NREL
Transforming ENERGY

Improvement in Reflected Target Non-Intrusive Assessment (ReTNA) Optical Measurement System

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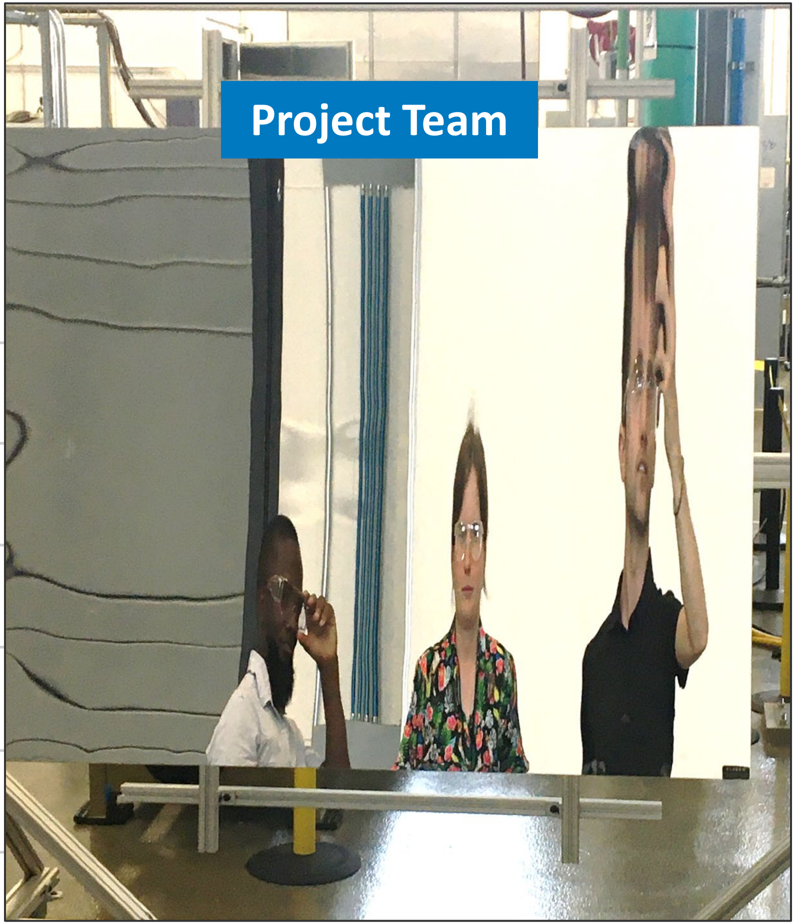


Background

Reflected **T**arget **N**on-intrusive **A**ssessment
(ReTNA)

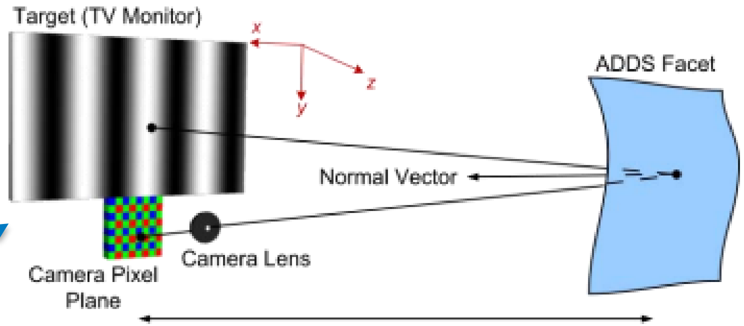
State-of-the-Art

Deflectometry: measurement by deflected reflection.

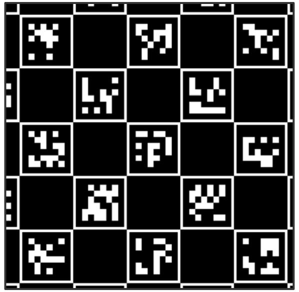
- **Fringes** – powerful, high resolution, more complicated setup: Qdec (DLR, CSP Services), SOFAST (Sandia), Fraunhofer ISE.
- **Reflected target or pattern** ReTNA (NREL), VIS-PT (ENEA, reflected lights).

Photogrammetry – 3D positional measurement: well established, but requires targets attached to mirror surface.

Interferometry: Ultra high precision, used for telescope mirrors, difficult on larger surfaces.



