U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Characterizing Heliostats at a Commercial Scale With Non-Intrusive Optics

conceptional design • components • integration • mass production • heliostat field

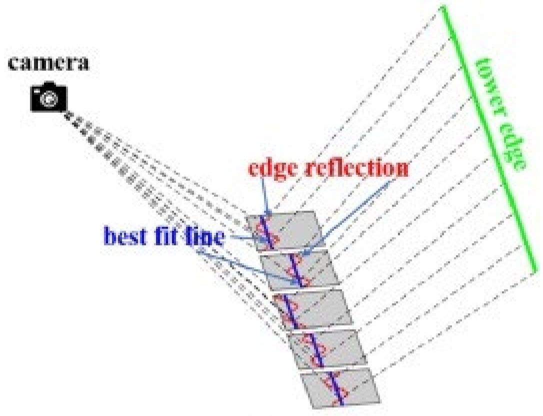
NIO Methodology

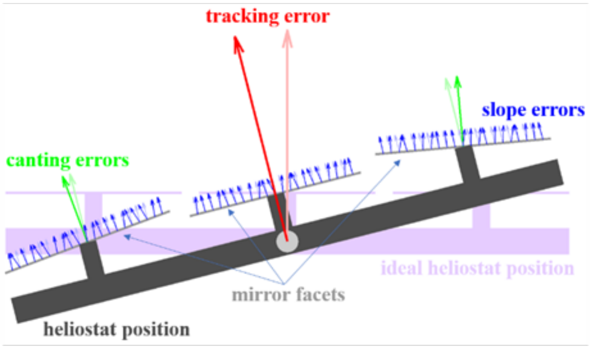
Objective

- *Precisely measure 3 sources of heliostat optical error quickly and automatically, without interfering with plant operations*

Solution

- *A UAS-based imaging platform to detect reflections of the central tower in the heliostat surface combined with a software tool to characterize reflector slope-error from the reflection data.*
- *From the slope-error data, derive canting and tracking errors*

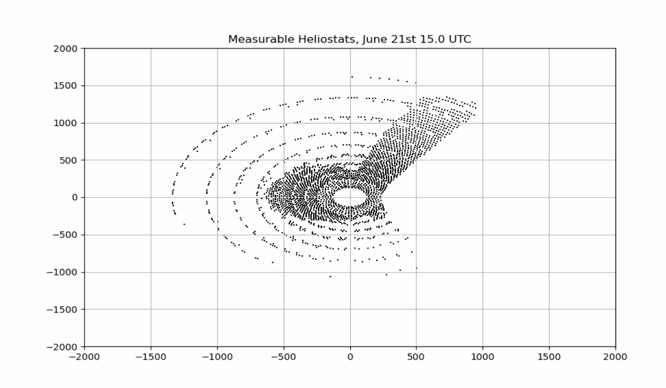




NIO Process *Point-wise deviations of the mirror surface normal vector*

1: Field model

- *Define heliostats and tower in space*
- *Assess measurability*

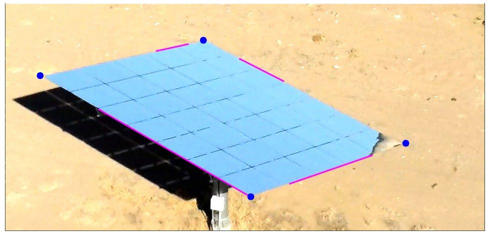


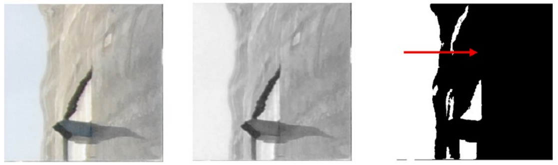
2: Data collection

- *Generate waypoints for sector of heliostats*
- *Collect video data*

3: Data parsing

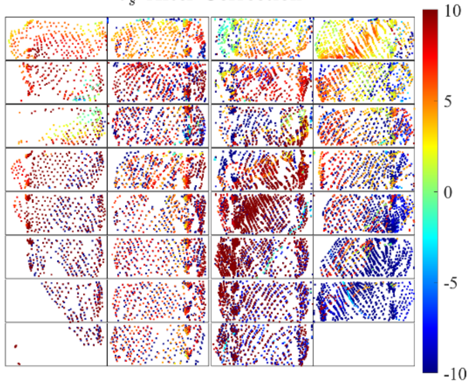
- *Define expected orientations*
- *Find heliostats*
- *Find features*





