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Heliostat Focal Length Impacts on SOFAST Sensitivity

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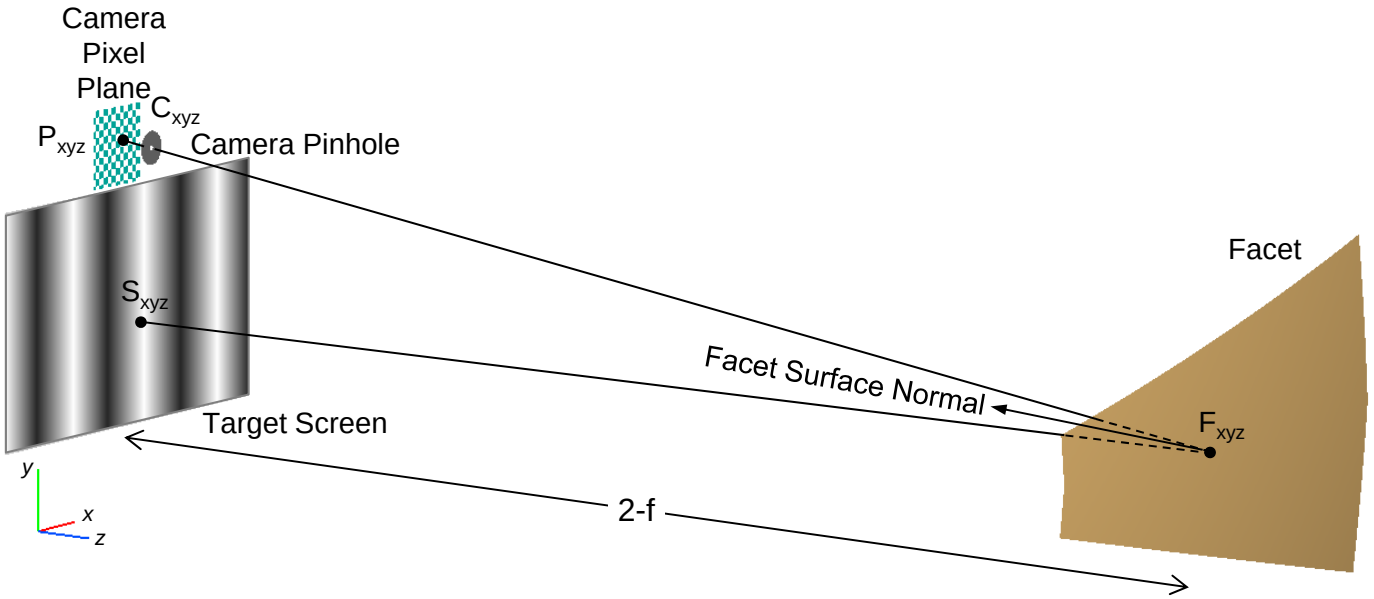
Abstract

The SOFAST system uses fringe reflection methods to provide a detailed surface normal map of a reflective facet used in concentrating solar power systems. SOFAST was recently extended from short focal length point-focus systems to support heliostat facets. This extension introduced additional variables in the physical set-up of the system. In addition, a large target screen and a short distance between the facet and the screen relative to facet focal length changes the system sensitivities to uncertainties. In characterizing heliostat facets, and in particular when focusing the facets, it is important to understand the uncertainties and sensitivities. In this paper, we explore the sensitivities of the SOFAST system when measuring and focusing heliostat facets of various focal lengths suitable for deployment in our 5 MW_{th} heliostat field at Sandia National Laboratories. We developed test case heliostat facets analytically, with "perfect" surface shapes, and then empirically explore the sensitivities of SOFAST to deviations in the system set-up parameters.

Background

- **SOFAST (Sandia Optical Fringe Analysis Slope Tool) uses fringe reflection methods to provide a detailed surface normal map of a reflective facet for CSP systems**
- **SOFAST is used at Sandia to characterize and align facets in short focal length point-focus systems**



