A Non-Intrusive Optical (NIO) Method Measure Optical Errors of *in-situ* Heliostats in Utility-Scale Power Tower Plants: Detecting Uncertainties in Heliostat Geometry

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Introduction

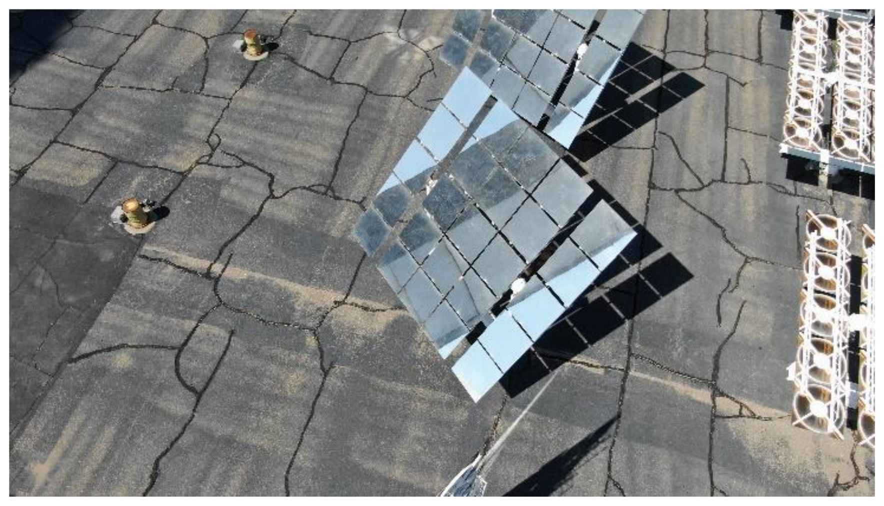
- **Power Tower Concentrating Solar Power (CSP) Technologies use heliostats (mirrors that track in two directions) to concentrate sunlight at a centrally located receiver tower**
- **Small heliostat optical errors (~1 mrad) cause major losses in plant efficiency**
- **Accurately measuring heliostat optical performance is critical to improving plant performance**

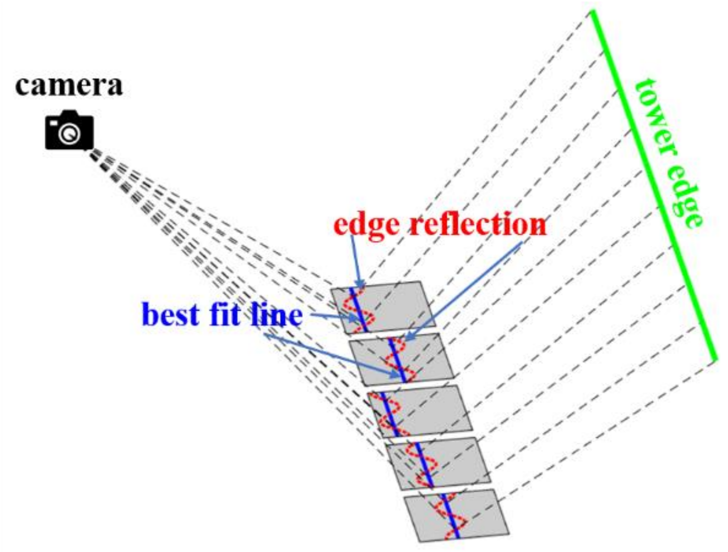
Crescent Dunes Plant in Tonopah Nevada contains overs 10,000 heliostats

The NIO Method

The NIO method allows for an efficient UAS image survey of thousands of heliostats and provides detailed optical error data.

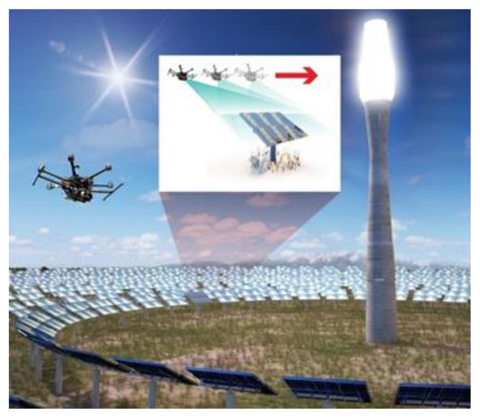
The reflected tower is used as a reference to calculate mirror surface errors by applying the law of reflections with calculated camera, mirror, and tower positions.



