pixeltraq

CAMERA CALIBRATION STATION SUMMARY

Quartus' PixelTraq Camera Calibration Architecture

- Quartus' patent-pending camera calibration architecture is configurable for a wide variety of camera systems including:
  - Multi-camera arrays
  - Wide Field of View (FOV > 180°) cameras
  - Shallow Depth of Field cameras
  - Long working distances (up to 3m)
    - Can re-conjugate to infinity as needed
  - Multiple chart designs and configurable illumination

- Trio of software tools for pose generation, automated capture, and post-processing of composite "Supercharts"

- Industry-leading traceability of captured object points and integrated solver for most common camera models


Calibration Service Outputs Include:
- Intrinsic Calibration Parameters:
  - Principal Point X, Y
  - EFL X,Y
  - Distortion Coefficients
- Volumetric SFR (Through Focus MTF, Depth of Focus)
- 6DOF Pupil Position & Pose (Relative to mounting fiducials)
- Residual and model reprojection plots
- Model quality Figures of Merit (FOMs)

Camera Calibration Applications Include:
- Computer Vision Inspection
- Vision Assisted Robotics
- Automated Quality Control
- Geometric Measurement (In plane, Angular, Depth)
- Virtual Image Distance Measurement
- Camera Array Epipolar Error

quartus

TRACEABILITY AND UNCERTAINTY IN CAMERA CALIBRATION

- One-time OMM/CMM inspections of chart and camera mount are required
- A calibrated laser-tracker in the loop provides traceable inspection of chart relative to camera for any programmed pose
- Each point correspondence (image/object space) is traceable with a known maximum permissible error

Optical CMM Data Set

Laser Tracker Data Set
(single pose)

CMM Data Set
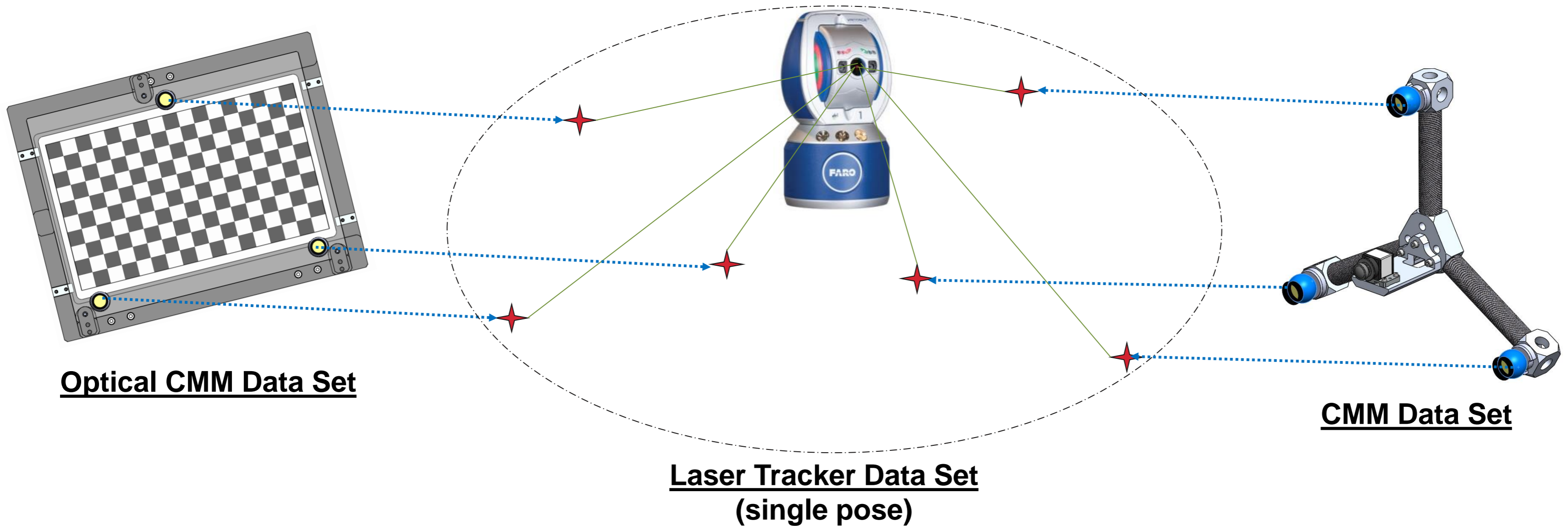
STANDARD CALIBRATION WORKFLOW & SOFTWARE TOOLS

Pre-Processor

- FOV and depth coverage
- Target density
- Trajectory simulation
- Laser Tracker programming