N. S. Finch and C. E. Andraka https://doi.org/10.1115/ES2011-54455



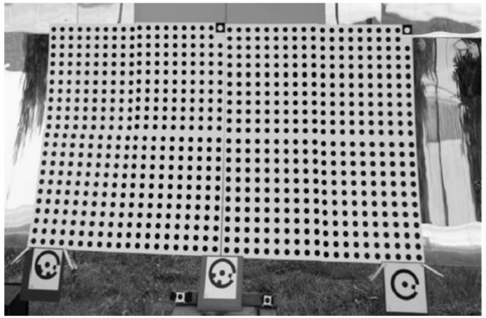


Fig. 6. Photogrammetry measurements carried out at ENEA's PTC facility by CENER's technicians.

C. A. Arancibia-Bulnes et al, doi: 10.1016/j.rser.2016.11.048.

Objective

Reflected **T**arget **N**on-intrusive **A**ssessment (**ReTNA**) - a tool for:

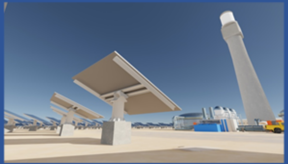
- Assembly line QA/QC, particularly at small installations.
- Adaptability to measurement at a variety of heliostat sizes and orientations.

NIO (NREL's tool for field analysis)

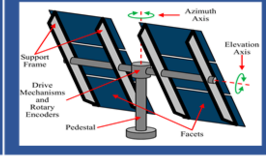
ReTNA

Heliostat Development Cycle

Conceptual Design:



Heliostats Components:



An Integrated Heliostat:

Mass Production of Heliostats:

A Heliostat Field:

Component testing – measurement after wind load simulation and repeated stress testing.

An Integrated Heliostat: full scale heliostat testing, facet canting measurement.

Mass Production of Heliostats: Assembly line quality assurance and control.

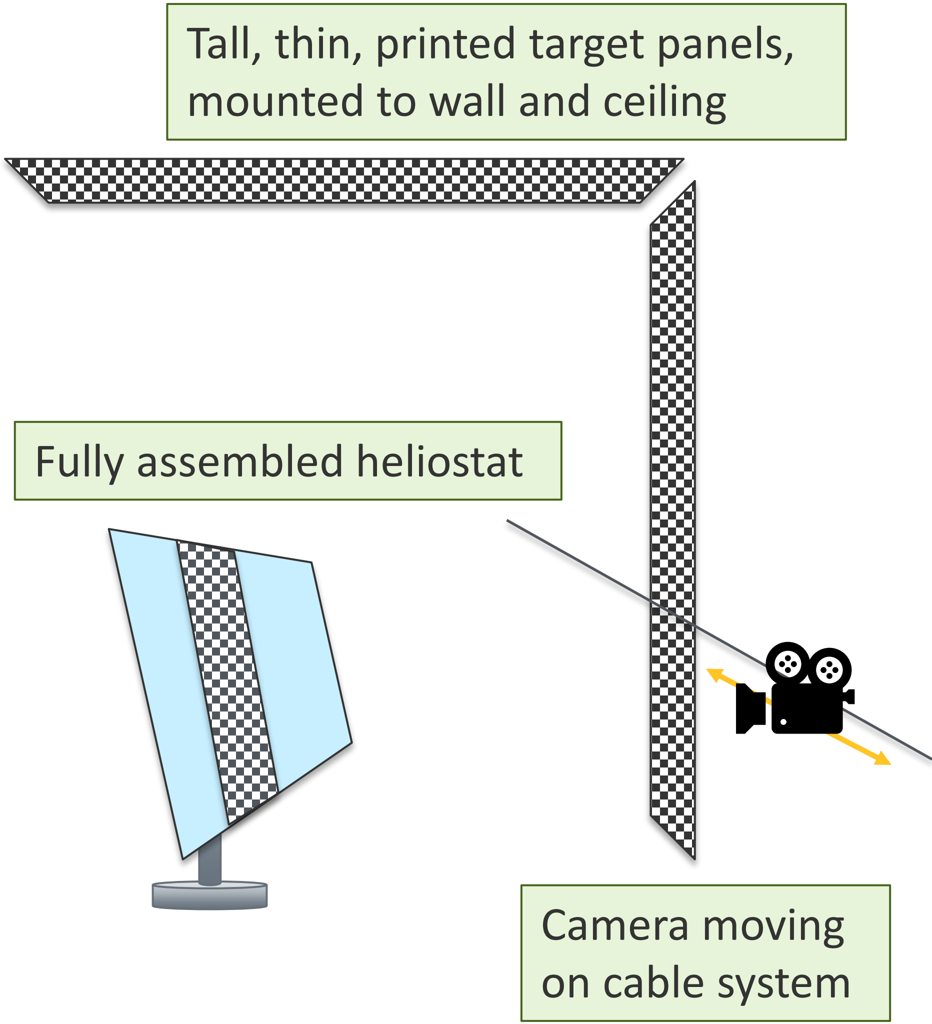
ReTNA Motivation

Powerful fringe deflectometry methods already exist. Deflectometry with coded targets have some advantages:

