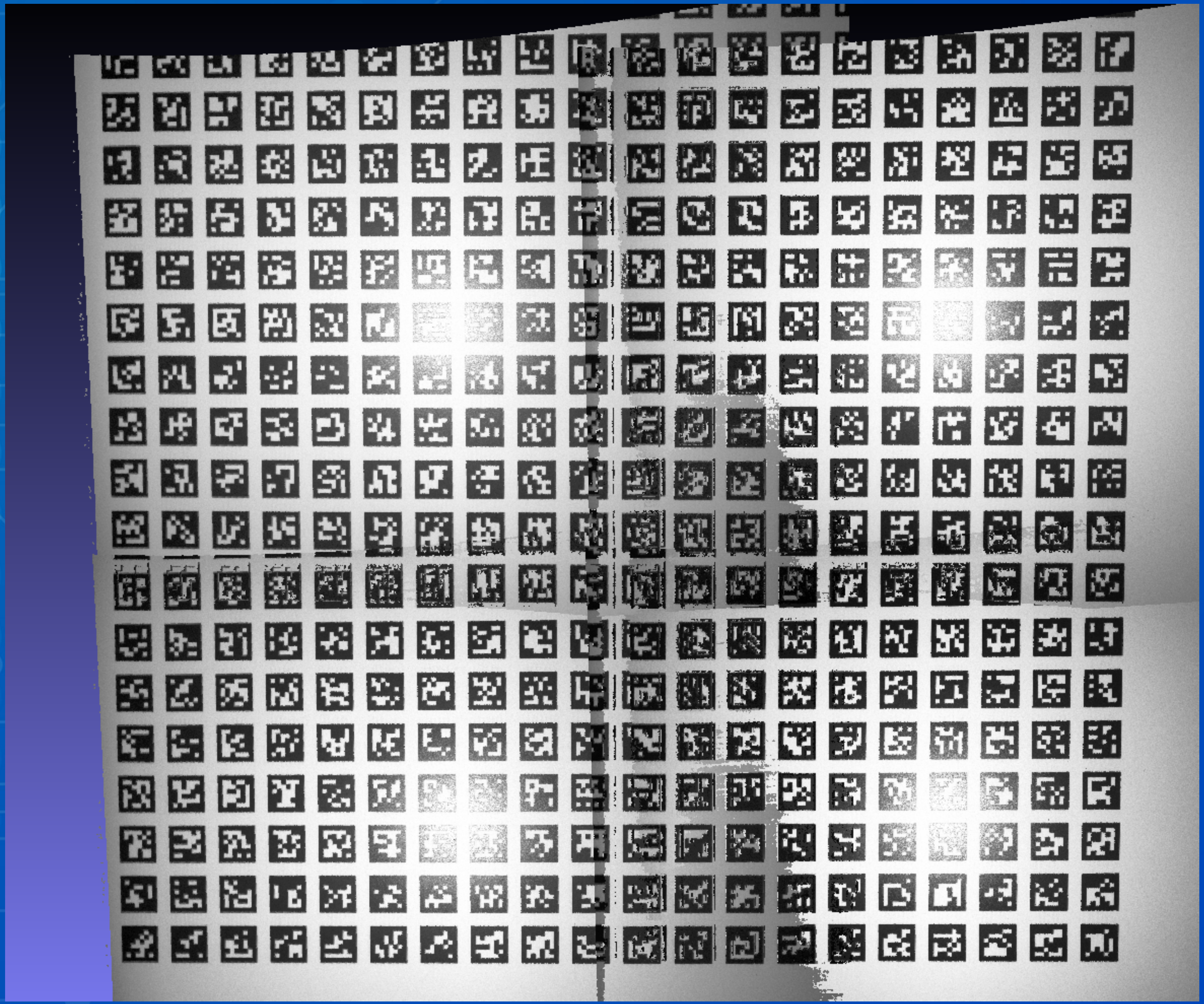
System extrinsic calibration scans show misalignment in overlapping scan regions