Sequencer

- Camera capture w/ live view
- Load calibration profiles
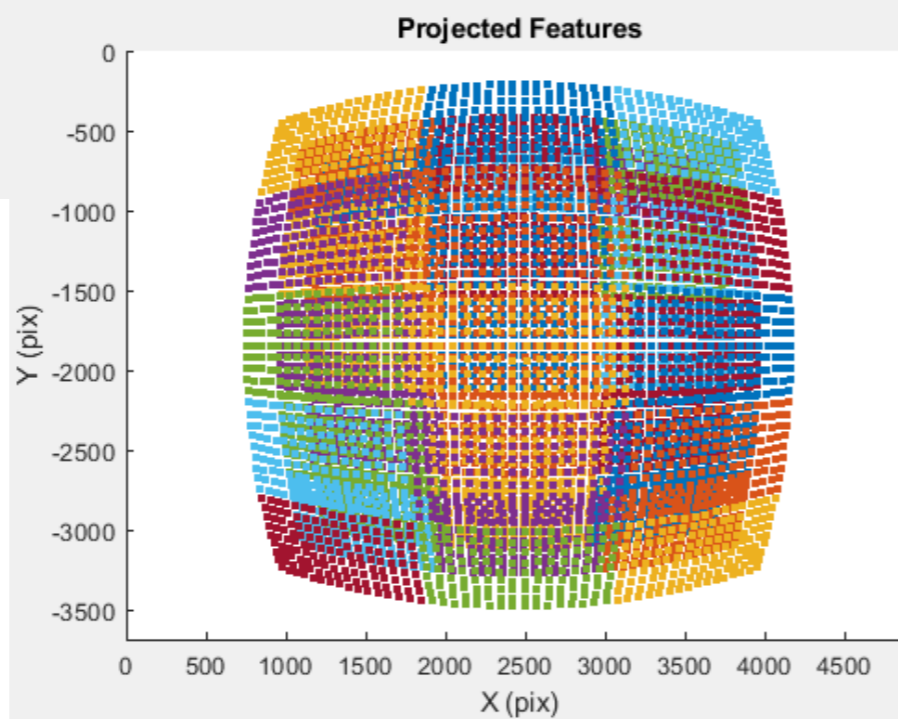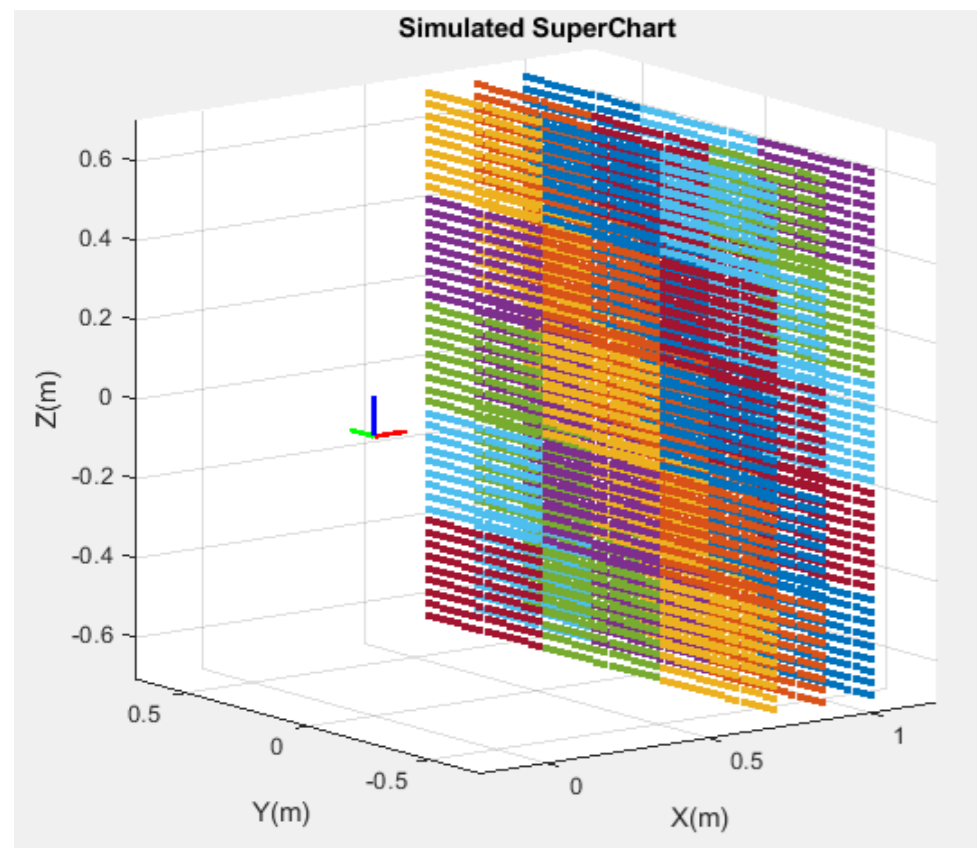- Motion control
- Laser tracker control