- **Low cost, easy setup** vs. large screen target needed for fringe deflectometry – easy to install for any size/orientation heliostat.
- Leverage **recent advances in computer vision**, open-source tools.
- **Easy to debug**, direct measurement of target points with PG removes setup precision and calibration requirements.
- **Ambient lighting**, for warehouse or assembly line (no projector).
- **2D slope measurement** with a single image.

<u>**Disadvantages:**</u>

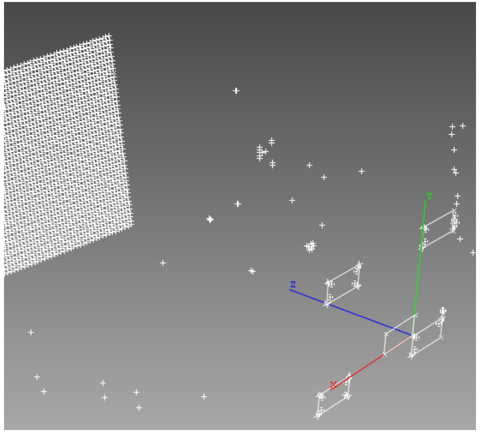
- **Lower resolution** compared to fringe methods



ReTNA Features

Reflected **T**arget **N**on-intrusive **A**ssessment (**ReTNA**)

1. Photogrammetry locates mirror and all target points in space.
2. Camera collects images of reflected targets.
3. Camera position is solved directly from image.
4. Reflected target points automatically identified
5. Measure mirror **surface slope** and facet **canting**.



ReTNA Workflow

Series of Images

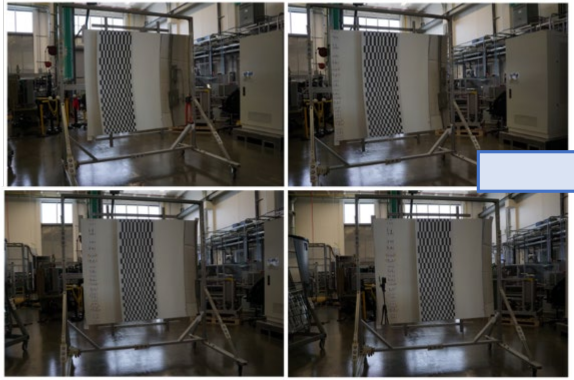
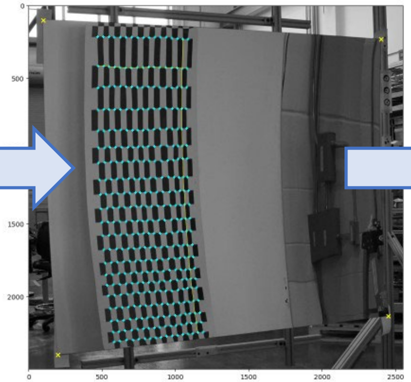
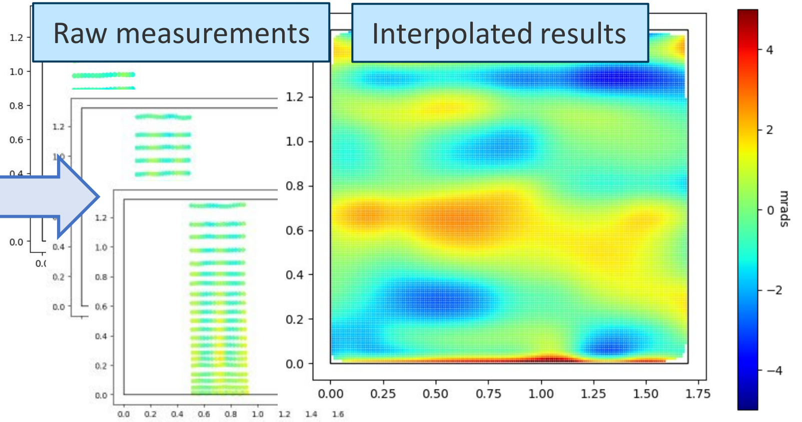