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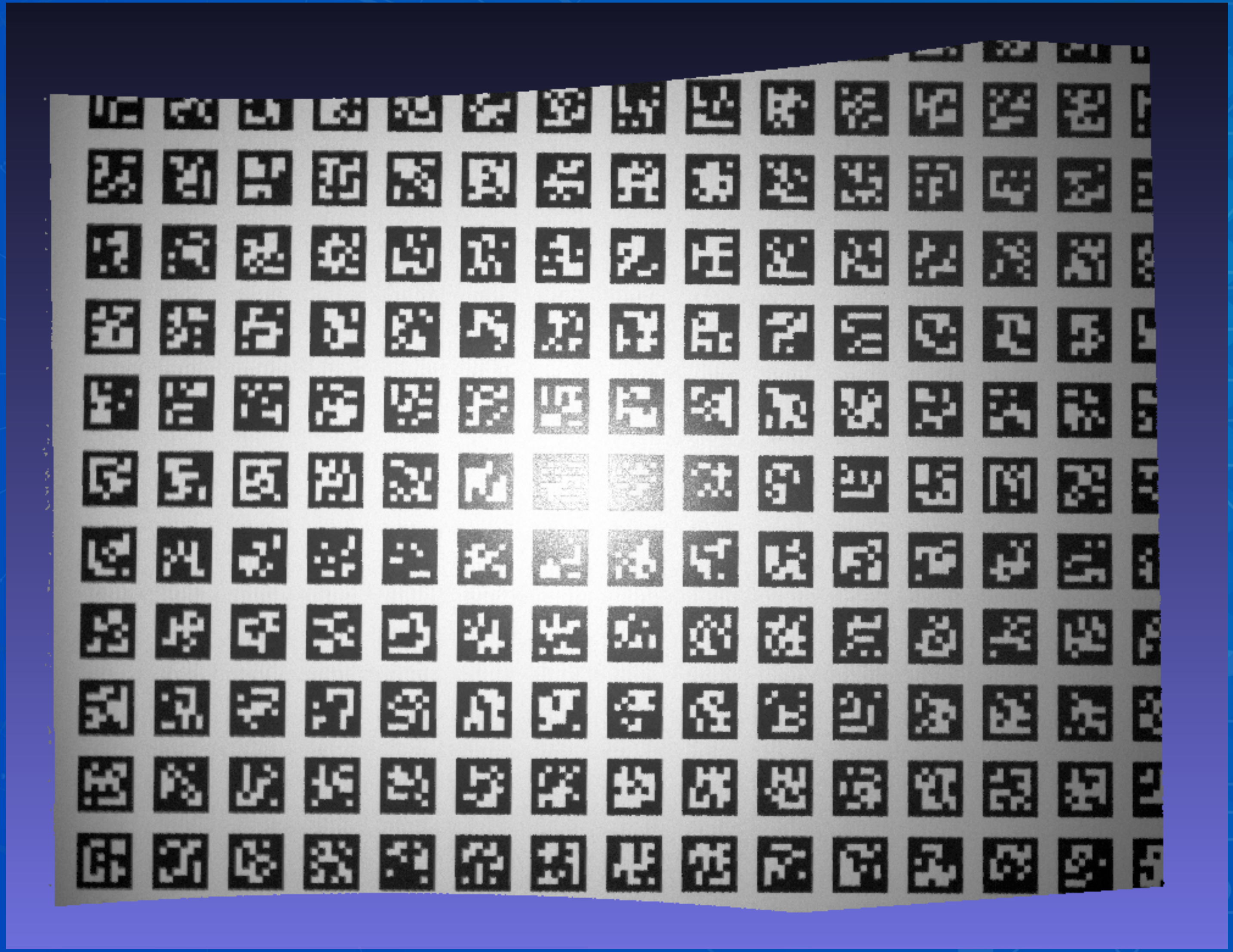