Post-Processor

- Parametric model optimization
- Image space error visualization
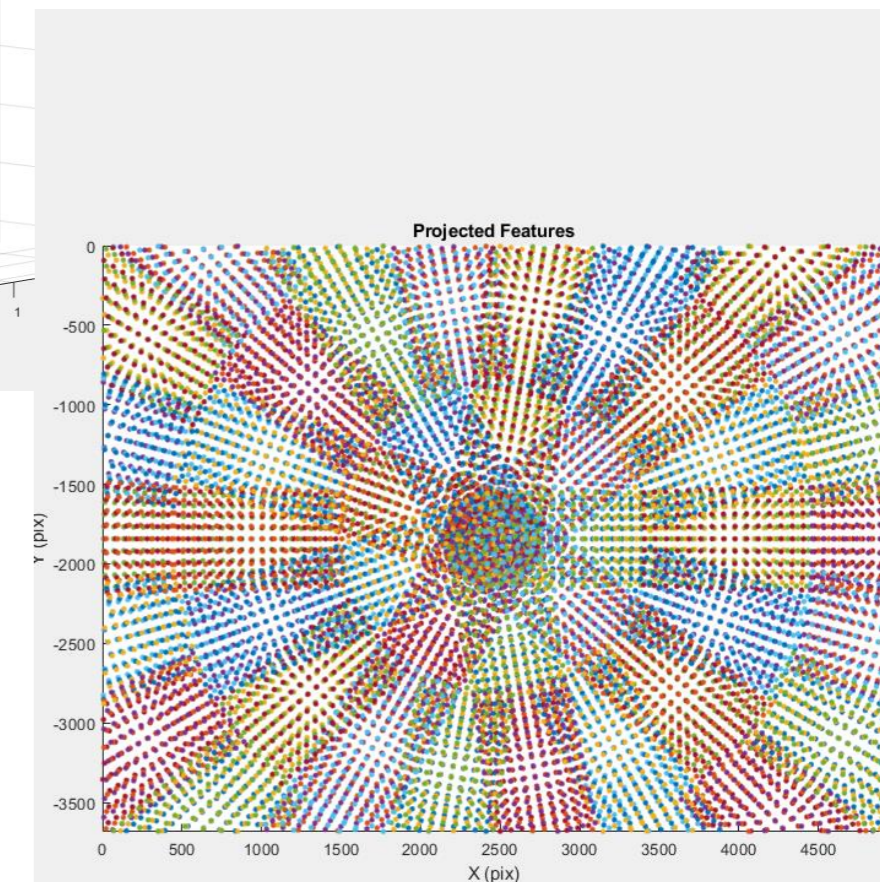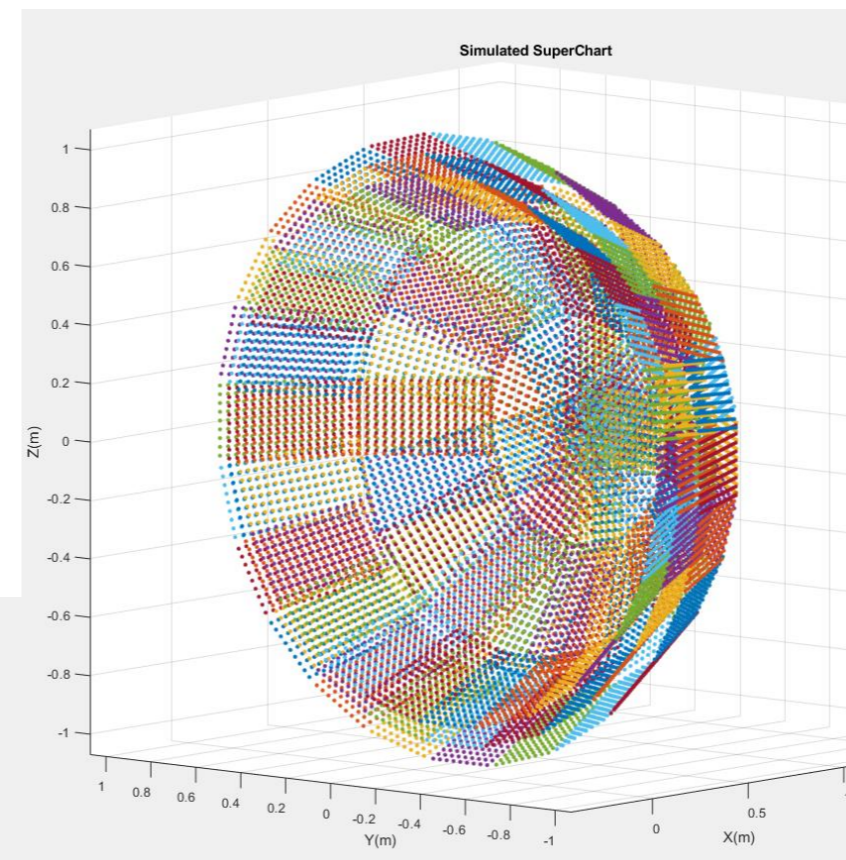- Object space error visualization