Image Processing



Full Facet or Heliostat Surface Analysis

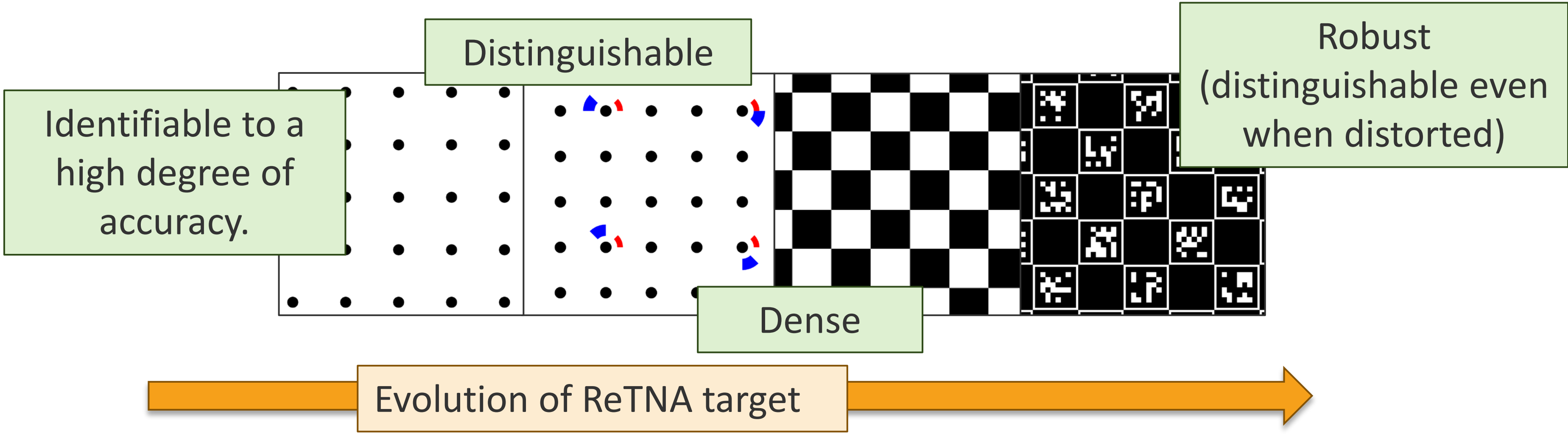


New Development: Portable System

Since SolarPACES 2022

New Targets for Faster Analysis

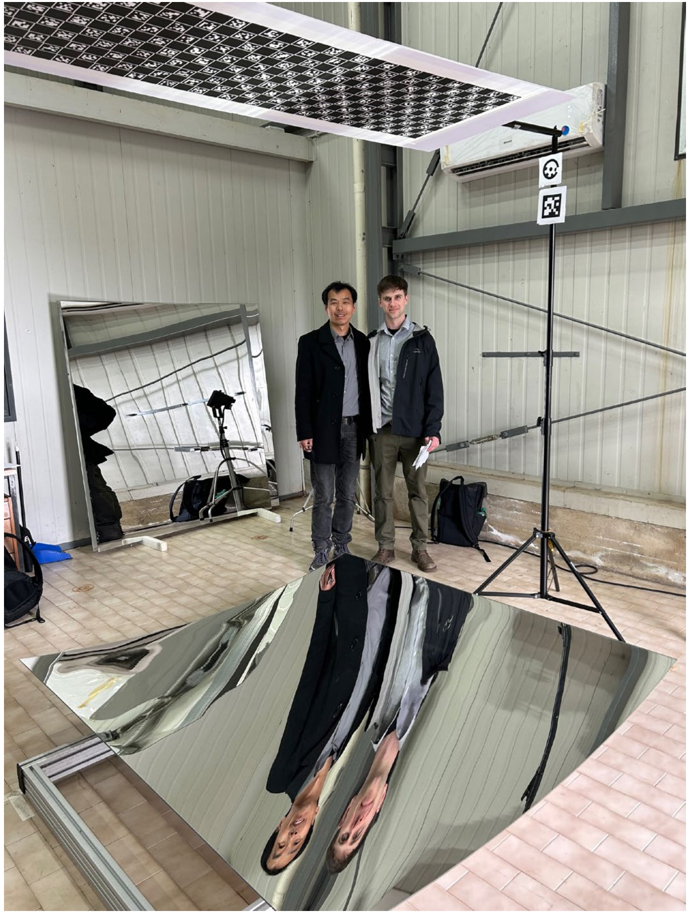
- Dots upgraded to ChArUco target: a coded chessboard using OpenCV ArUco targets[1].
- These allow for a dense and automatically distinguishable target, even when distorted.