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Motivation

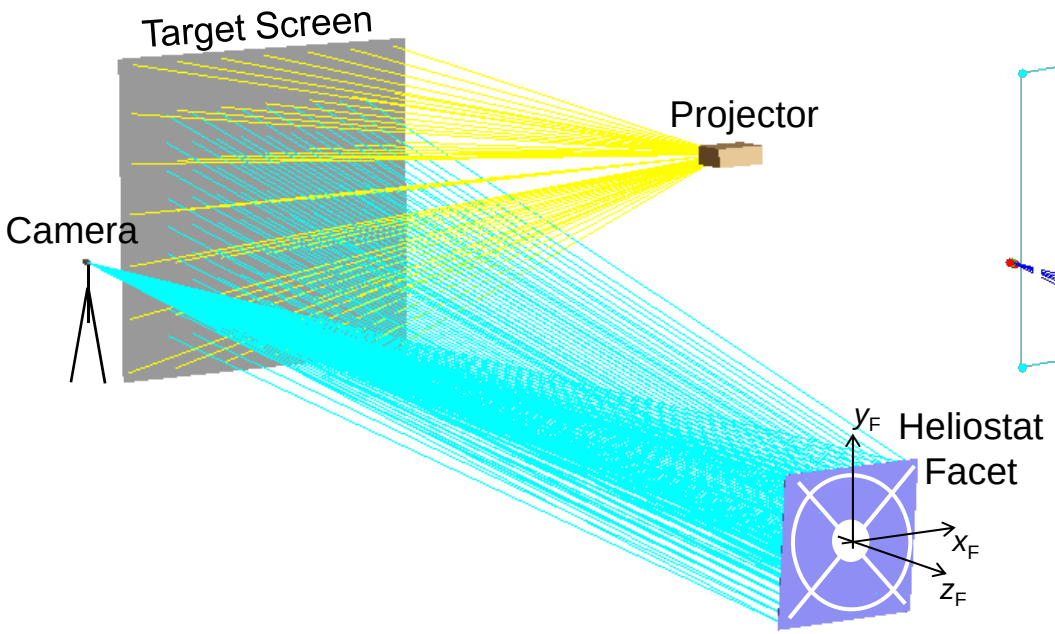
- **SOFAST was recently extended from point-focus dish systems to support heliostat facets with long focal lengths (> 60 m)**
- **This extension introduced …**
  - additional variables in the physical set-up of the system, and
  - a large target screen; the large screen and the short distance between the facet and the screen relative to the facet focal length changes the system sensitivities to uncertainties
- **For the purpose of measuring and setting the focal length of heliostat facets before deployment, it's important to understand the sensitivities to the set-up parameters of our measurement system**

Approach

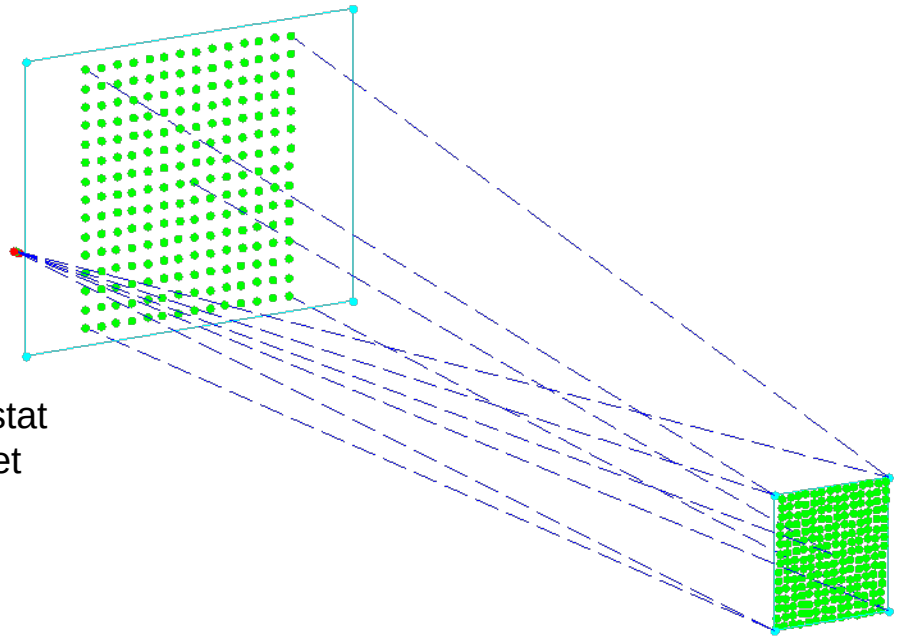
- **We chose to study a few key parameters that appear to have a profound effect on the facet focal length measurement**
- **We developed two test case heliostats analytically with perfect surfaces, and then empirically explore the sensitivities of SOFAST to deviations in the system set-up parameters**
  - Using the baseline measurement set-up, we generated analytical facets with focal lengths 100 and 200 m
  - We then varied the value of one set-up parameter at a time and re-ran the SOFAST analysis on the analytical facets and observed the sensitivities in the focal length calculations

Baseline SOFAST Measurement Set-up

Solid Model



MATLAB Model



- The projector projects the fringe patterns onto the target screen
- The camera views the fringe patterns in reflection through the facet