- Audit data testing
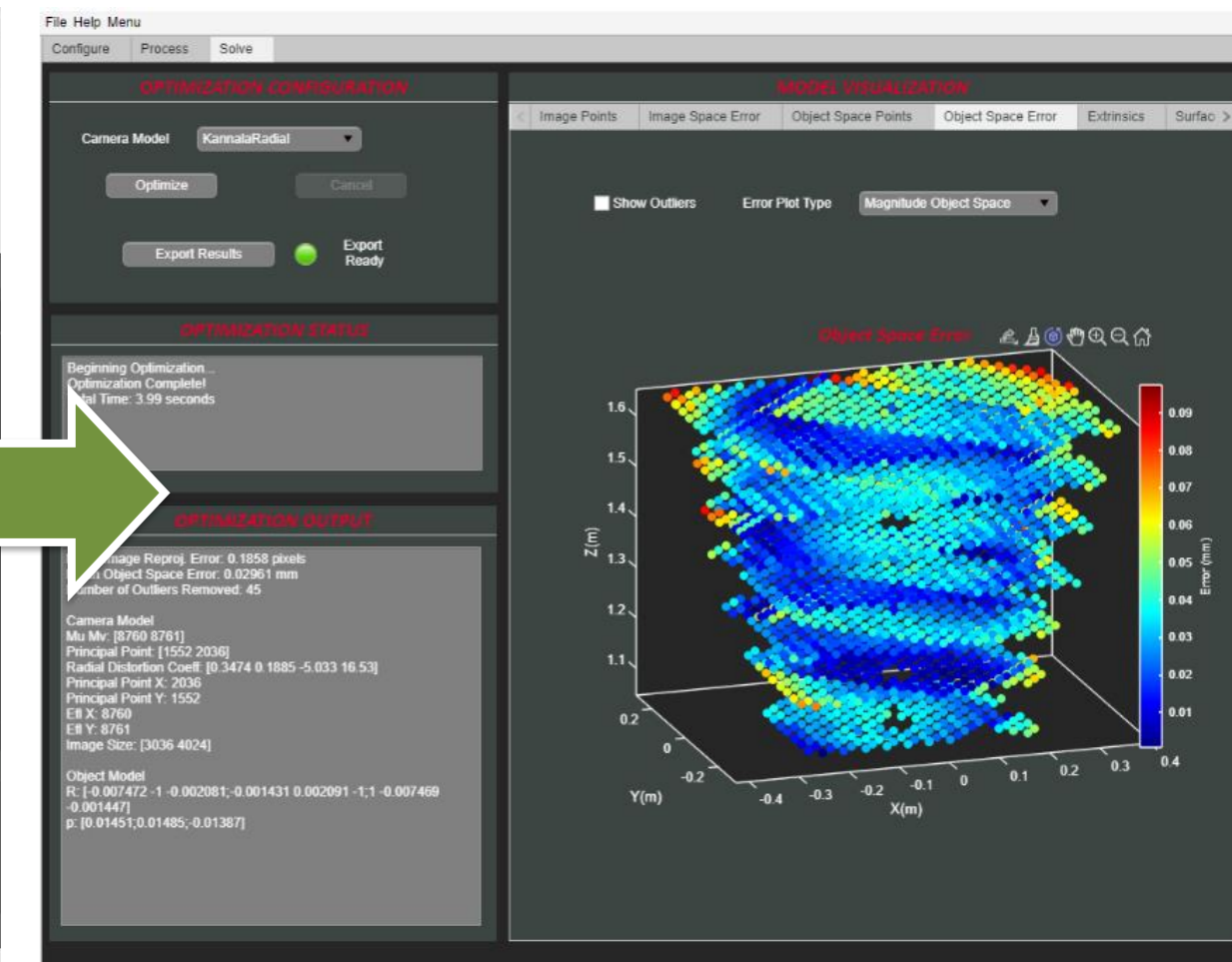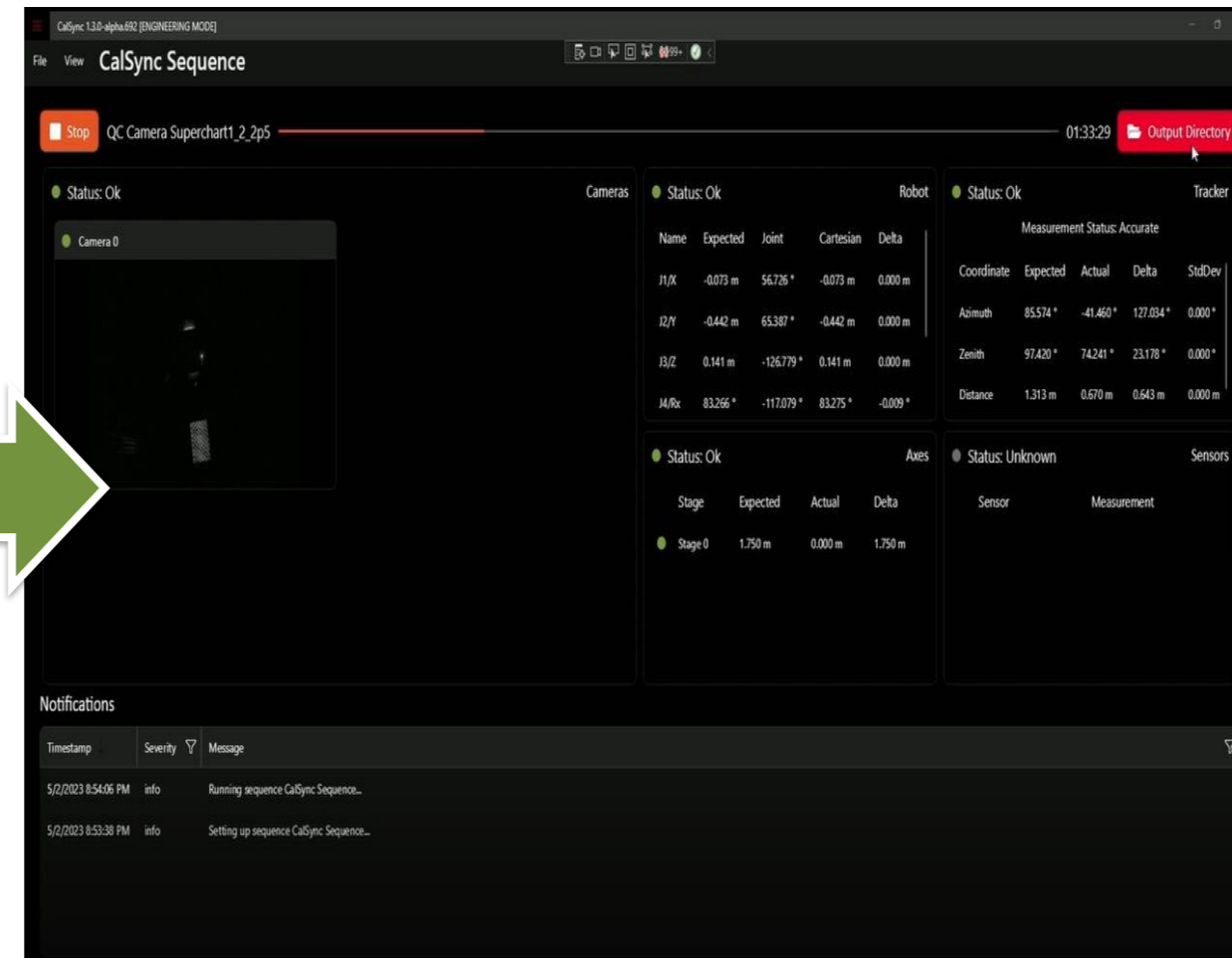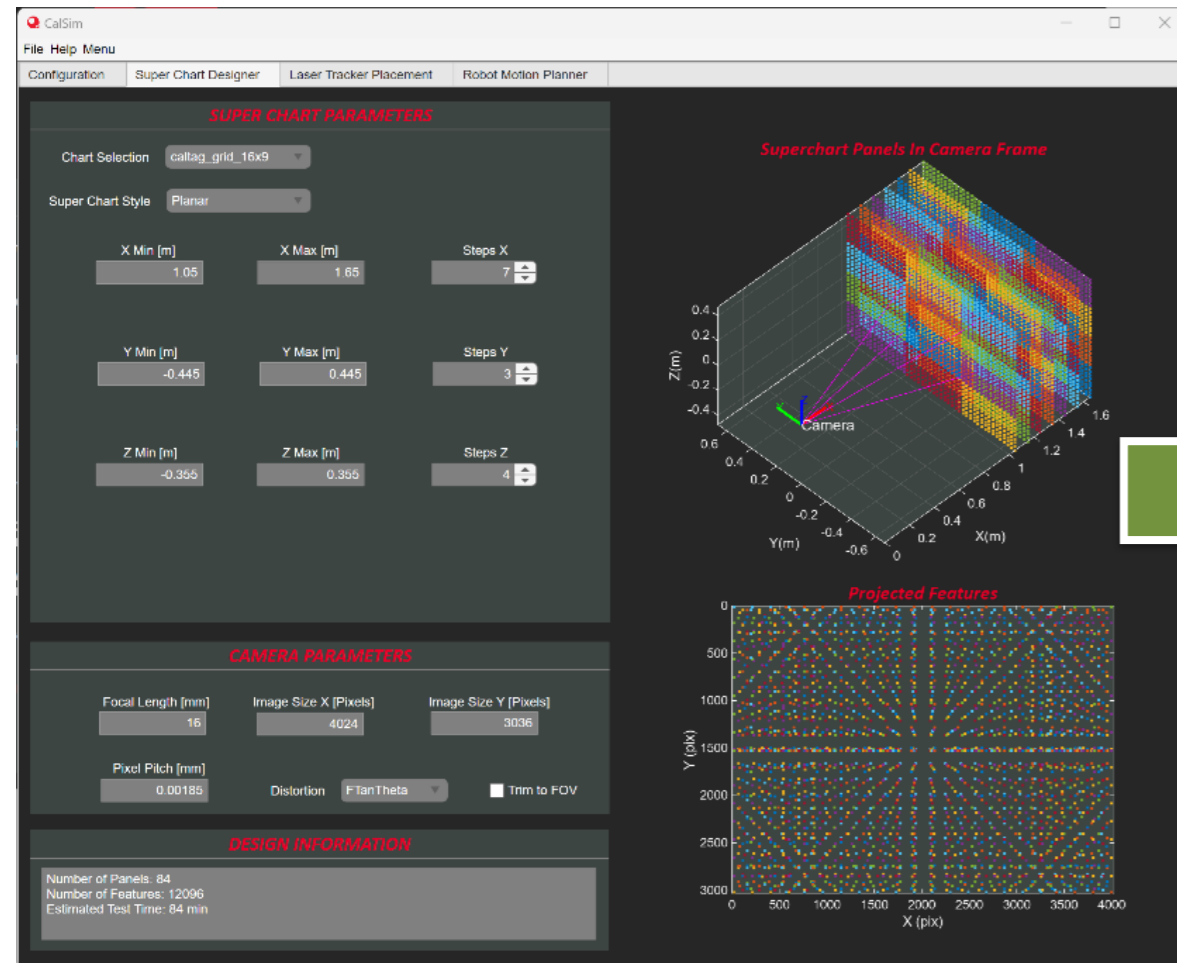
Configurable "Superchart" Geometry