[1]S. Garrido-Jurado, R. Mu noz Salinas, F.J. Madrid-Cuevas, and M.J. Marín-Jiménez, https://doi.org/10.1016/j.patcog.2014.01.005

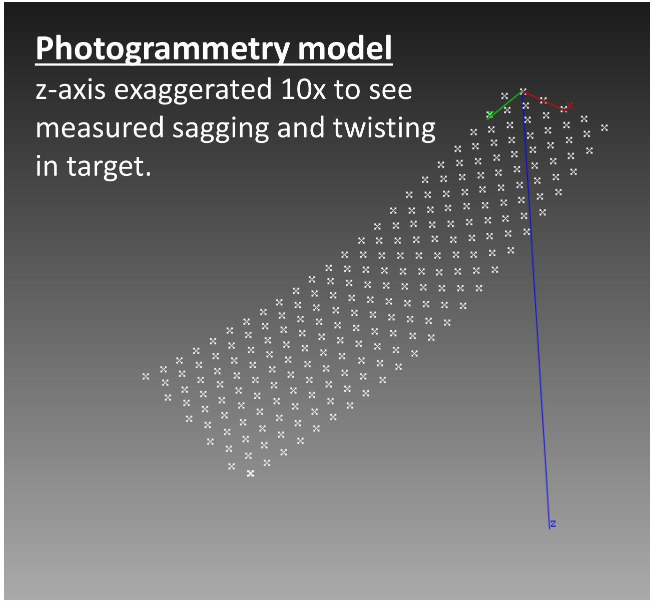
Coded, Lightweight Target

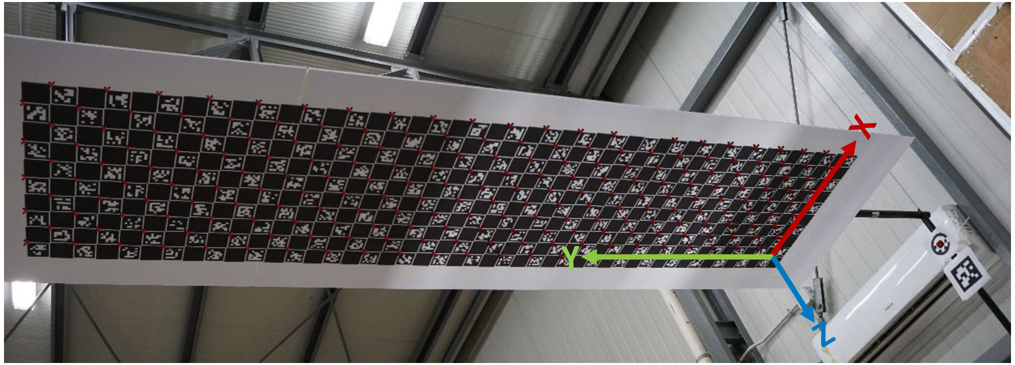
- Portable version for measurement at ENEA.
- **Keep an eye out for the metrology system round robin results, led by ENEA!

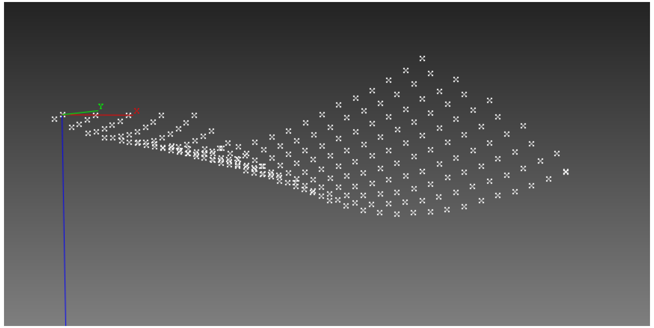


Photogrammetry Work

- Reducing target flatness requirements was essential for the portable system.
- Target is located with respect to mirror using photogrammetry. ChArUco targets located automatically.
- Lightweight, warped targets are fine, if we can correctly quantify it with photogrammetry.
- We can estimate precision with the photogrammetry model, which leads to quantified uncertainty in the results.



