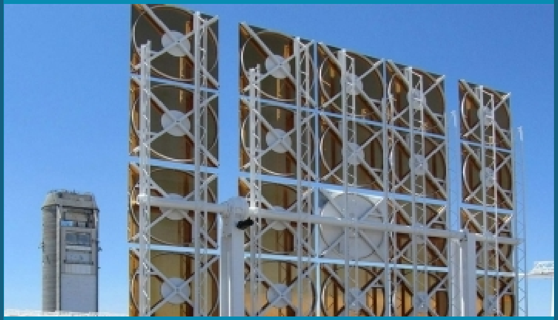
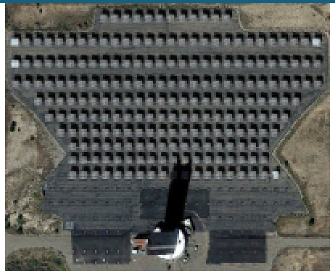
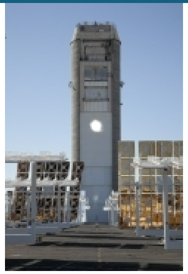
SAND2021-11540C

Sandia National Laboratories

High-Speed In-Situ Scanning of Heliostat Fields







R. Brost, P. Apostolopoulos, D. Small, D. Novick, N. Jackson, M. Mann, E. Tsiropoulou

September 30, 2021

Thanks:
Luis Garcia Maldonado
Kevin Good
Benson Tso
Julius Yellowhair
NREL NIO Team

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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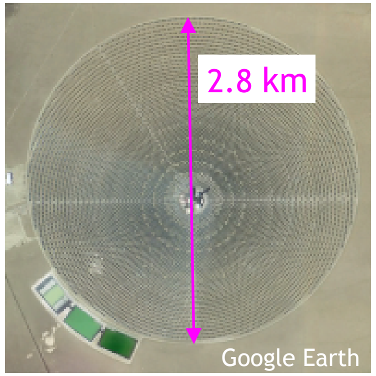
Motivation

- A commercial solar field can cover a vast area, and can have 10,000 to over 100,000 heliostats.
- What is the status of each heliostat?
  - ➢ Damage?
  - ➢ Optical precision? → NIO[1], UFACET[2]
  - ➢ Soiling? → Qfly[3]
- How can we measure and inspect such a large number of heliostats:
  - ❑ Efficiently?
  - ❑ Without disrupting operation?
  - ❑ Safely?

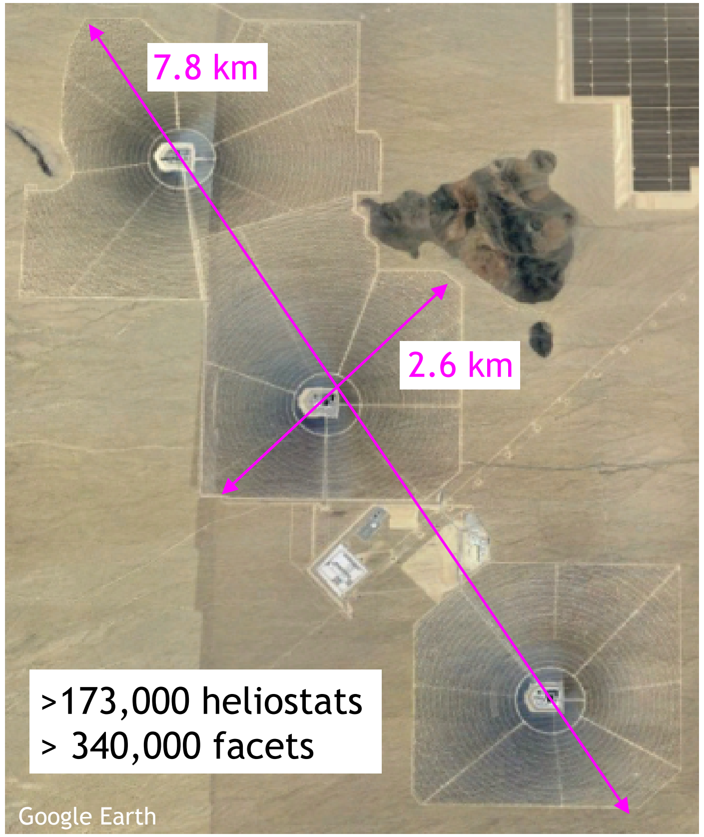
[1] R. Mitchell and G. Zhu, A non-intrusive optical (NIO) approach to characterize heliostats…, Solar Energy 209, 2020.
[2] J. Yellowhair, et al. Development of an Aerial Imaging System for Heliostat Canting Assessments. *SolarPACES 2020*.
[3] F. Wolfertstetter, et al. Airborne soiling measurements of entire solar fields with Qfly. SolarPACES 2019.