MATLAB model used to generate synthetic (analytical) facet data

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Key Variables Studied

- **Key physical set-up parameters**
  - **Camera position, C_{xyz} – measured with tape measure from the target screen center (origin)**
  - **Facet *z* position, F_{xyz} – measured with camera extrinsic analysis (in the Camera coordinate frame)**
  - **Target screen dimensions, (w_S, h_S) – measured with tape measure**
- **Error in measuring these parameters impact the focal length calculation**
- **Focal length calculation:**

Fit the slope functions to the facet surface normal data

The 'A' and 'B' coef. are related to the focal length

Parabolic Model

$$z = Ax^2 + By^2 + Cx + Dy + Exy + F$$

Slope Functions

$$s_x = \partial z / \partial x = 2Ax + C + Ey$$

$$s_y = \partial z / \partial y = 2Bx + D + Ex$$

Focal Lengths

$$f_x = \frac{1}{4A}$$

$$f_y = \frac{1}{4B}$$

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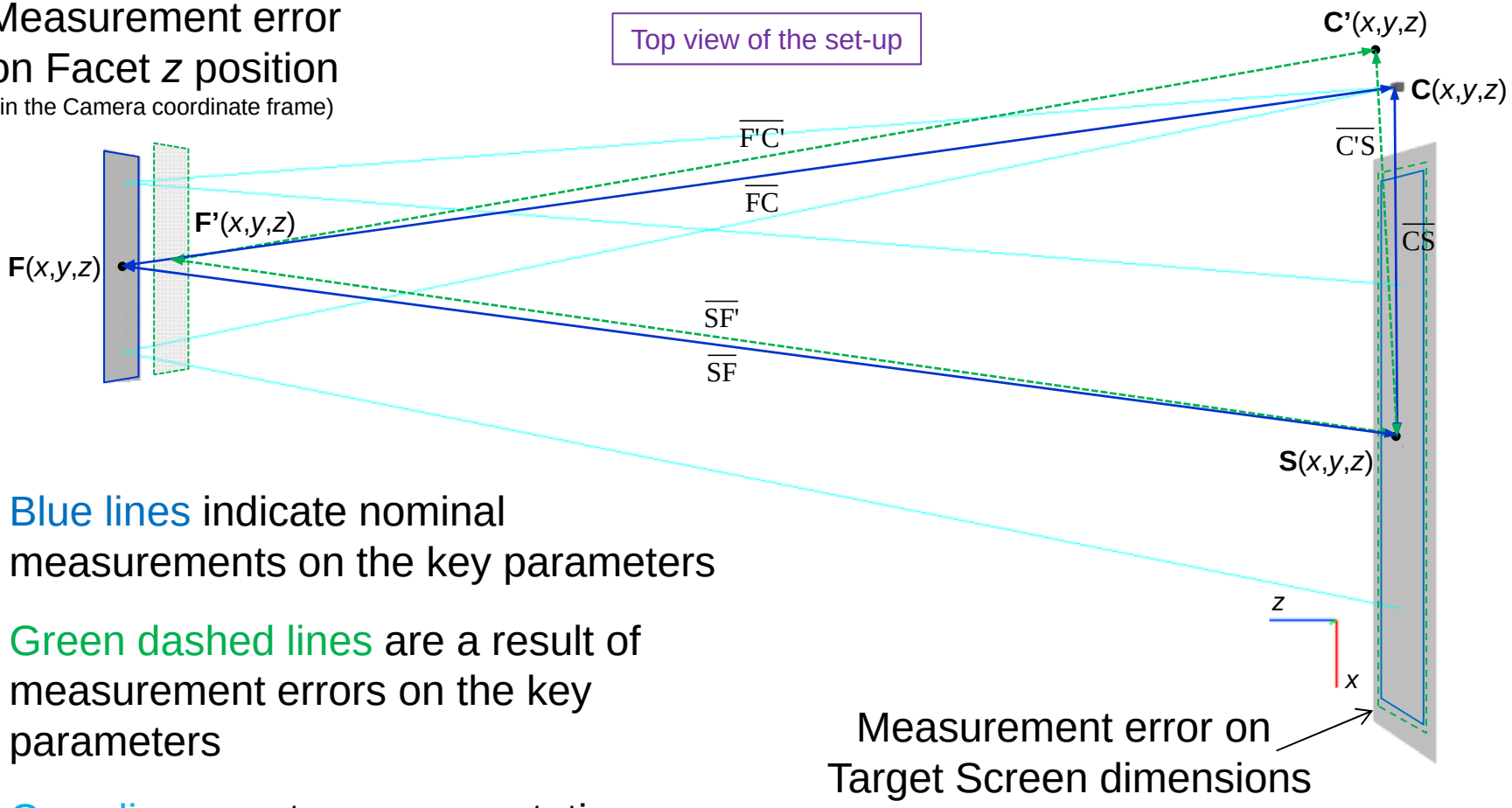
Measurement Errors on Key Parameters