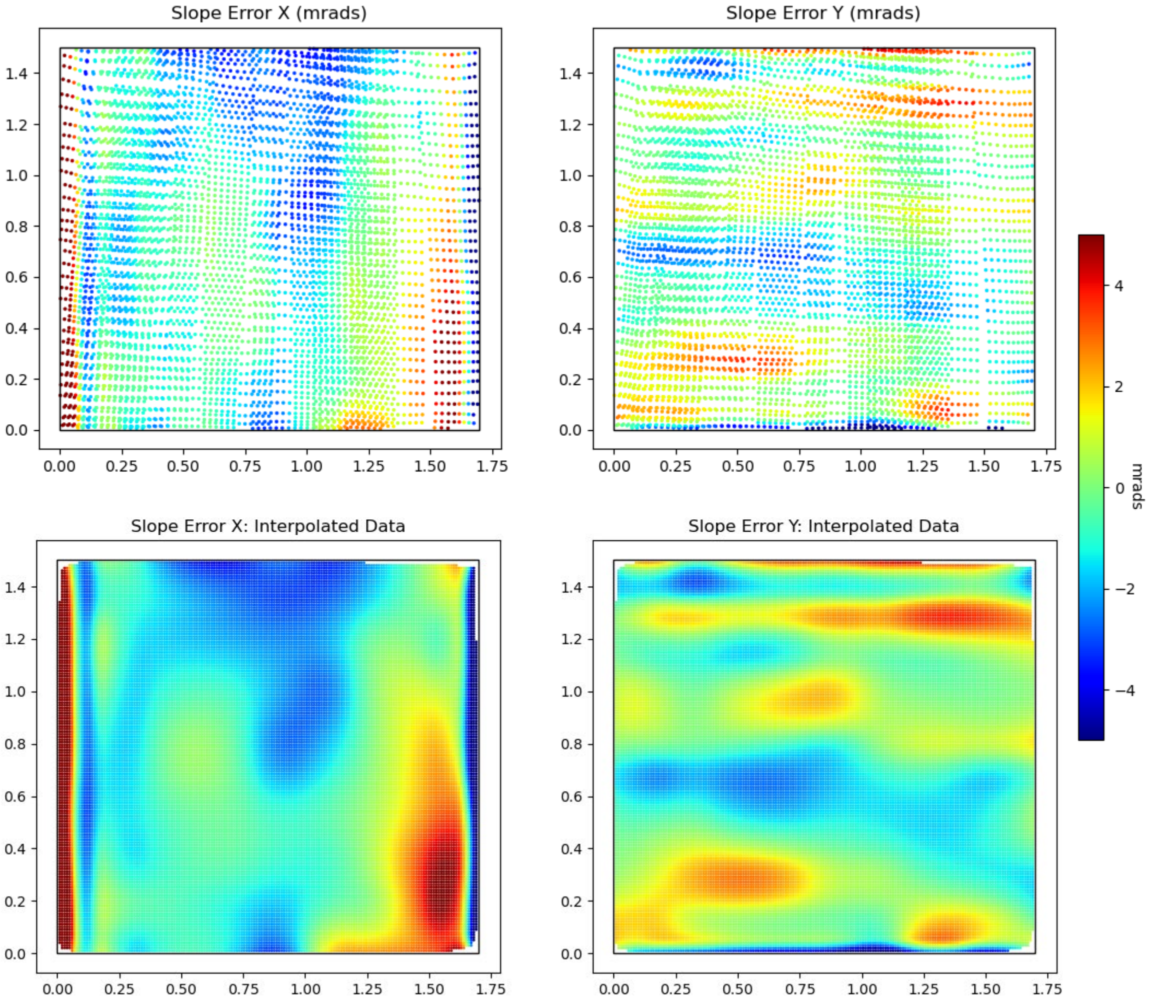




Results

Lastly, this system required us to use a thinner target, and many images.

1. Results interpolated onto regular grid.
2. Overlapping grid points identified.
3. Results stitched together into interpolated surface slope map.