Crescent Dunes:



>10,300 heliostats
> 360,000 facets

Ivanpah:



Approximately the same scale.

Concept: Scanning Flight

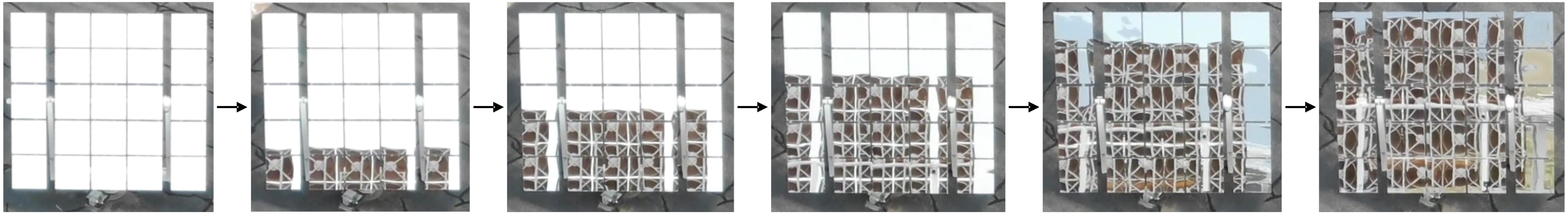
An Unmanned Aircraft System (UAS) can cover a lot of ground with a camera.

Challenges:

- Non-intrusive ⇒ Collect data during normal tracking.
- Solar Flux[1] ⇒ Stay low.
- Speed ⇒ (a) Efficient heliostat tour. (b) Smooth motions, few accelerations.
- Image analysis ⇒ Sky reflection first, then track.
- Numerous points ⇒ Exploit all active heliostats.

Solution:

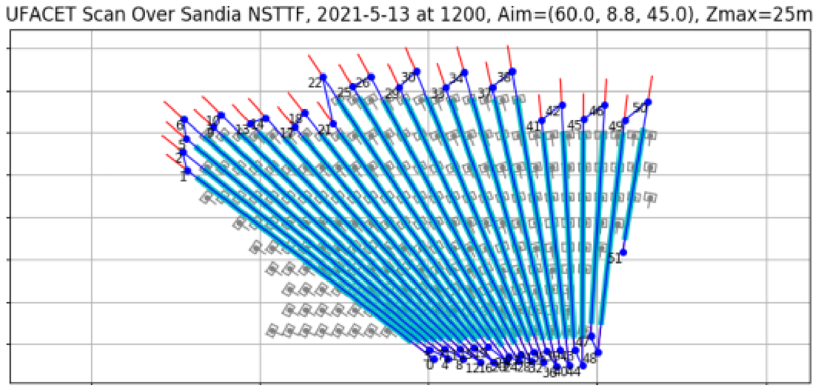
- Reflected edge scanning.



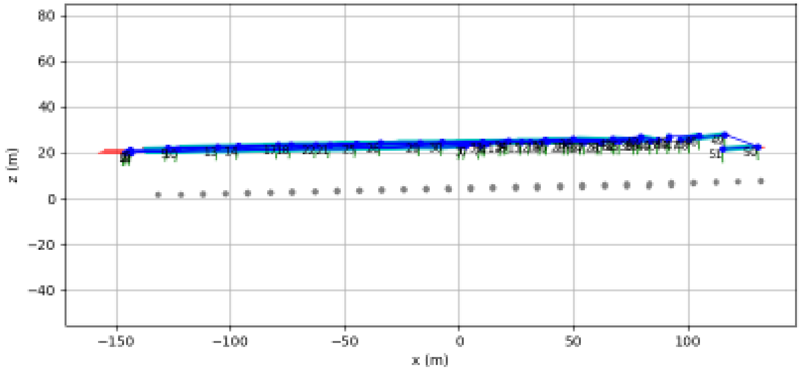
[1] See D. Novick, et al. Here Comes the Suns – Flight Safety for Unmanned Aircraft Over Active Heliostat Fields. SolarPACES 2020.

Flight Planning

XY Analysis:

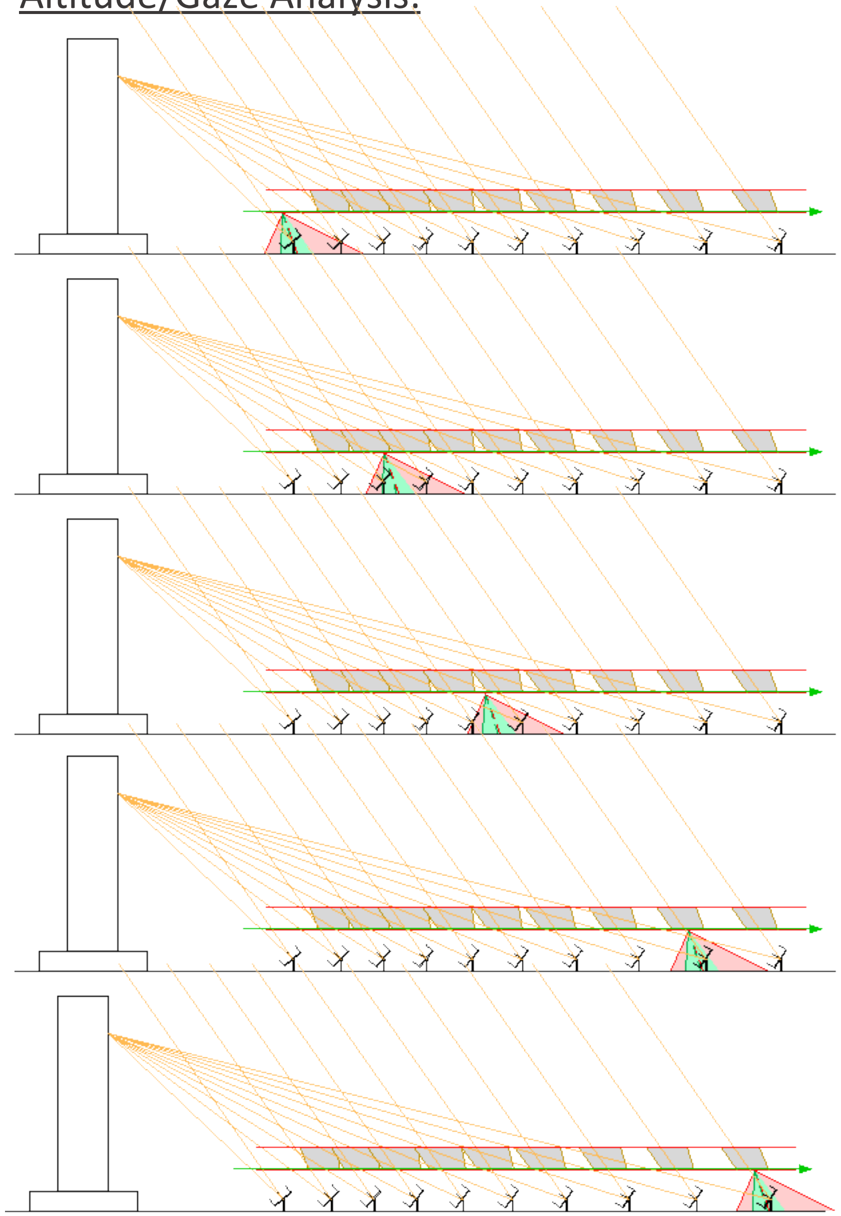


Terrain Slope Correction:

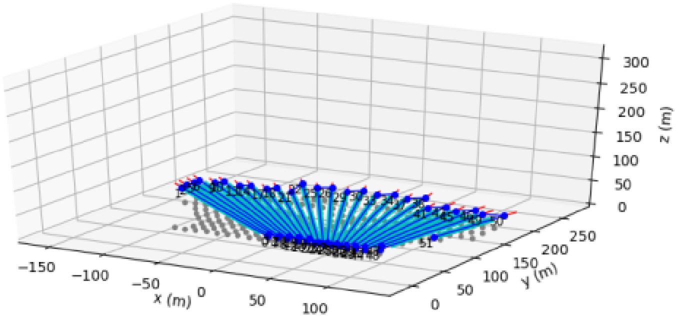


Planner considers multiple constraints to find a flight path that is feasible, safe, and achieves data capture goals.

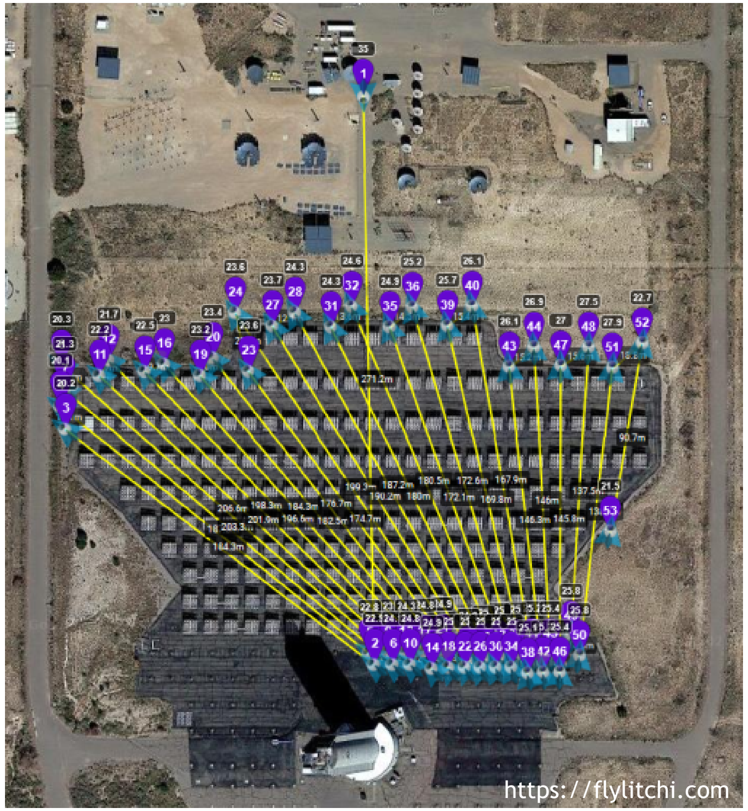
Altitude/Gaze Analysis:



