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A Non-Intrusive Optical Technology to Measure *in-situ* Heliostat Optical Errors

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Introduction

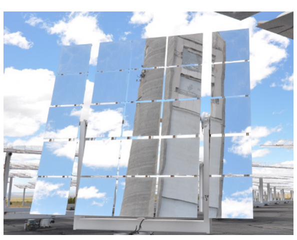
- Concentrating Solar Power (CSP) is a type of solar technology that uses mirrors to concentrate solar power to a receiver
- Past methods of optical characterizations of heliostat fields are inefficient because they require timely surveys of the field and provide limited results
- An innovative non-intrusive optical (NIO) characterization method is presented to measure slope errors and canting errors of heliostats
  - ✓ Will not interrupt the heliostat field operation
  - ✓ Can measure multiple types of optical errors
  - ✓ Can survey the entire field within a day or two

Background

Heliostats

- Heliostats track the sun in two axes and concentrate solar light to a receiver on top of tower
- The heliostat field at Crescent Dunes (depicted below) consists of 10,347 heliostats and has a power generation of 110 MWe with 10 hour thermal storage.

- The heliostats considered for this investigation consist of a grid of mirror facet panels mounted on a motorized system

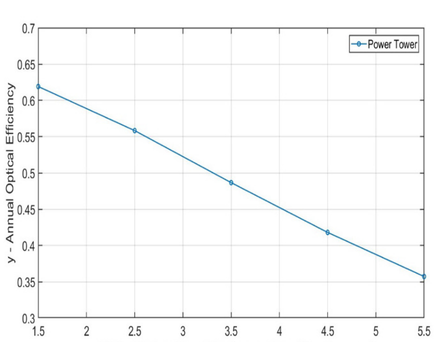


Optical Errors

- Mirror specularity – error resulting from scattering of the reflected light due to microscopic surface structure
- Mirror slope error – angular difference between ideal surface normal and true surface normal at a point on the mirror
- Mirror canting error – averaged slope error over a facet
- Mirror tracking error – error in the overall orientation of the heliostat with respect to the receiver

Impact of Optical Degradation

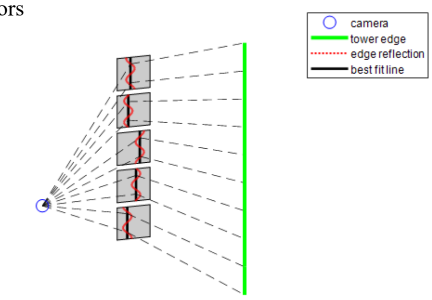
- The annual optical efficiency may decrease about 10% with an increase of 1.5 mrad in optical error.



Approach

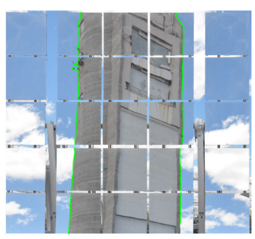
Concept

- Given a series of images of a heliostat, compare the reflected tower edge in each facet with that of a reference facet with known canting.
- Distortions and misalignments of the reflected edge can be measured to calculate slope errors and canting errors

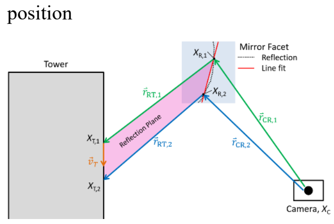


Algorithm

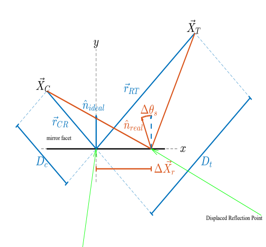
1. Correct for image distortion and use collinearity to locate the camera and heliostat in three-dimensional space
2. Identify the reflected tower edge in each facet using image processing tools



3. Using multiple images of a reference facet with known canting error, find the location of the tower edge
   - The center facet is designated as the reference facet with known canting error
   - A reflection plane is defined by two reference points $X_{r,1}$ and $X_{r,2}$, chosen along the reflected tower edge, and the corresponding rays to the tower edge $\vec{r}_{T,1}$ and $\vec{r}_{T,2}$, which are known because the canting of the facet is known
   - The tower is defined by a three-dimensional direction vector $\vec{v}_T$ and a point $\vec{X}_T$, which makes up six unknowns, so at least three reflection planes/images are required to solve for the tower position



4. Calculate the slope error θ_s for the points along the reflected edges in each facet for each image using Snell's law
   - $\vec{n}_{\text{ideal}}$ defines the ideal orientation and $\vec{n}_{\text{real}}$ defines the true orientation at a reflection point
   - The slope error can be calculated by using Snell's law, since the ideal and real normal vectors are related by a rotation matrix that depends on θ_s

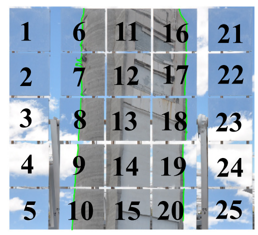


5. Calculate the canting error θ_c by averaging the slope errors over a facet

Case Study

Test Heliostat at Sandia

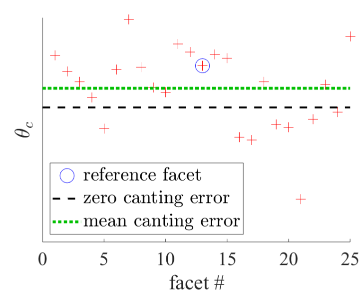
- To test the algorithm, images were taken of a heliostat at Sandia National Labs
- The heliostat consists of a 5-by-5 grid of 25 facets, numbered column wise from left to right.



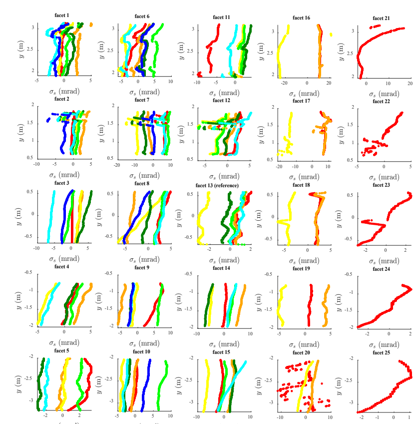
- The center facet (facet # 13) is used as the reference facet with assumed known canting error

Results

- The figure below shows canting errors for all 25 facets

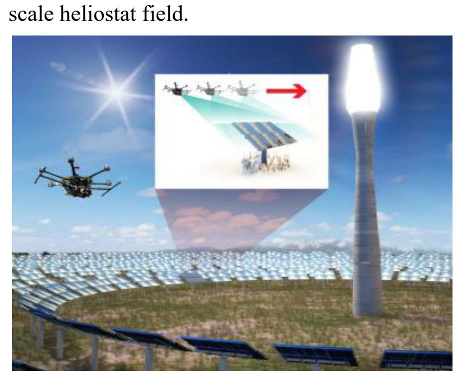


- The figure below shows the slope error values for each image of each facet
- The canting error has been subtracted from the slope error so that the distributions for each facet have zero mean
- Different colors correspond to different camera positions
- Instances when the slope error "juts out" from the curve happen when there are protrusions on the reflected tower edge



Future Work

- An Unmanned Aerial System (UAS) will be adopted to collect reflection images in a utility-scale heliostat field.



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