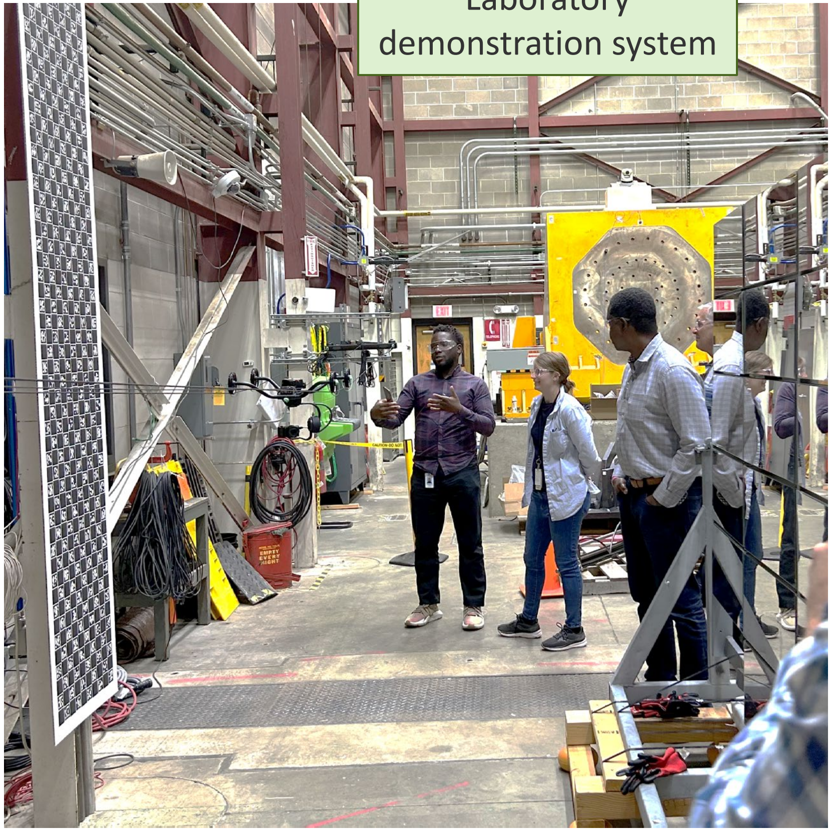
Automated System Development

Many lessons learned from the portable system development are being used in the laboratory system.

Raspberry Pi for automated control

Syrp Slingshot camera motion system

Laboratory demonstration system



Questions or Comments?

Thank You!

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Additional Slides

Extra info

Approach Accuracy

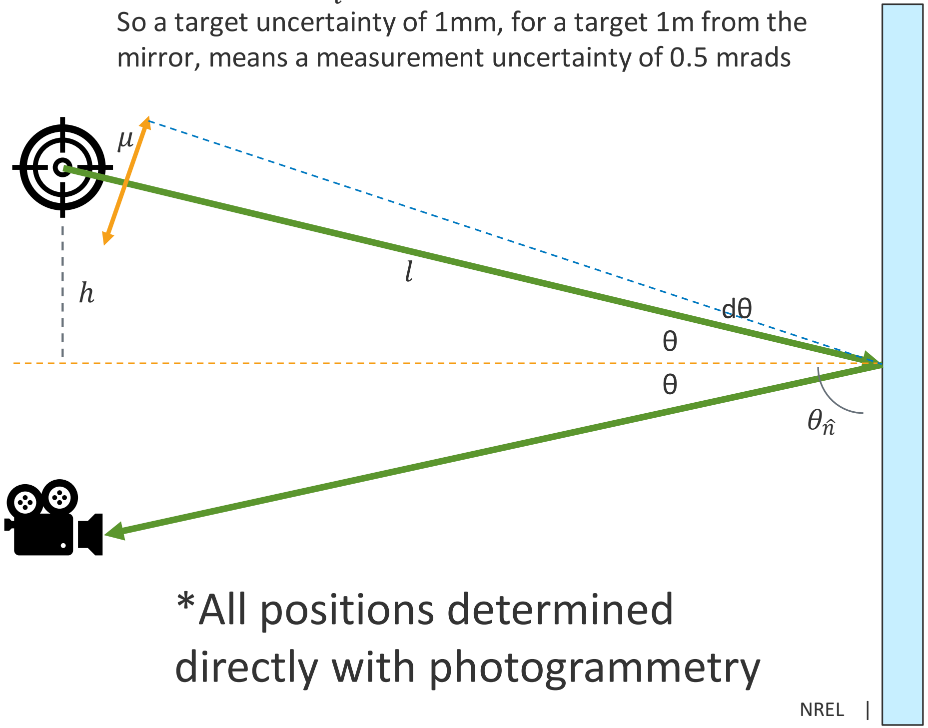
Since target positions are solved directly using photogrammetry, measurement accuracy is determined by the accuracy of these photogrammetry measurements.