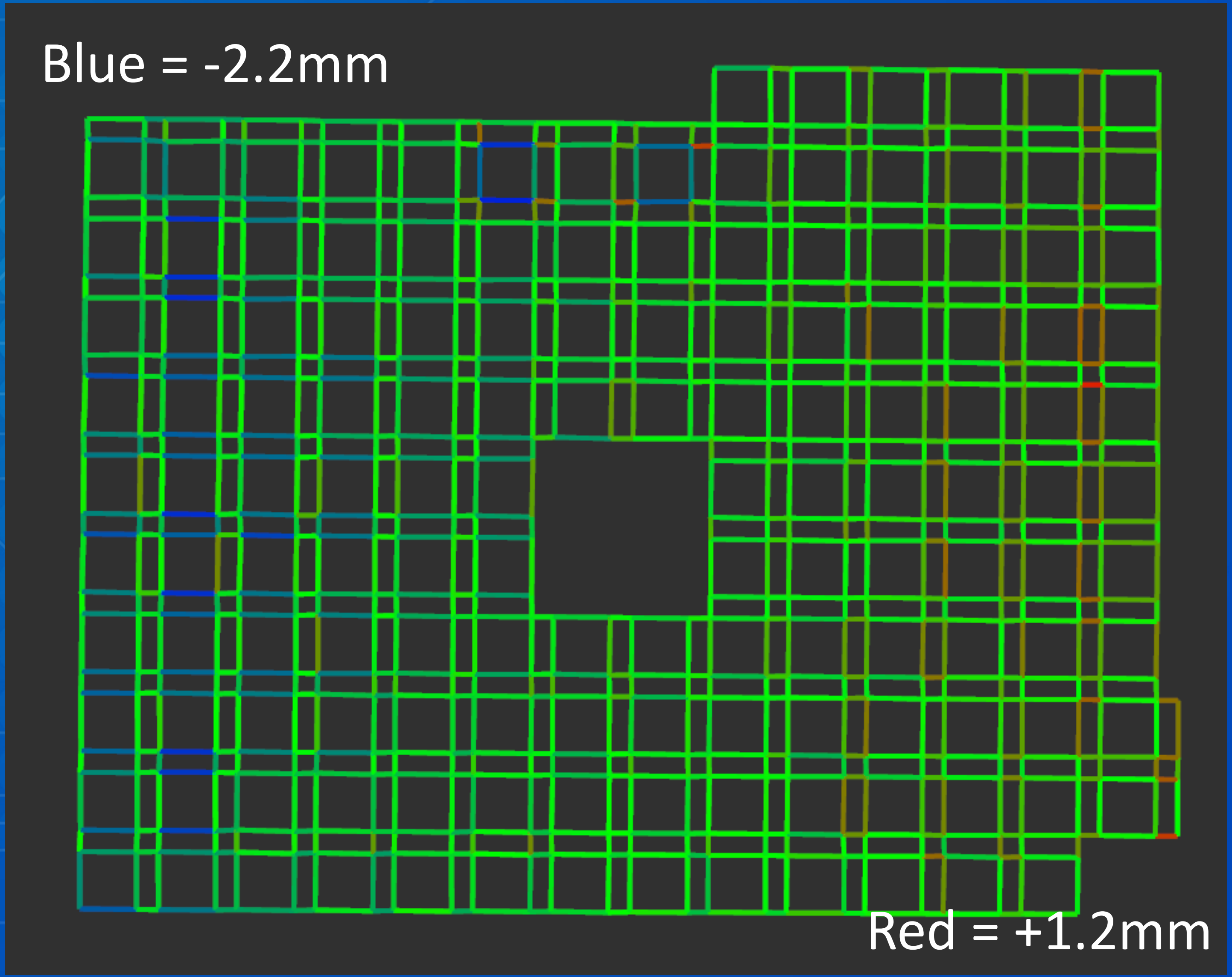
Comparing expected vs. actual corner positions shows asymmetric skew in point cloud