Planar Charts
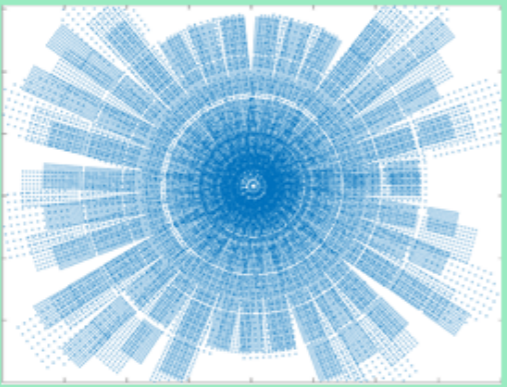
Hemispherical Charts

6480 Chart features in Image Frame

15230 Chart features in Image Frame

Camera Specs:
- **Sensor: Basler acA4024-29um**
- **Lens Focal Length: 2.8mm**
- **FOV: 156°**

	pixeltraq	OpenCV	OpenCV + High Quality Chart
Features	>38,000	1683	4114
Traceable Extrinsics	✓	✗	✗
FOV Coverage			
Data Collection	Automated	Manual	Manual
Mean Reproj. Error	Calibrated: 0.36 pixels Audit Set: 0.37 pixels	Calibrated: 0.30 pixels Audit Set: 2.1 pixels	Calibrated: 0.28 pixels Audit Set: 0.91 pixels
Object Space Reproj. Error	0.48mm	2.31mm*	1.16mm*

Angular Error vs. Field Angle

- Quartus Mean Error (radial model)
- Quartus Mean Error (Higher order model)
- OpenCV Mean Error
- OpenCV + Imatest Mean Error