3-d Plan:



Flight-Ready:



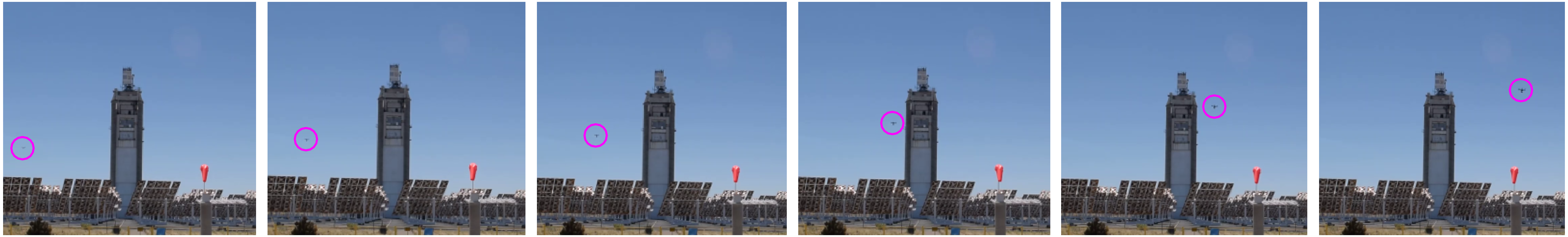
Flight Execution

Unmanned Aircraft System (UAS):

Operation issues:

- Checklists:
  - ❑ Weather
  - ❑ UAS flight systems
  - ❑ Imaging devices
  - ❑ GPS RTK
  - ❑ Communications
  - ❑ Air space
- Energy management – all systems.
- Image collection capacity.
- Post-flight temperature.
- Log data.

May 13, 2021:



The entire Sandia NSTTF field is tracking on-sun to a standby aim position.

At scan speed of 25 km/h, typical flight time to scan Sandia NSTTF field is 16-21 minutes.

Post-flight temperatures ranged from 25 °C to 47 °C.