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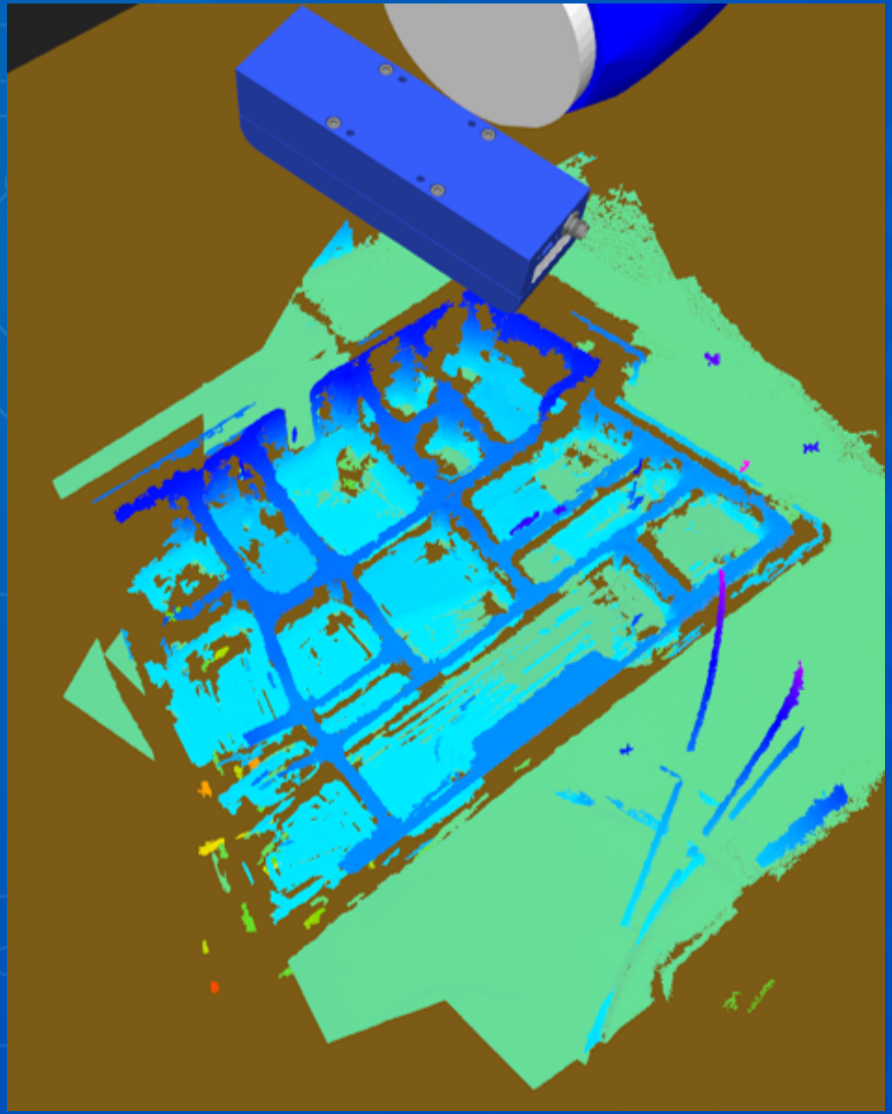
Qualitative sensor evaluation using a shiny part