4: Optical errors

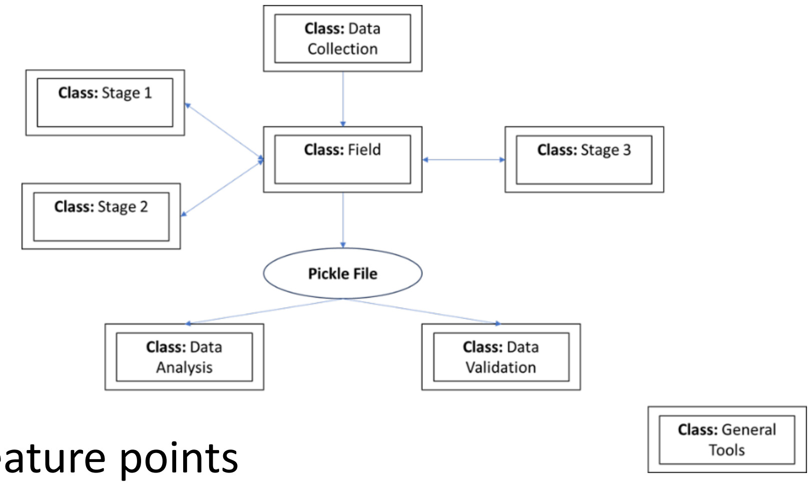
- *1D – calculate slope, canting, and tracking normal to reflected tower edge*
- *Apply tracking correction to refine*
- *2D – solve for vector that satisfies reflection conditions for two orientations at single point*