View from the Air

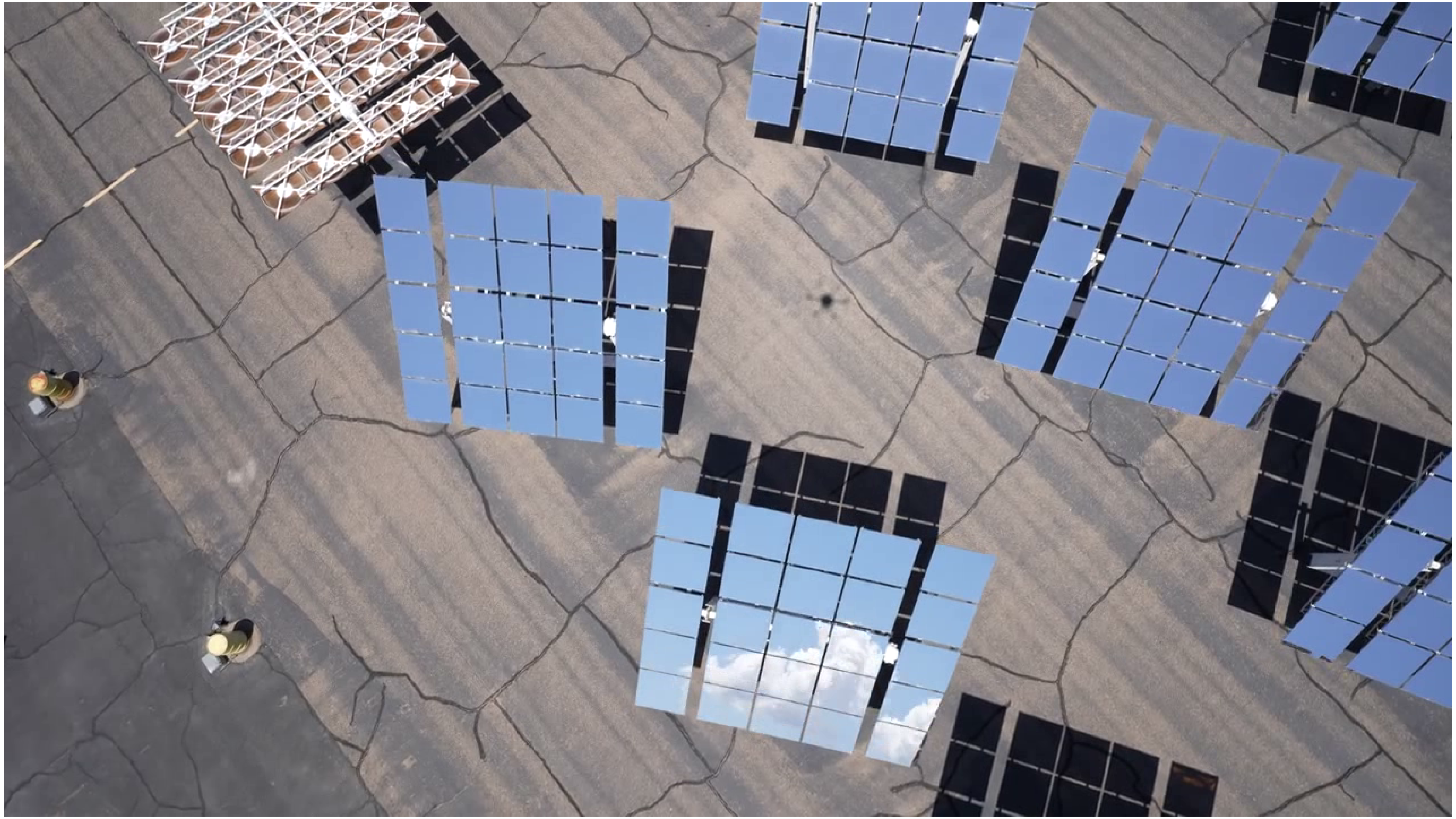
View video

“210513-1210_NSza45_U_sony_C0039_s3m15_d825_HD.MP4”

Suggested cue range: 5:40 → 7:00.

In some flights, not all reflected edge sweeps match ideal goal. This can be solved by linearly varying gaze angle during pass – reserved for the the future. Meanwhile, current performance is suitable for analysis.

View from the Air



<u>Goal:</u> Sky first, then sweep.