- Useful to see how sensors perform with adverse geometry.



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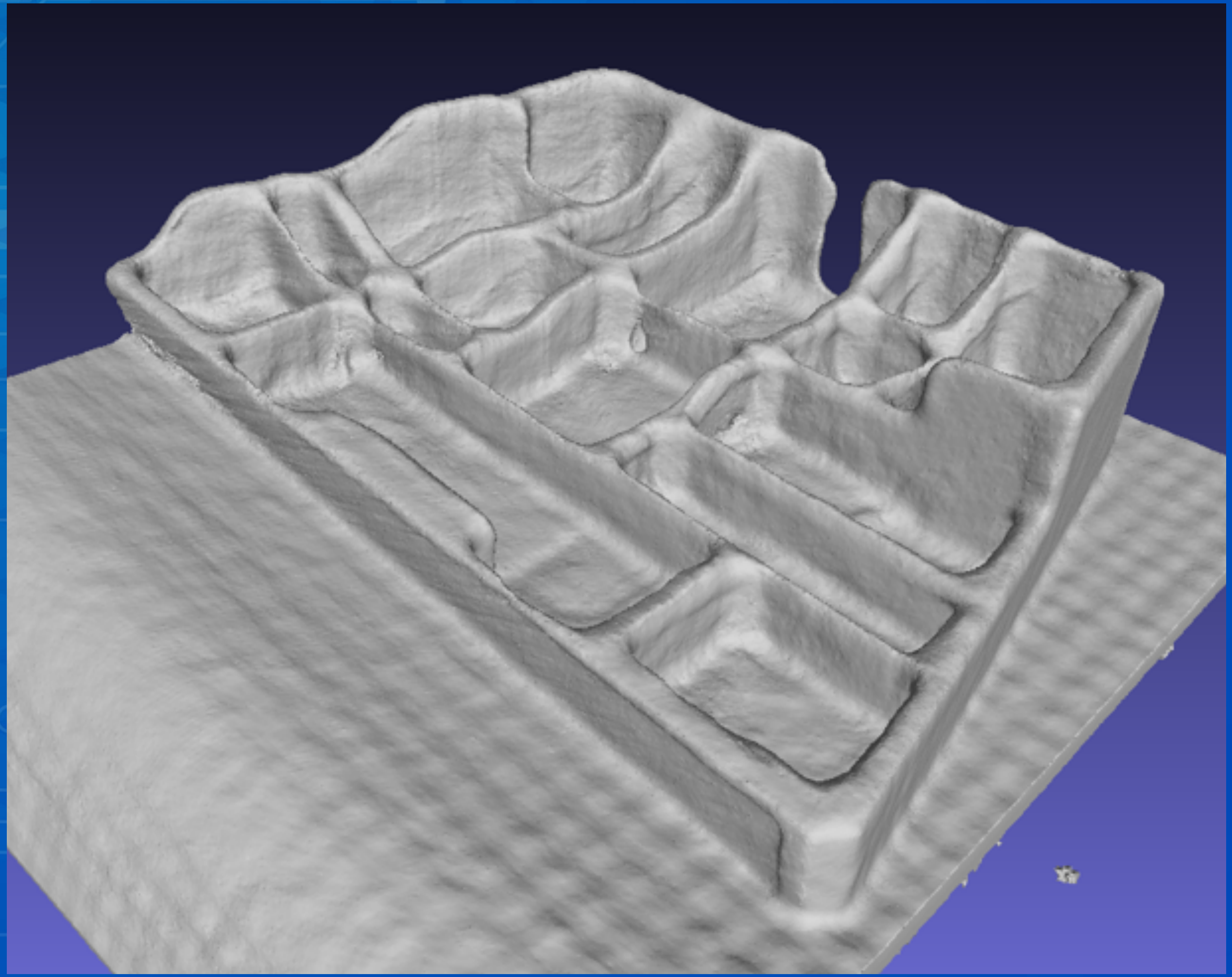
Multi-view methods address some sensor issues

- Truncated Signed Distance Field (TSDF) algorithm integrates numerous noisy incomplete depth images into a smooth mostly-complete mesh surface.



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Clients ask us for guidance on which cameras are suitable for their applications.

- What is the sensor's effective range and field of view?
- What is the spatial accuracy of the points in the cloud?
- How are the points distributed across the surface of a given object?
- How well does the sensor work in direct sunlight? High-contrast lighting?
- What is the smallest resolvable feature? Smallest hole vs. smallest bump?

Info available from sensor manufacturers generally doesn't answer all these questions.

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A structured light scanner: Photoneo PhoXi

Scanner model	XS	S	M	L	XL
Resolution (3D points)	3.2 M	3.2 M	3.2 M	3.2 M	3.2 M
Scanning range (mm)	161 - 205	384 - 520	458 - 1118	870 - 2150	1680 - 3780
Optimal scanning distance (mm)	181	442	650	1239	2326
Scanning area (mm)	118 x 78	360 x 286	590 x 421	1082 x 802	1954 x 1509
Point to point distance(mm)	0.057	0.174	0.286	0.524	0.947
Calibration accuracy (mm)	0.025	0.050	0.100	0.200	0.500
Temporal noise (mm)	0.030	0.050	0.100	0.190	0.400