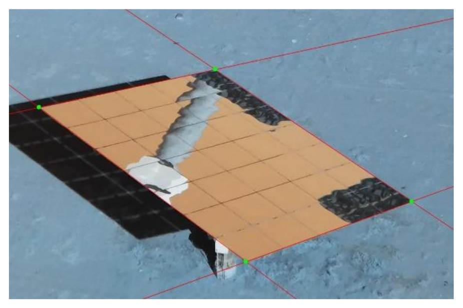


The primary steps of the NIO data collection and postprocessing are:

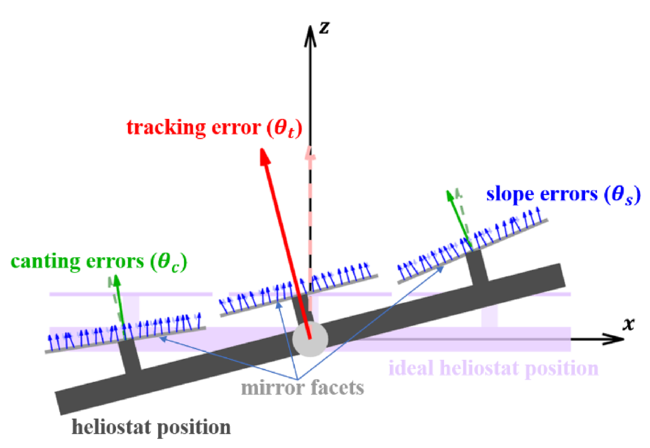
1. UAS Image Scan of Heliostats



2. Image processing to identify heliostat features



3. Construct 3D model and calculate optical errors

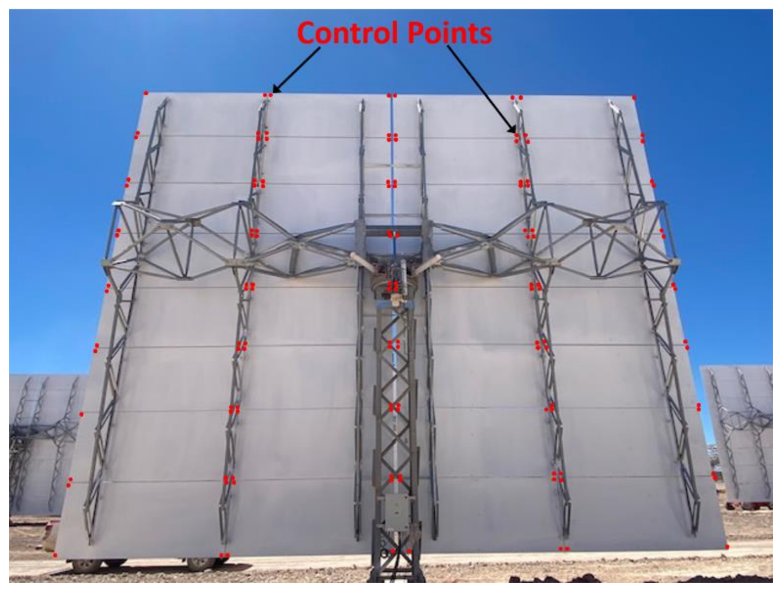


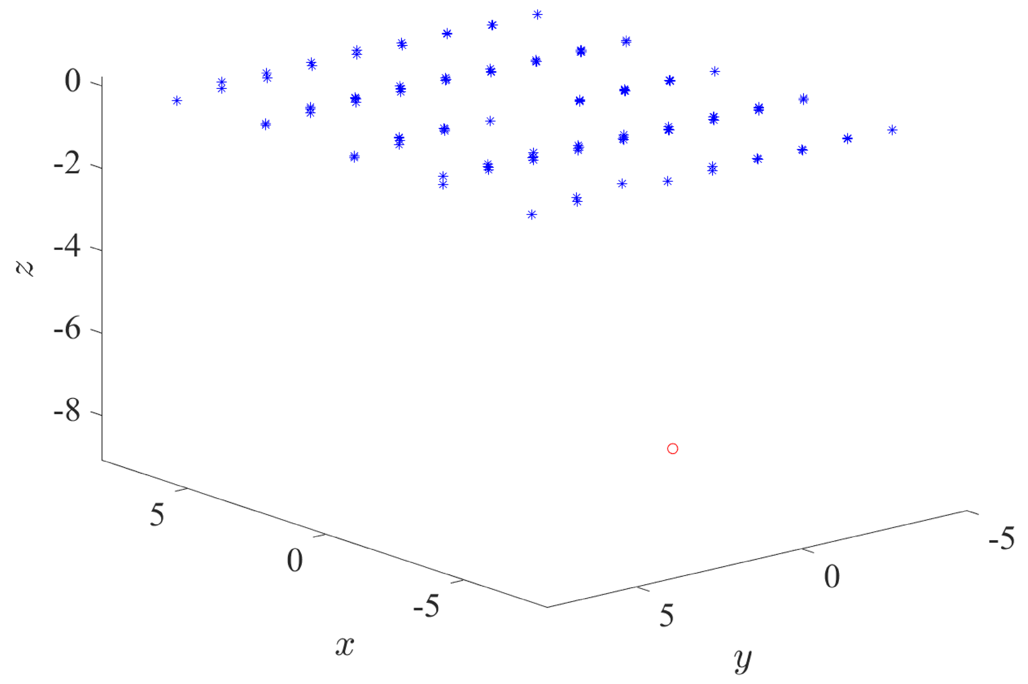
The NIO method assumes known heliostat geometry/position, which isn't always available. For example, plant operators may not have access to all manufacturer data, or there is uncertainty in recorded heliostat azimuth/elevation positions. Two methods have been developed to detect uncertainties in heliostat geometry:

1) **Heliostat manual measurements**
2) **Slope Error distribution corrections**

Heliostat Manual Measurements

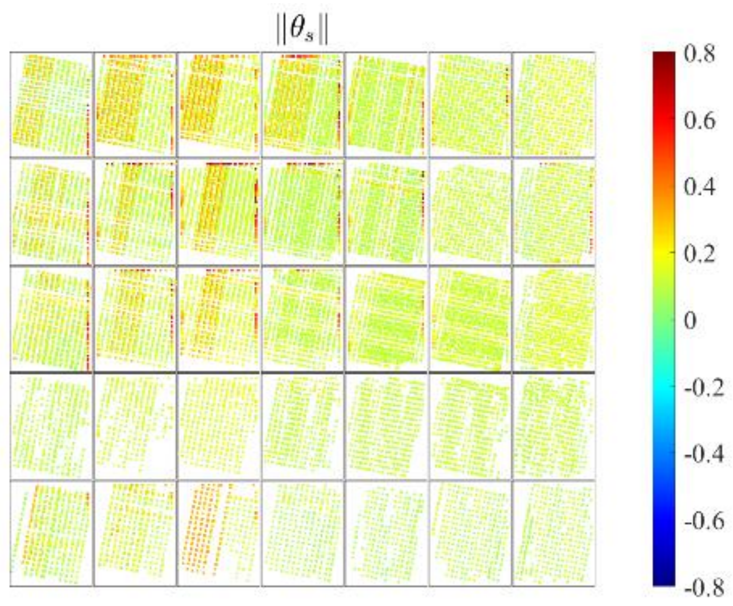
A laser distance measurement device records distance measurements from control points on the heliostat backing structure to an observer position. The collected measurements and heliostat dimensions are used to create a 3D reconstruction to estimate facet positions.



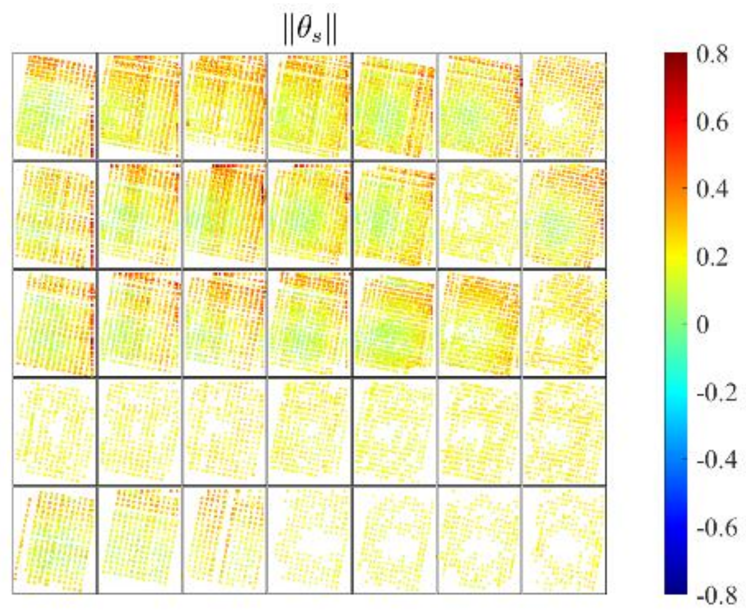


Slope Error Distribution Corrections

Facet or heliostat level skews in the slope error distribution are indicative of systemic error in the mirror shape. The true mirror focal length can be estimating by minimizing the root mean square (RMS) of the slope error distributions.



Synthetically generated slope error distribution of heliostat with facet focus 1565 m



Slope error distribution when facets incorrectly assumed to be flat

Ongoing work

- **Verify reliability of measured results against BCS and ground truth measurements**
- **Develop sensitivity analysis and process measurement procedures for manual method to guarantee accuracy goal**
- **Continue testing with commercial plant data**

References

[1] R. A. Mitchell and G. Zhu, "A non-intrusive optical (NIO) approach to characterize heliostats in utility-scale power tower plants: Methodology and in-situ validation," Solar Energy, vol. 209, pp. 431–445, Oct. 2020, doi: 10.1016/j.solener.2020.09.004.
[2] R. A. Mitchell and G. Zhu, "A non-intrusive optical (NIO) approach to characterize heliostats in utility-scale power tower plants: Sensitivity study," Solar Energy, vol. 207, Art. no. NREL/JA-5500-75833, Jul. 2020, doi: 10.1016/j.solener.2020.06.093.
[3] T. Farrell, K. Guye, R. Mitchell, and G. Zhu, "A non-intrusive optical approach to characterize heliostats in utility-scale power tower plants: Flight path generation/optimization of unmanned aerial systems," Solar Energy, vol. 225, pp. 784–801, Sep. 2021, doi: 10.1016/j.solener.2021.07.070.

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