Projected Error: 1m

- Quartus Camera Calibration (radial model)
- Quartus Camera Calibration (full model)
- OpenCV Chart
- OpenCV + Imatest chart
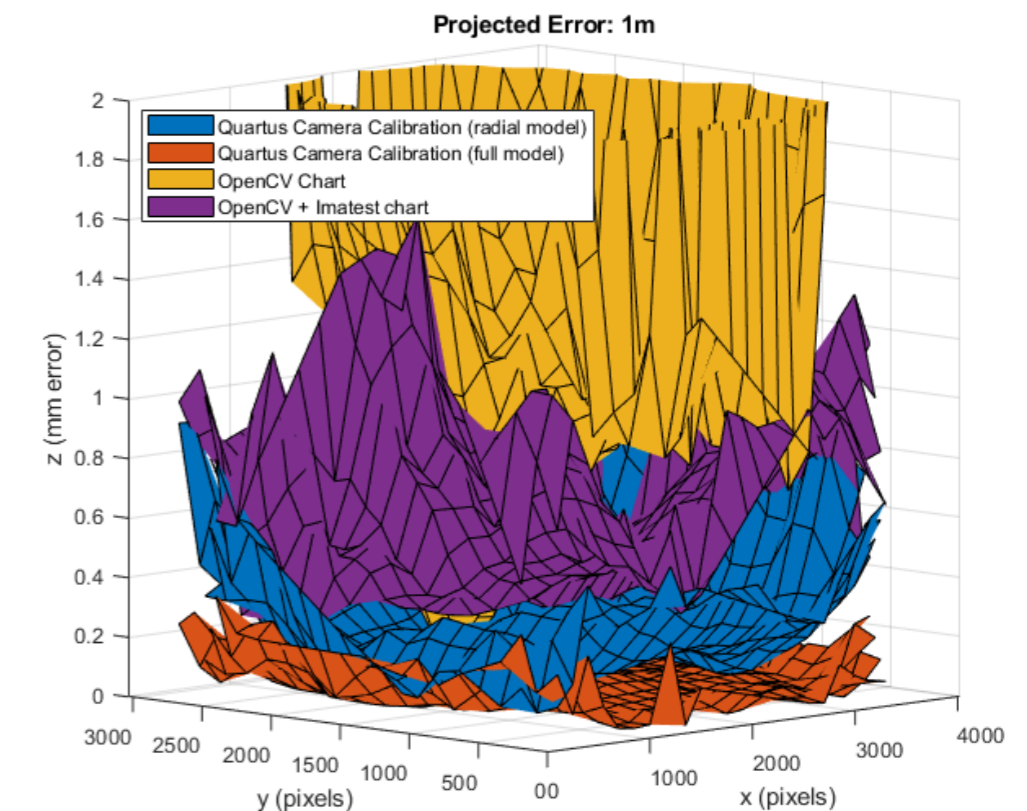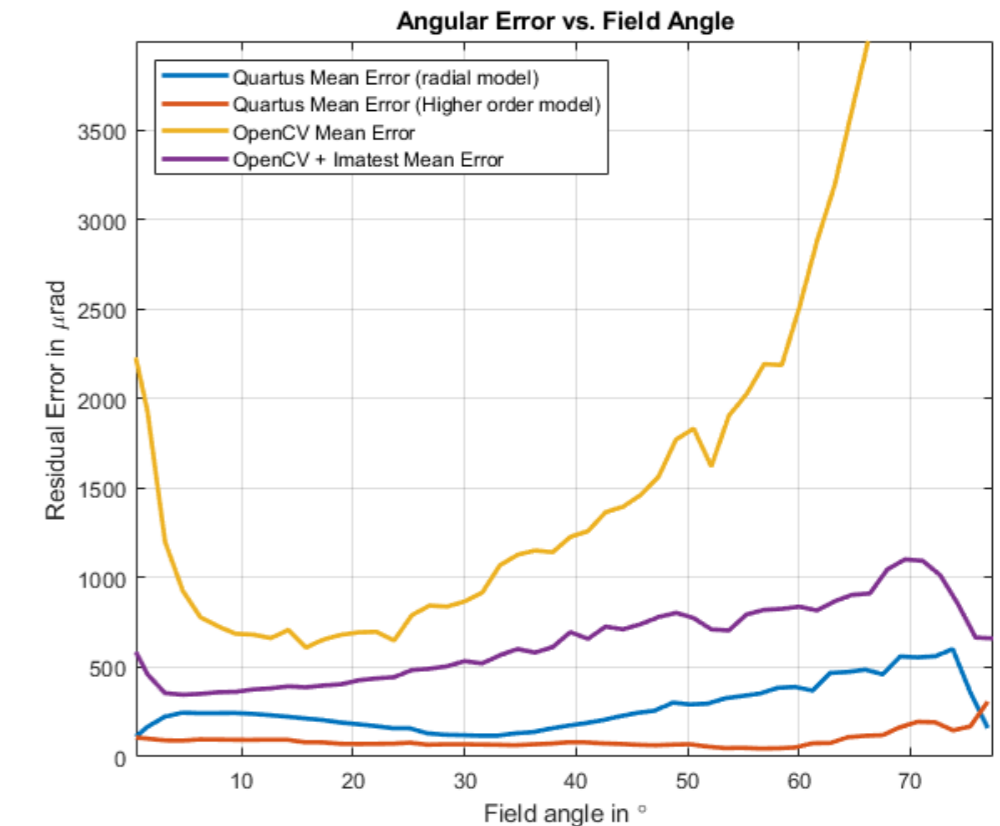
PixelTraq Case Study - Wide FOV Binocular Array

End-Effector Specs:
- **Cameras: M2020, 1/1.8" Monochrome, Dalsa Genie Nano GigE PoE**
- **Lens: 3.5mm, f/2.8 Cr Series Fixed Focal Length Lens**
- **FOV: 75° (V) x 100° (H)**
- **Focus Distance: 1m**
- **Binocular Camera Spacing: 100 mm**

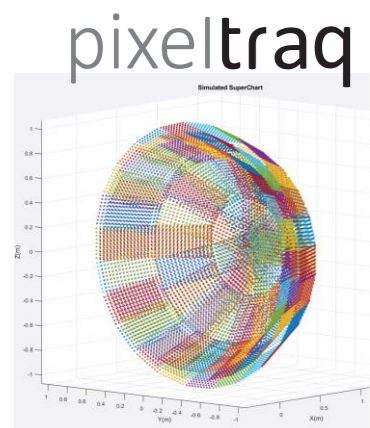**DEPTH HEATMAP OUTPUT**

IMAGE PROCESSING WORKFLOW
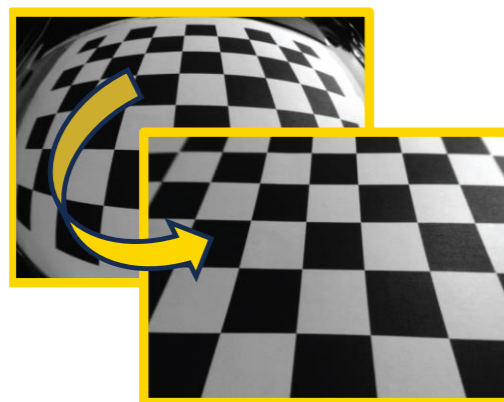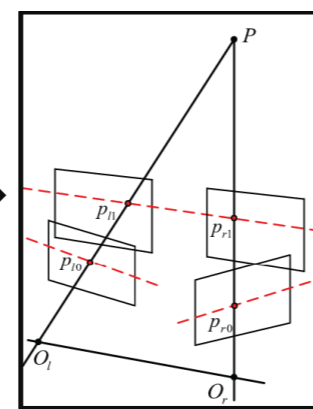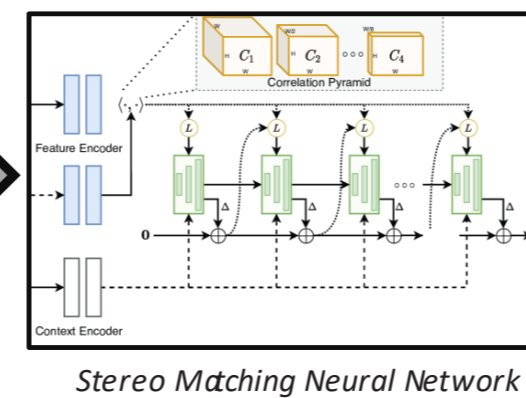