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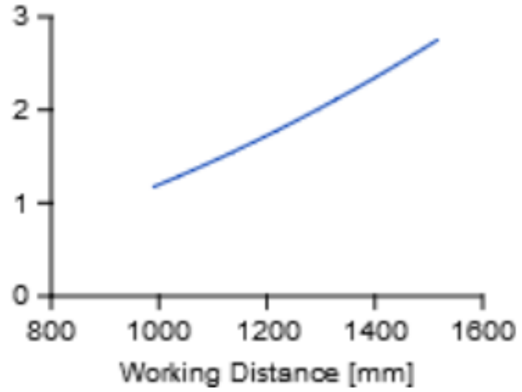
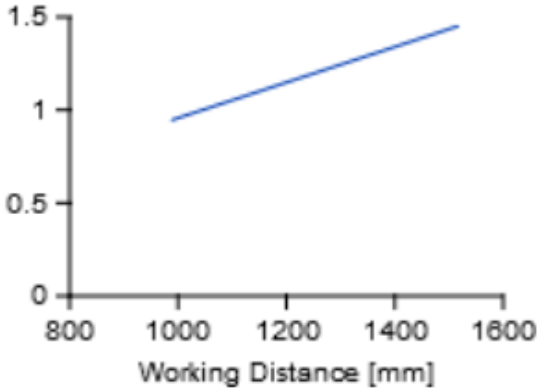
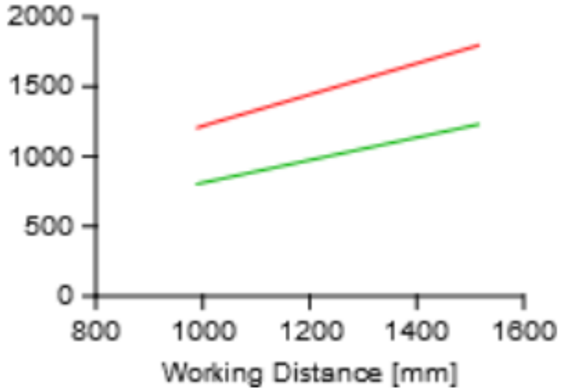
A stereo camera: Ensenso N35

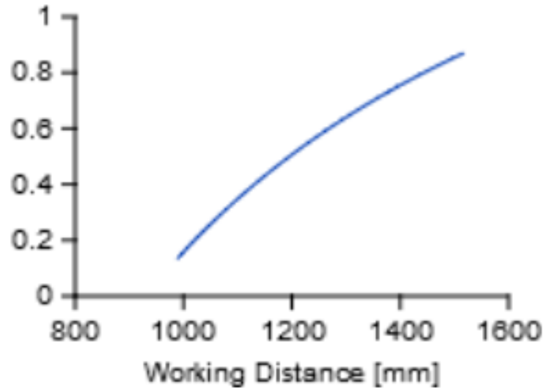
☐ **Model**	N35-602-16-BL
Vergence ⓘ	2.0°
a x b x c [mm]	1207 x 967 x 509
d [mm]	987
Disparity ⓘ **(Min / Num)**	-39 / 38

Z-Accuracy [mm]	**XY Pixel Size ⓘ [mm]**	**View Field X, Y [mm]**	**Optics Blur [px]**
1.17 – 2.68	0.94 – 1.43	X: 1200 – 1800 Y: 800 – 1250	0.13 – 0.85









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Would be useful to independently quantify each stage of 3D perception

- 2D feature detection algorithm
  - Errors in pixel positions due to inaccurate camera intrinsics or lens blur.
  - Metric for number of correspondence features per unit surface area?
- 3D point position calculation
  - Error due to inaccurate position/orientation between stereo cameras.
  - Important to separate theoretical optimal behavior from actual in-practice performance.

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In conclusion…

- Standards for raw sensor data would be useful to us.
- More inspiration for quantifiable metrics for 3D scan quality.

Joseph Schornak

joseph.schornak@swri.org

github.com/schornakj

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