NIO Developments

Field model and measurability

- *Generalized NIO framework and architecture*
- *Sector-based measurability*

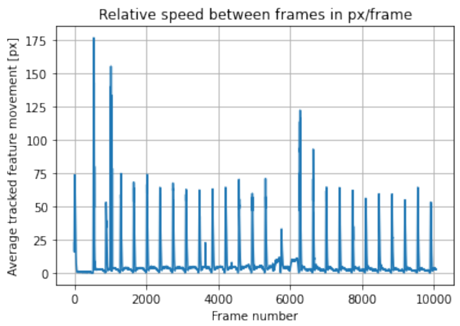


Data processing

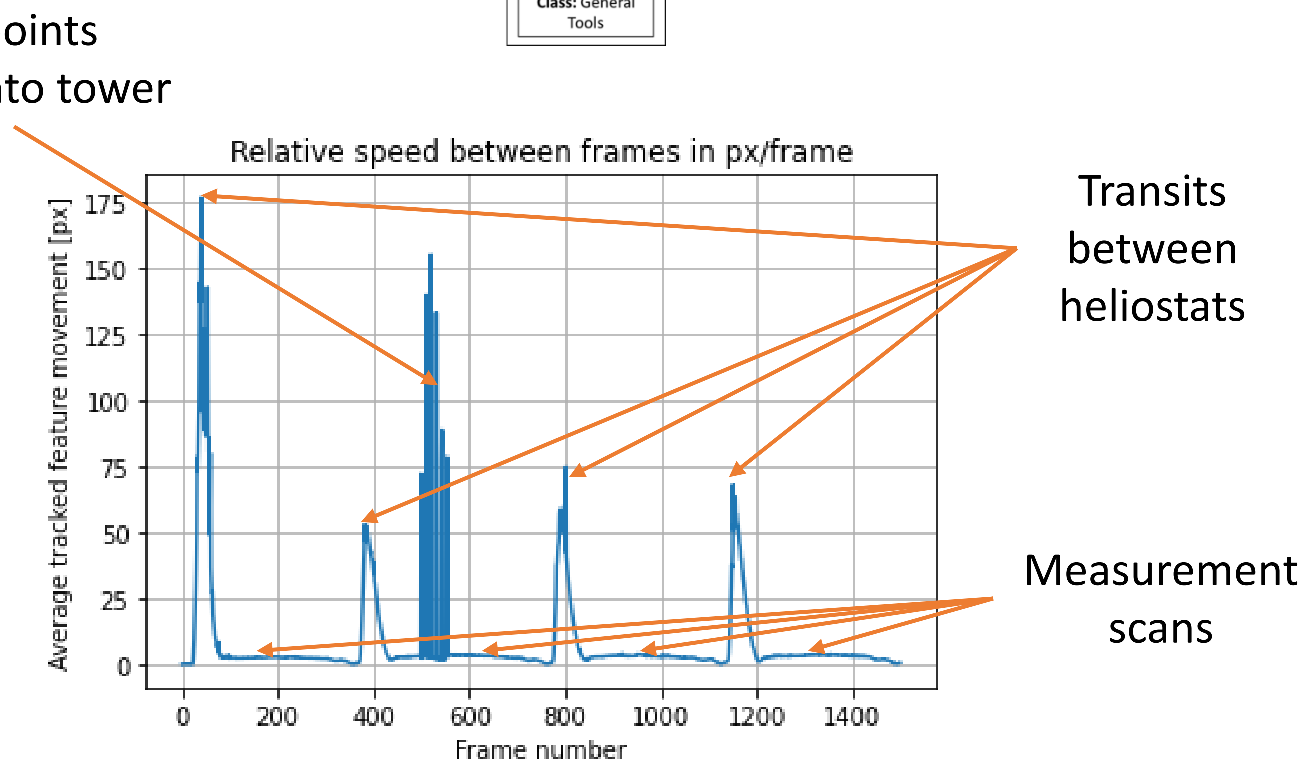
- *Optical flow for heliostat frame identification*
- *Features move faster between heliostats*

Optical error

- *Codebase transcription and validation*
- *Compiled test cases and scripts to verify consistent performance*



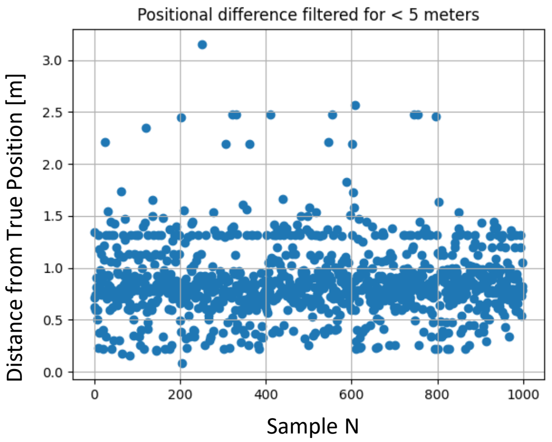
Shown is video 1 of 2 from 50-heliostat flight with 25 scans per video

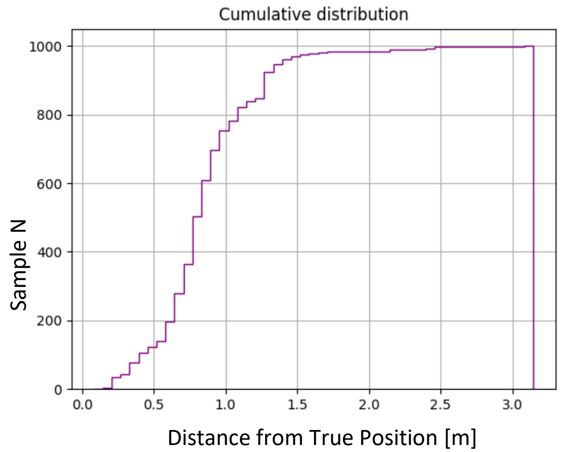


NIO Results

Camera position estimation

- *Camera position can vary for a fixed bounding box*
- *This is dependent on camera resolution*
- *Measured against "True Position" where the true corners are user-defined*