CAMERA CALIBRATION → *IMAGE UNDISTORTION* → *IMAGE RECTIFICATION* → *DISPARITY CALCULATION*

Stereo Matching Neural Network

POINT CLOUD OUTPUT (XYZ)

# PixelTraq Case Study – Volumetric SFR

Camera Specs:
- **Camera: IOI Victorem 62G41-CX**
- **Sensor: Gpixel GMAX0505**
- **Lens Focal Length: 50 mm**
- **FOV: 15° (V) x 15° (H)**
- **Focus Distance: 1.1m**

- By collecting a dense data in PixelTraq, shallow Depth of Focus (DOF) imagers can have their entire field characterized for resolving capability (contrast)
- The circular features on PixelTraq charts are used to extract circular Spatial Frequency Response (SFR) such that contrast can be evaluation for a wide range of frequencies, MTF values, and directions (sagittal, tangential, XY)
- This volumetric data is critical in evaluating Depth of Focus as well as impacts from real-world alignment errors such as sensor tilt relative to optical axis
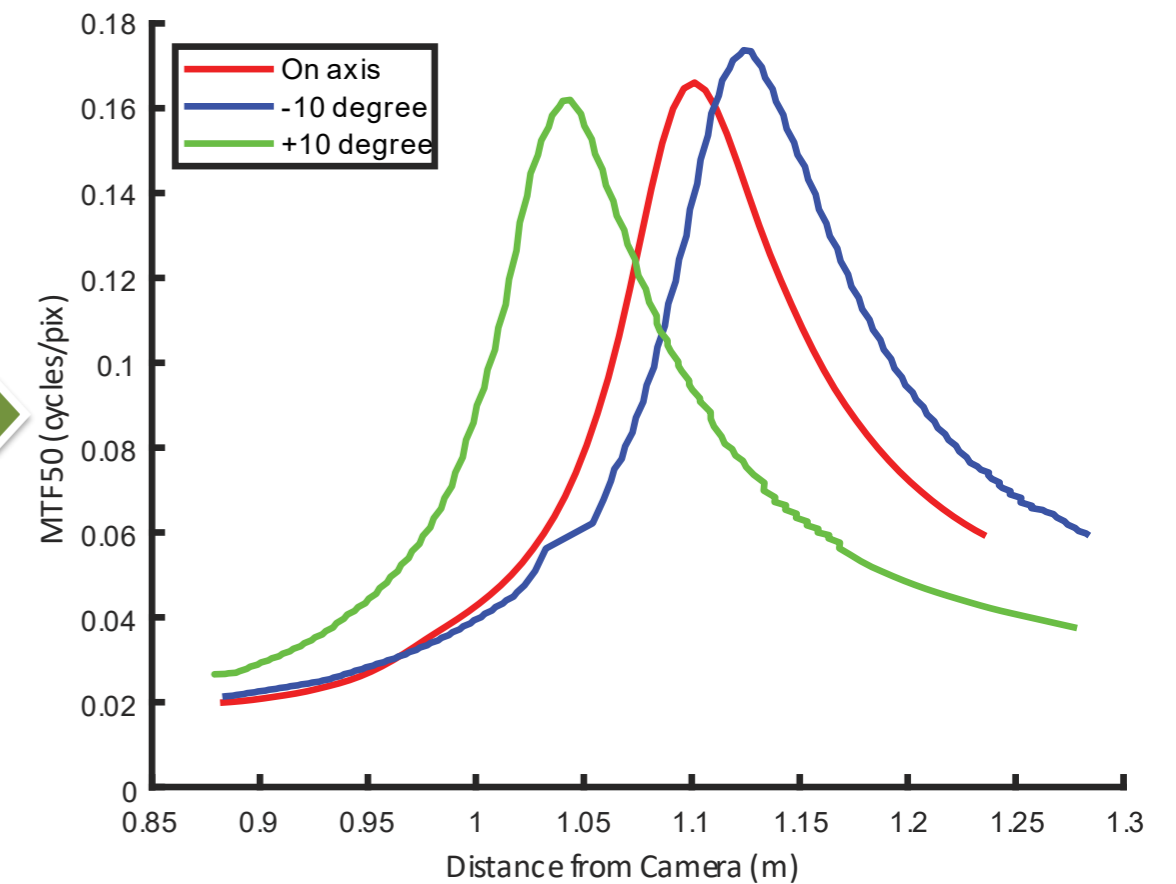- The data set can additional be processed for conventional thru-focus MTF plots