- First order estimate by small angle approx. More detailed studies completed.
- Balancing act:
  - Smaller distances = higher precision required.
  - Larger distances = unrecognizable targets.
- Higher accuracy than slope measurement with direct PG

Small angle approx.:

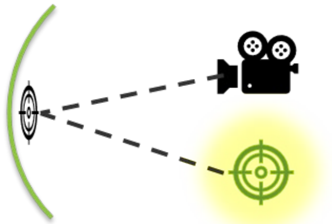
$$\frac{\mu}{l} = Sin(d\theta) \approx d\theta = 2\theta_{\hat{n}}$$

So a target uncertainty of 1mm, for a target 1m from the mirror, means a measurement uncertainty of 0.5 mrads

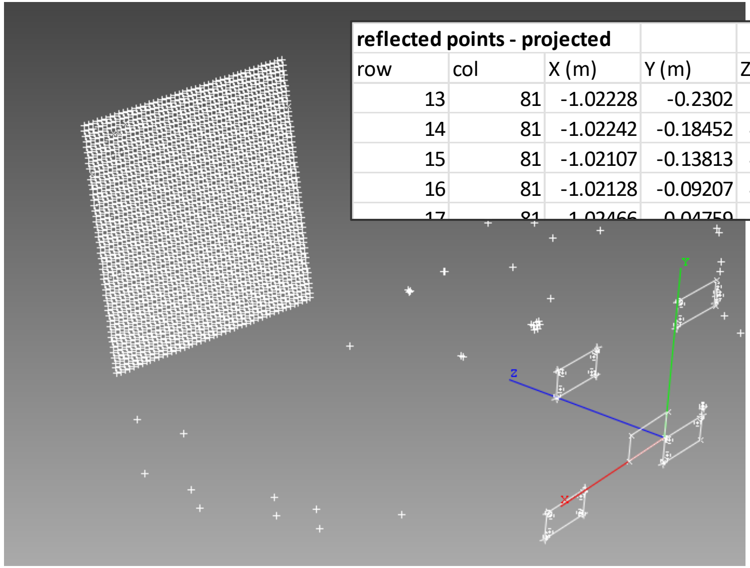


*All positions determined directly with photogrammetry

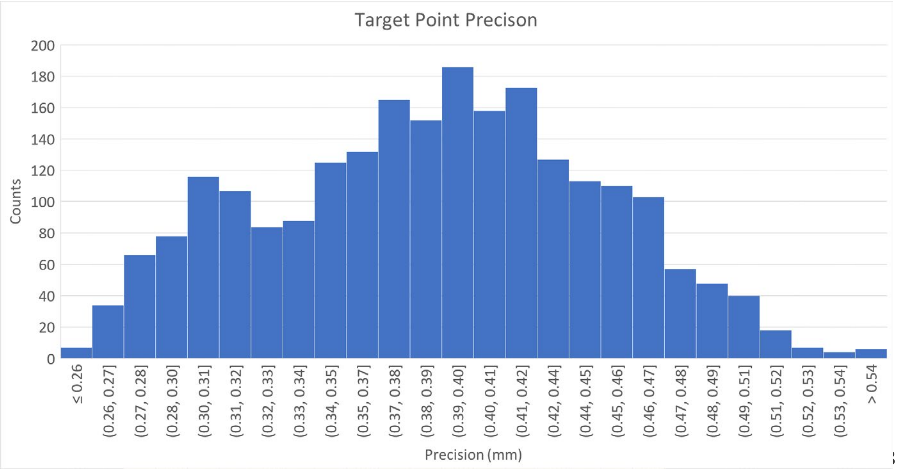
Photogrammetry Precision



- Photogrammetry used to create 3D scene (find target points in mirror reference frame).
- From this, we can create a target point dictionary and measure point precision.
- Once per setup.
- We are working to move from commercial photogrammetry software to custom tools.
- Since target points are found in 3D directly, we can ignore projector distortion and target bending.



reflected points - projected				
row	col	X (m)	Y (m)	Z (m)
13	81	-1.02228	-0.2302	3.998268
14	81	-1.02242	-0.18452	4.008303
15	81	-1.02107	-0.13813	4.017723
16	81	-1.02128	-0.09207	4.026391
17	81	-1.02466	-0.04759	4.04001



Thank You

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