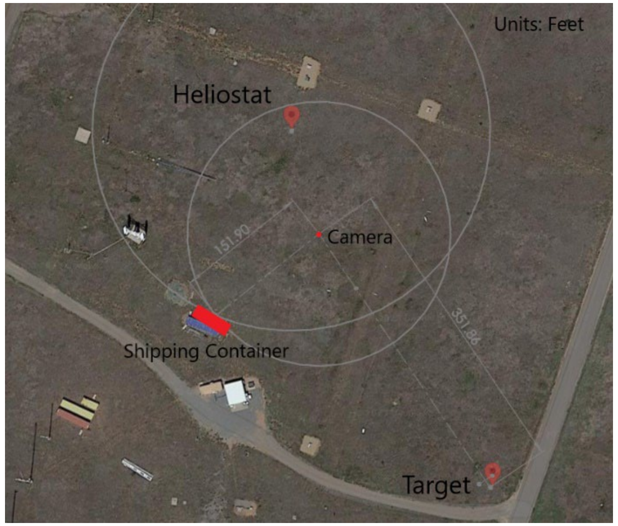


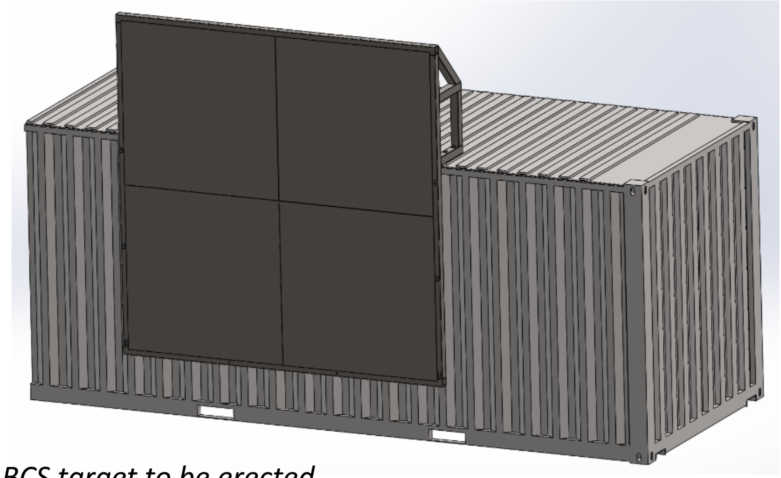


Positions derived for a single image and given bounding box for N=1000, compared against "True" position

Validation planning

- *Validation planned with new NREL BCS under development at Flatirons*





Proposed site and rendering of BCS target to be erected

NIO Benchmarks and Status

Goal	Metric	Current status	Plan forward
Collection speed	5 sec/heliostat	5 sec/heliostat	Smooth path planner, replace pivoting, focused dynamics with fixed camera heading scan to improve object tracking.
Processing speed	1 sec/frame	1.8 sec/frame tracking, 4 sec/detection	Replace detection with more rapid detection algorithm (YOLO, faster RCNN) to increase detection times. Optimize corner finding to speed up general frame. 1 sec/frame yields ~2.5 minutes/heliostat.
Accuracy	0.25 mrad	Under validation	Test code against BCS results from commercial plants and validate at Flatirons test facility at end of FY23, early FY24.
Accuracy	Feature detection accurate on 95% of input data	80% accurate on average	Testing iterative and stochastic estimation techniques for filtering detected features more accurately.
Generalizable	Train and test on 3 heliostat variants.	Used on 1, with data on 2 additional.	Training improvements for speed will include additional heliostat models for detection. Validate performance on additional heliostat shapes.
Ease of use	Functional GUI	65%	Finish tying in as performance is validated

NIO Milestones and Upcoming

FY23 milestone status

Upcoming work

- *Validation plan*
  - *Verify performance against synthetically generated data*
  - *Repeatability verification*
  - *Validation against BCS*
  - *Comparison with ReTNA*
- *Improvements*
  - *GUI functionality*
  - *Processing speed*
  - *Image segmentation updates*