HD Calibration Data Set
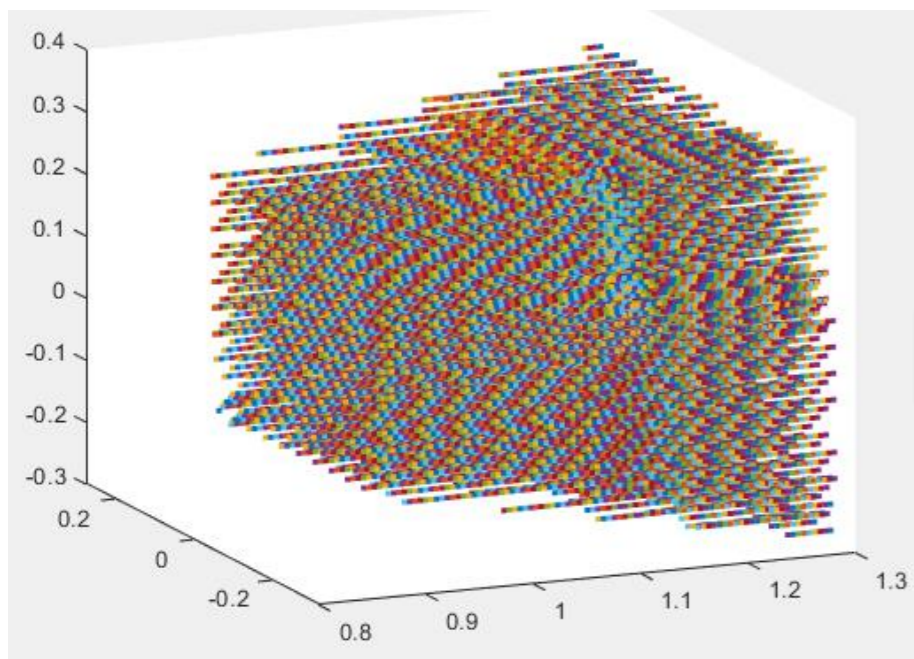
Volumetric MTF and Best Focal Surface
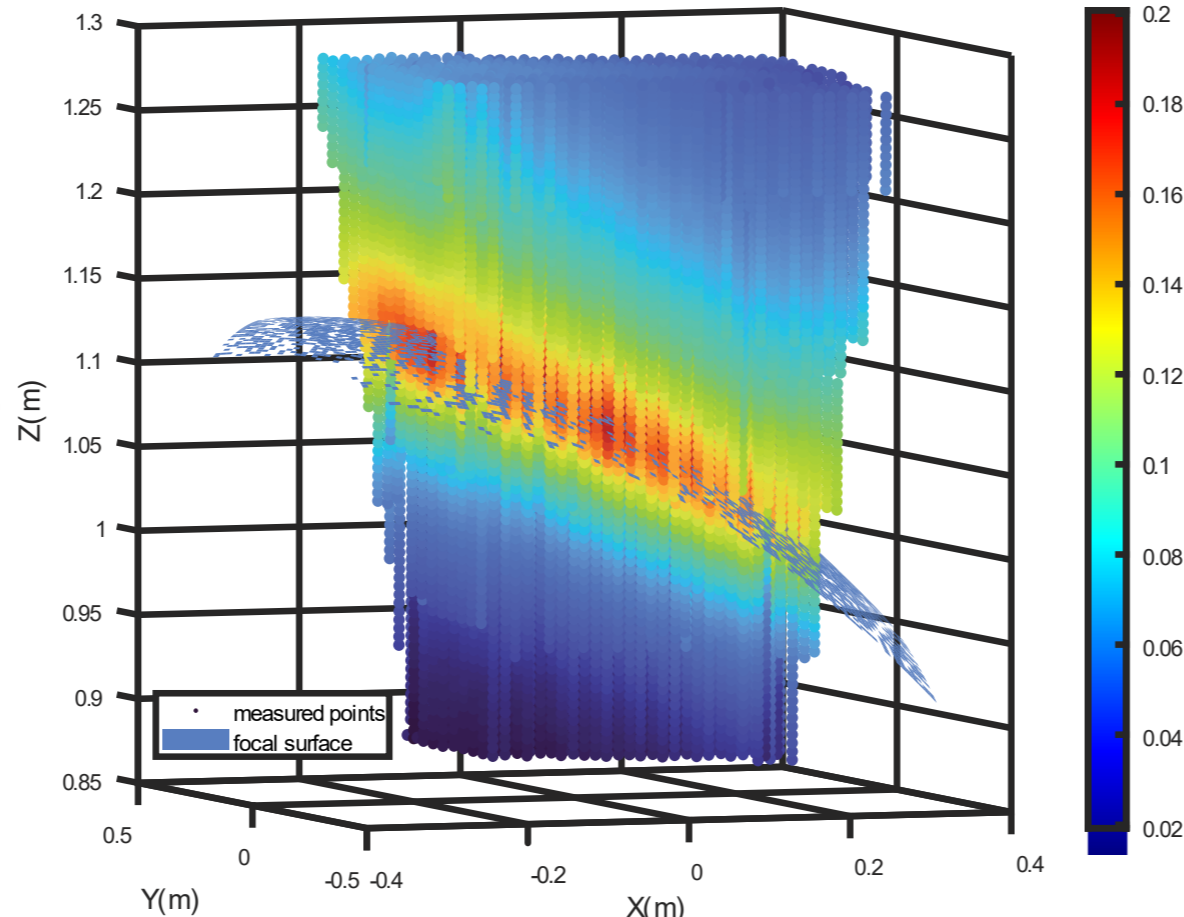
MTF50 vs Distance

CAMERA CALIBRATION ENGAGEMENT MODELS

- **Customer camera / instrument calibration on Quartus' stations**
  - Setup fee + hourly rate

- **Fixed price machine vision camera modules**
  - Quartus assists in selection of camera and lens, provides assembly and calibration services

- **Camera Calibration Station sold as a complete fixture**
  - Standard configurations or customized per each installation:
    - Robot payload and reach (UR5/UR10e/UR30)
    - Chart mount (single fixed vs. indexing turret)
    - Linear travel range for chart mount

CAMERA / INSTRUMENT INTAKE REQUIREMENTS

- **Camera Details:**
  - Sensor size, pixel size
  - Software interface – USB, gigE, CXP, CameraLink, etc
  - Mechanical interface – CAD file or ICD with key datum callouts
  - Nominal focal length

- **Calibration Parameters:**
  - Wavelengths (white light, monochromatic, multiple, etc)
  - Chart design (Quartus chart or customer specific)
  - Nominal working distance
  - Field of View (FOV) coverage

- **Calibration Outputs:**
  - Camera model desired (Kannala, Brown Conrady, Radial/Full, Best fit etc.)
  - Extrinsic calibration coordinate frame
  - Pass/Fail limits required
    - MTF, reprojection error, object space error, etc