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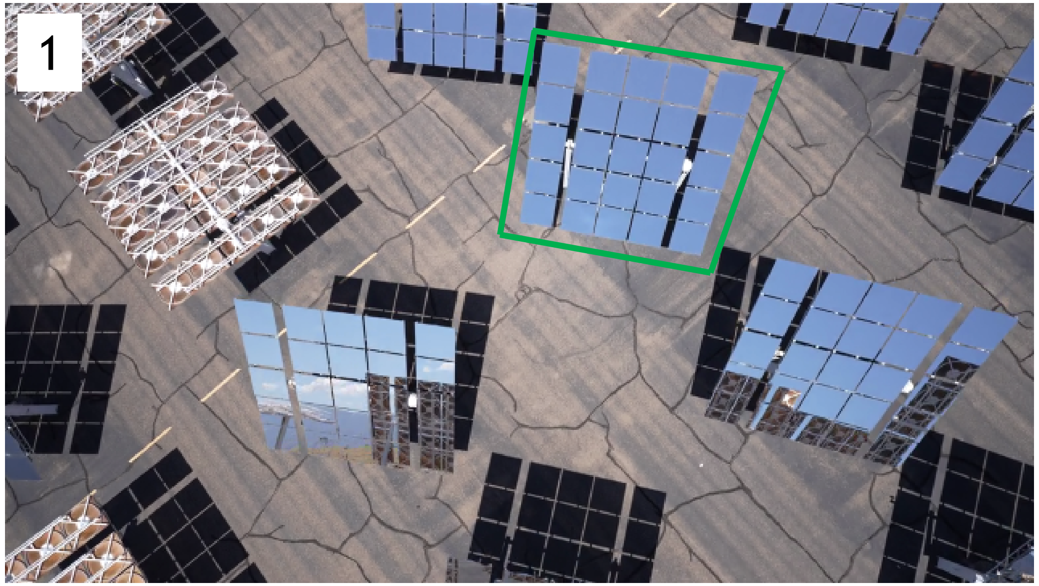
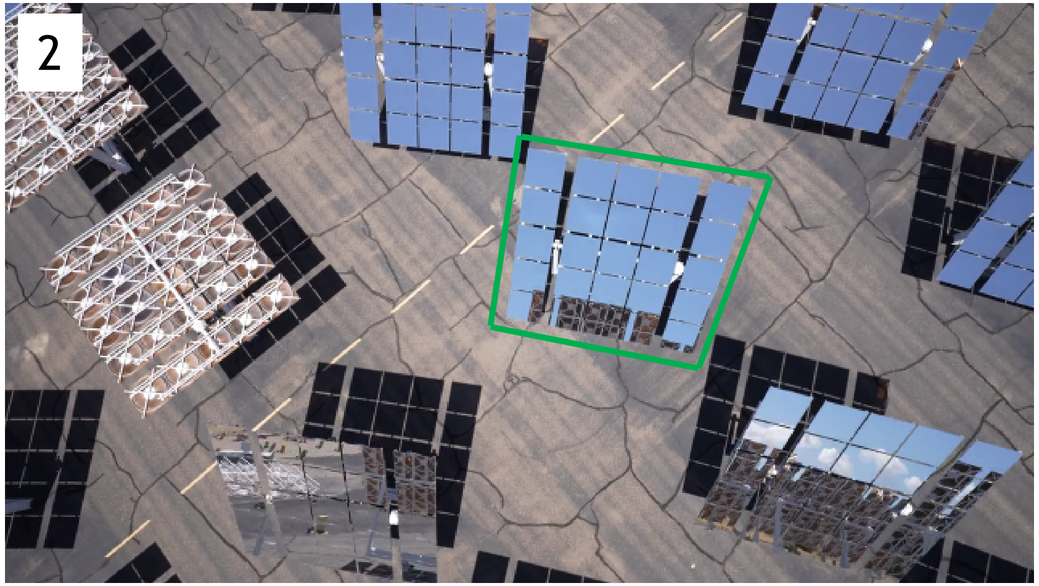
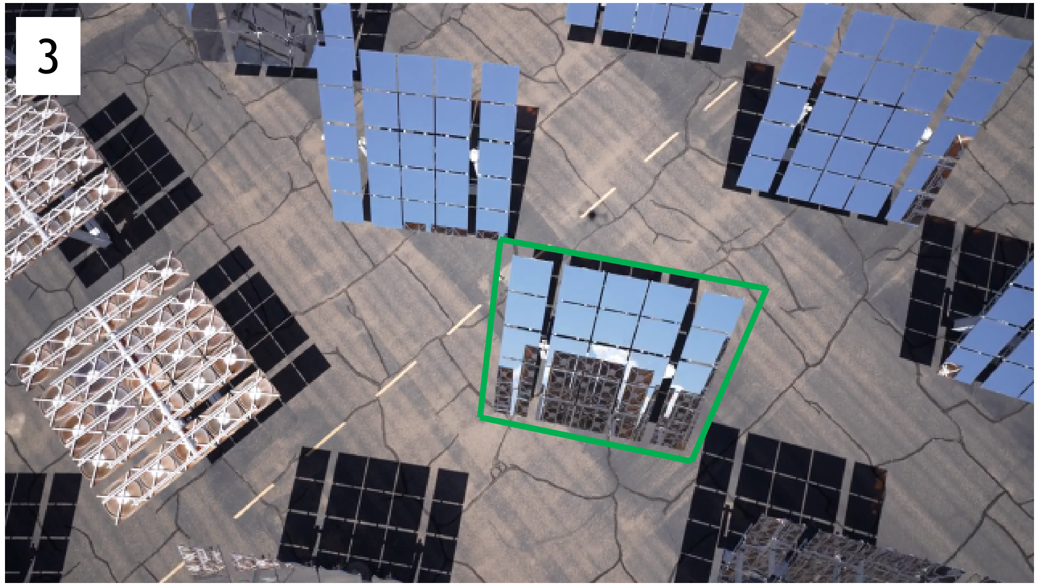
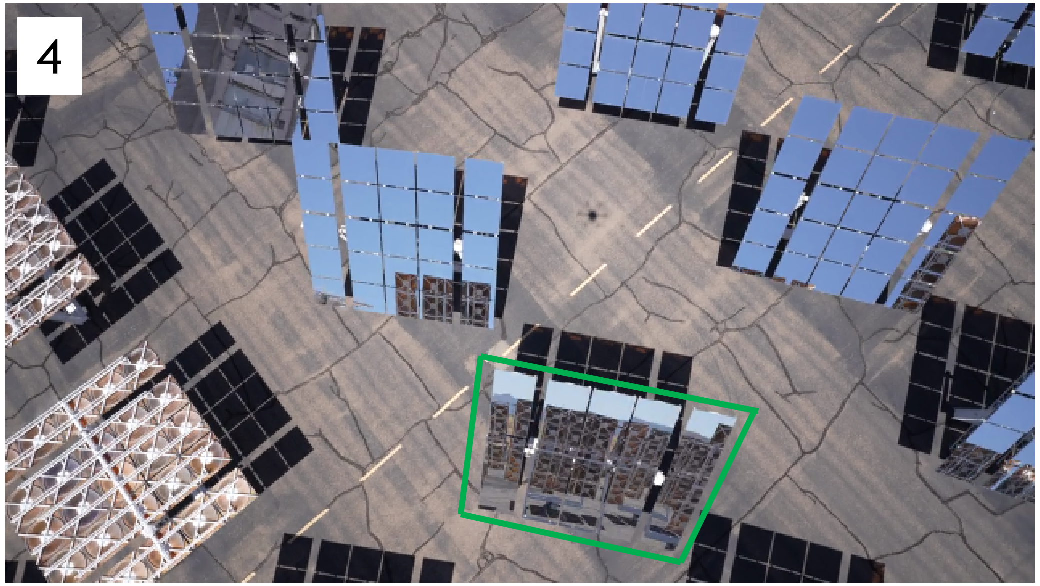
Video excerpts:





Goal: Sky first, then sweep.





Green outlines added manually for orientation.

Post Processing

Approach:

Analyze video frames:

1. Identify key frames suitable for image search. Manual, for now
2. Search key frames for heliostat corners.
3. Track corners over time, exploiting temporal locality.

$\Rightarrow$ Semantic model of heliostats and their boundaries across image sequence.

Automatic*

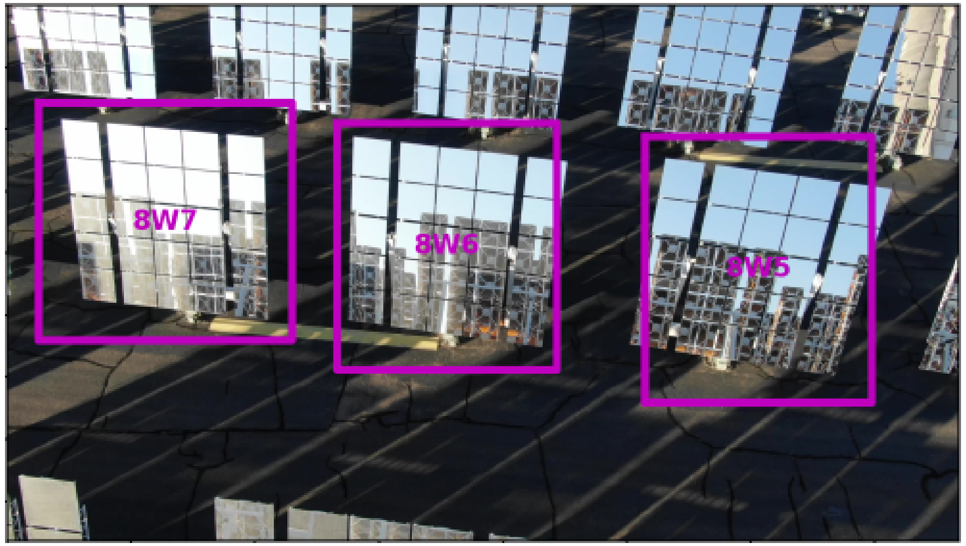
Can be used to compute value-adding products:

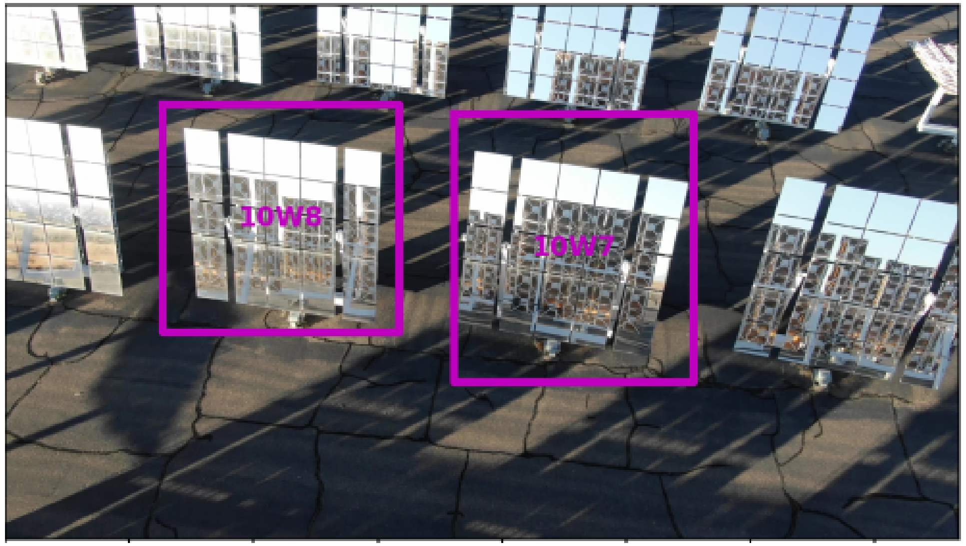
- 3-d geometry Automatic*
- Optical metrology
- Damage inspection
- Soil inspection
- …

(Optical metrology, Damage inspection, Soil inspection: Future)

* Automated codes are still under development. Some include "magic numbers," have not been generalized across examples, can be brittle, etc.

