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

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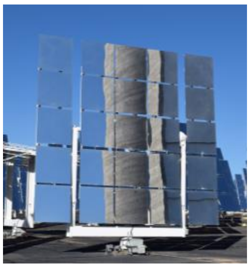
1. Introduction

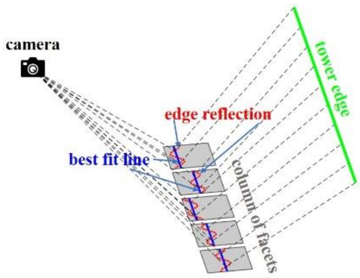
Heliostat optical errors can account for significant losses in efficiency of power tower concentrating solar power (CSP) plants. Accurately measuring heliostat optical errors can help to improve plant performance. A **Non-Intrusive Optical (NIO)** method has been developed to efficiently measure heliostat optical errors from UAS collected images of the mirror surface reflection [1]–[3]. In some cases, plant data of heliostat geometry can be incomplete or contain inaccuracies, in which case field collected data can be used to detect and correct uncertainties, which is valuable information for plant operators.

2. Measuring Heliostat Optical Errors

In a power tower CSP plant, heliostats track the sun in two dimensions to focus sunlight at a receiver located on a central tower. Figure 1a shows a heliostat at Sandia National Lab's National Solar Thermal Test Facility (NSTTF). Slope error (θ_S) is a type of optical error defined as the pointwise deviation of the local surface normal vector from the ideal surface normal. The NIO method was developed to measure various optical errors, by analyzing images of the reflected tower structure in the mirror surface, like the one shown in Figure 1a. By the detecting the reflected tower edge in the images, the method calculates local slope errors by using knowledge of the relative camera, tower, and reflected tower positions, and the ideal heliostat geometry, as depicted in Figure 1b. Mirror facet canting error and heliostat tracking error can be derived by averaging the slope error distribution over the facet and full heliostat respectively.



(a)



(b)

Figure 1: (a) Image taken of a heliostat at Sandia's NSTTF. (b) Diagram showing how detected distortions in the tower reflection can be used to quantify optical errors with a known camera, heliostat, and tower position.

3. Detecting Uncertainties in Heliostat Geometry

The NIO method calculates optical error results with respect to an assumed heliostat geometry, that depends on heliostat dimensions, canting focus, facet focus/curvature, position, and azimuth/elevation. This data can normally be acquired from plant operators, but this may not always be the case. For example, recorded data of heliostat azimuth and elevation positions may contain uncertainty. Additionally, plant operators may not always possess detailed heliostat geometry known by the heliostat manufacturers or deployers. To obtain accurate optical error estimates, two methods have been developed to detect uncertainties in heliostat geometry, described in the sections below:

3.2 Heliostat Manual Measurements

A procedure was devised to collect manual measurements of control points on the backing structure of a heliostat using a laser distance measuring device from a fixed observer position to reconstruct a 3D model of the heliostat shape. Figure 2 shows a 3D reconstruction with respect to an observer position of a heliostat measured in the field using this method.

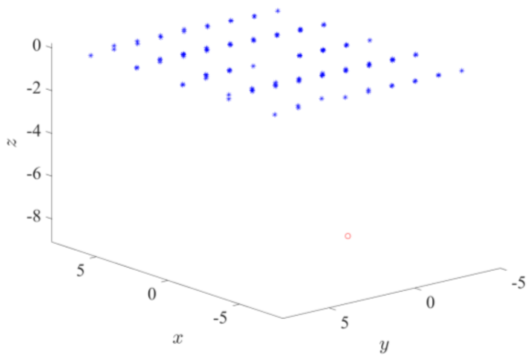


Figure 2: A 3D reconstruction of helisotat facet geometry using the manual measurment method. Facet corner positions (blue) are shown with respect to an observer position (red)

3.3 Slope Error Distribution Corrections

Uncertainty sources can be identified and refined based on the shape of the measured heliostat slope error distribution. Geometry uncertainty sources impact the slope error distribution in different ways. Figure 3 shows how slope error exhibits a facet level skew when facets are wrongly assumed to be flat. The optimal facet focal length can be determined by minimizing the standard deviation of the slope error distribution. This method has been used to identify and quantify discrepancies in heliostat orientation and facet curvature in collected data from commercial solar fields.

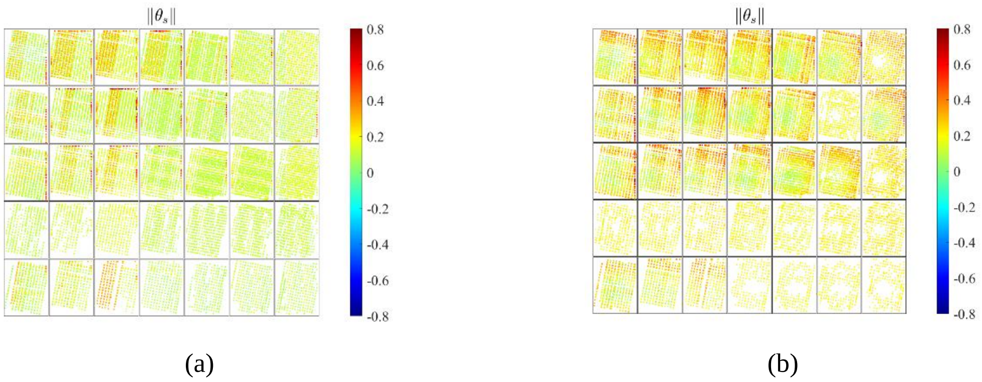


Figure 3: (a) synthetically generated slope error distribution of heliostat with facet focus 1565 m. (b) slope error distribution when facets incorrectly assumed to be flat for same heliostat.

4. References

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