Measurement error on Camera position

Measurement error on Facet *z* position
(in the Camera coordinate frame)



Measurement error on Target Screen dimensions

- Blue lines indicate nominal measurements on the key parameters
- Green dashed lines are a result of measurement errors on the key parameters
- Cyan lines are two representative camera "rays" for a nominal set-up

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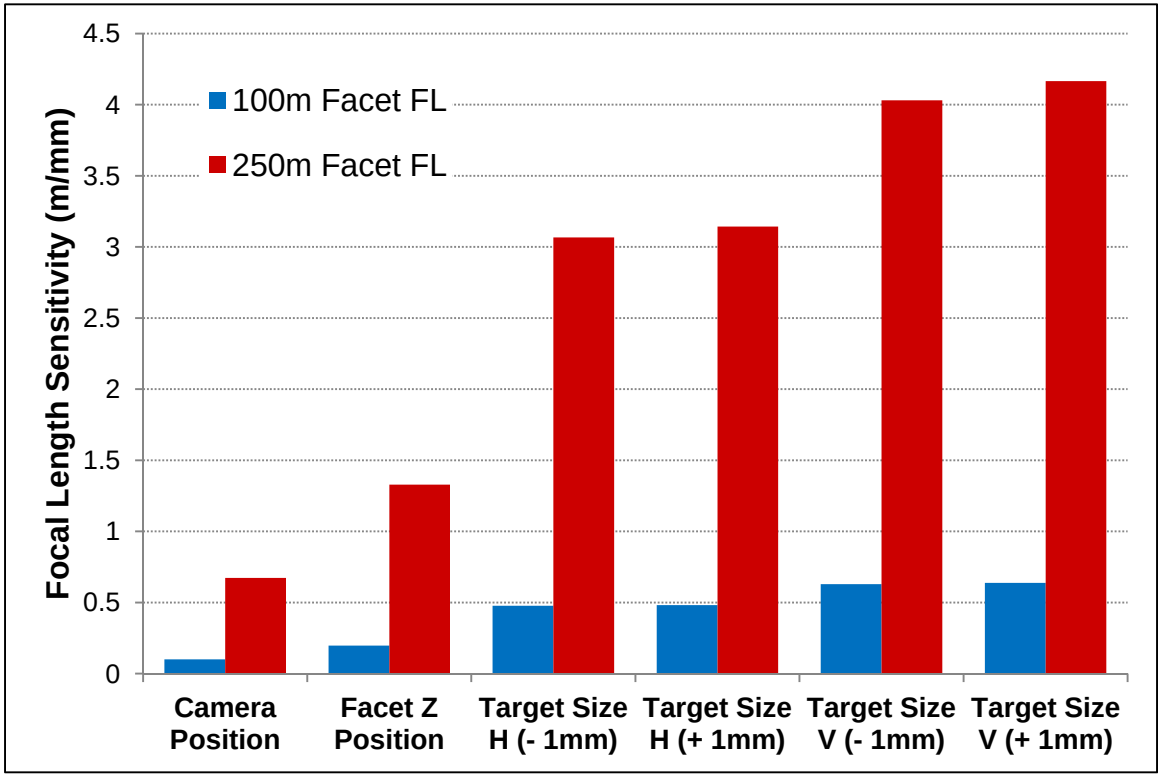
Focal Length Measurement Sensitivity



H = horizontal dimension
V = vertical dimension

- Measurement error of +/- 1 mm on each key parameter
- For example, 1 mm measurement error on the Camera position gives ~0.7 m of focal length error, if measuring a 250 m focal length facet

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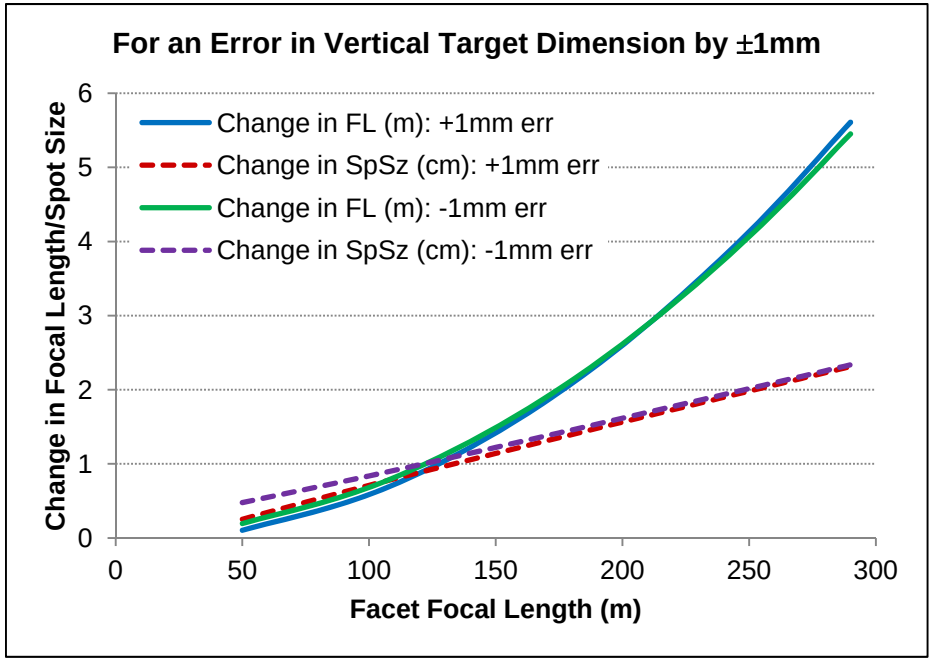
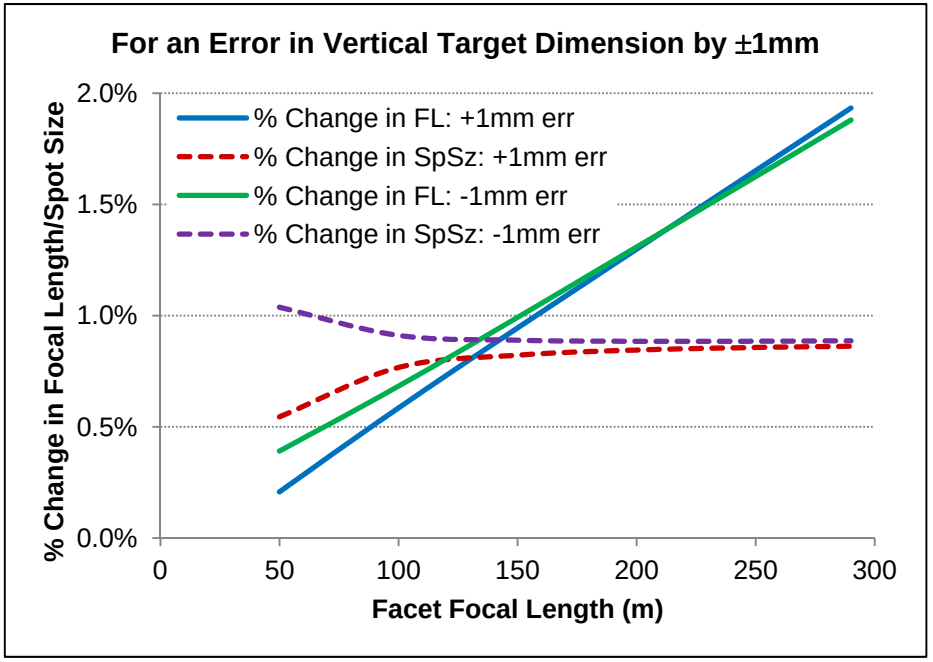
Focal Length Error Impacts on Spot Size



(a)



(b)

- **Shifts in focal lengths and corresponding spot size variations (at the receiver) for a measurement error in the vertical target dimension by ±1 mm, shown as (a) physical changes and (b) percentage changes**

Discussions

- **Key set-up parameters have different sensitivities**
  - Errors on Camera position are not as sensitive, while errors in measuring the Target dimensions are very sensitive
- **Sensitivity dramatically increases for long focal length facets**
  - Given a facet with a smaller curvature (i.e. longer focal length), specified changes in curvature impact the facet focal length to a greater extent
- **Changes in spot sizes are not as sensitive, therefore the focal length error impacts are somewhat mitigated with increasing focal lengths**

Conclusions

- We studied the impacts of key set-up parameters on the SOFAST sensitivity for measuring heliostat facets
- For the purpose of setting the focus of heliostat facets, it's important to understand these sensitivities
- Errors in measuring the Target dimensions are the most sensitive
- Sensitivity increases with increasing focal length, but low sensitivity on the spot size somewhat mitigates this
- From this study, we can place appropriate tolerance bands on the key parameters