Example Key Frames:





Magenta boxes and labels defined manually.
Box location can be approximate.

Tracking Video

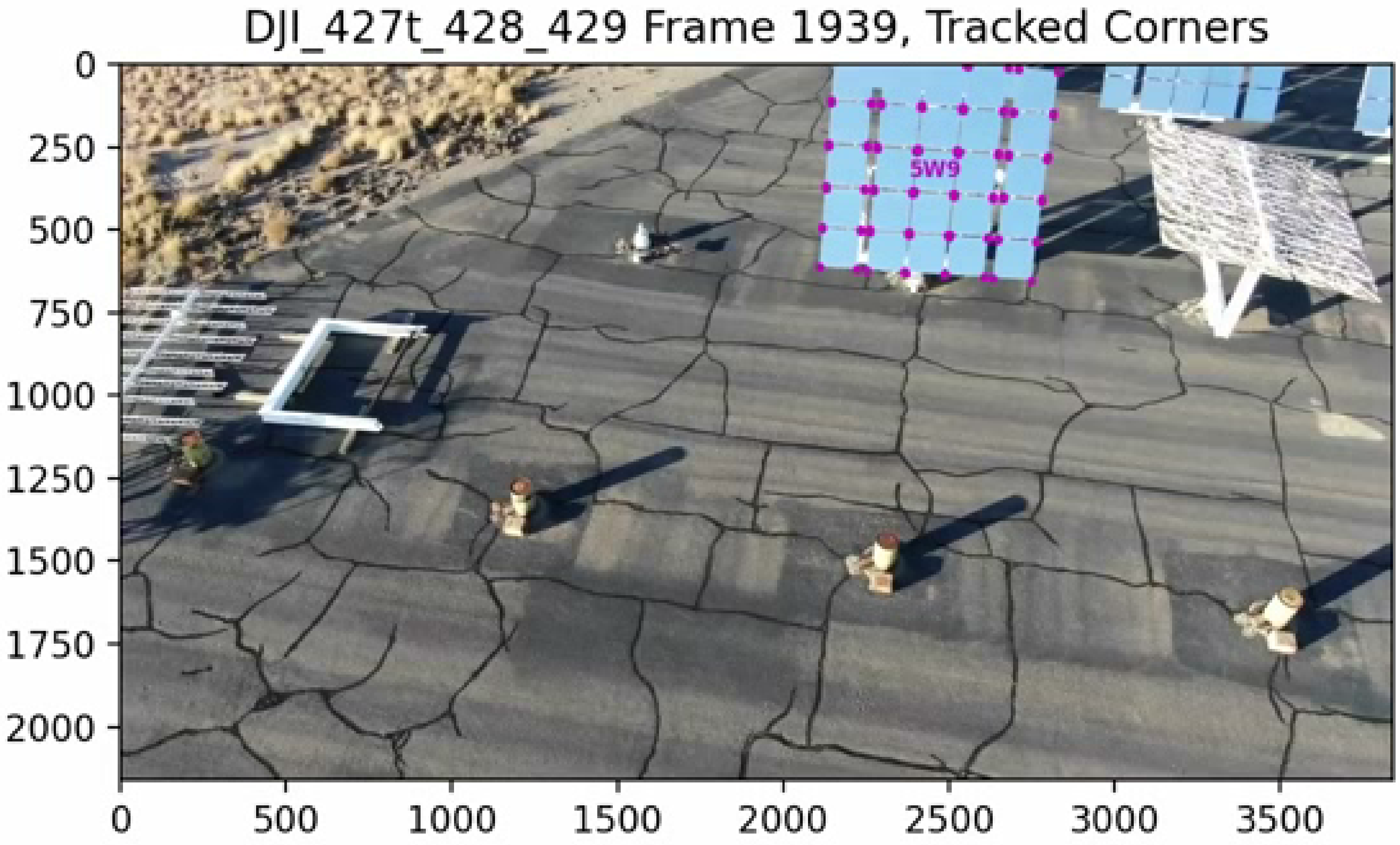
View video
“DJI_427t_428_429_video_tracks_Trim_1.22-3.20.mp4”

Flight December 3, 2020

Video length:	12 min, 22 sec
Frames in video:	18,570
Manual key frames:	188
Frames tracked:	12,939
Points tracked:	2,702,019
Heliostats tracked:	168

Note that our goal is not to track every appearance of a heliostat. But rather, to obtain a solid data set for every heliostat by successfully tracking each heliostat through one or more contiguous portions of the video.

Tracking Video



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Tracking Video

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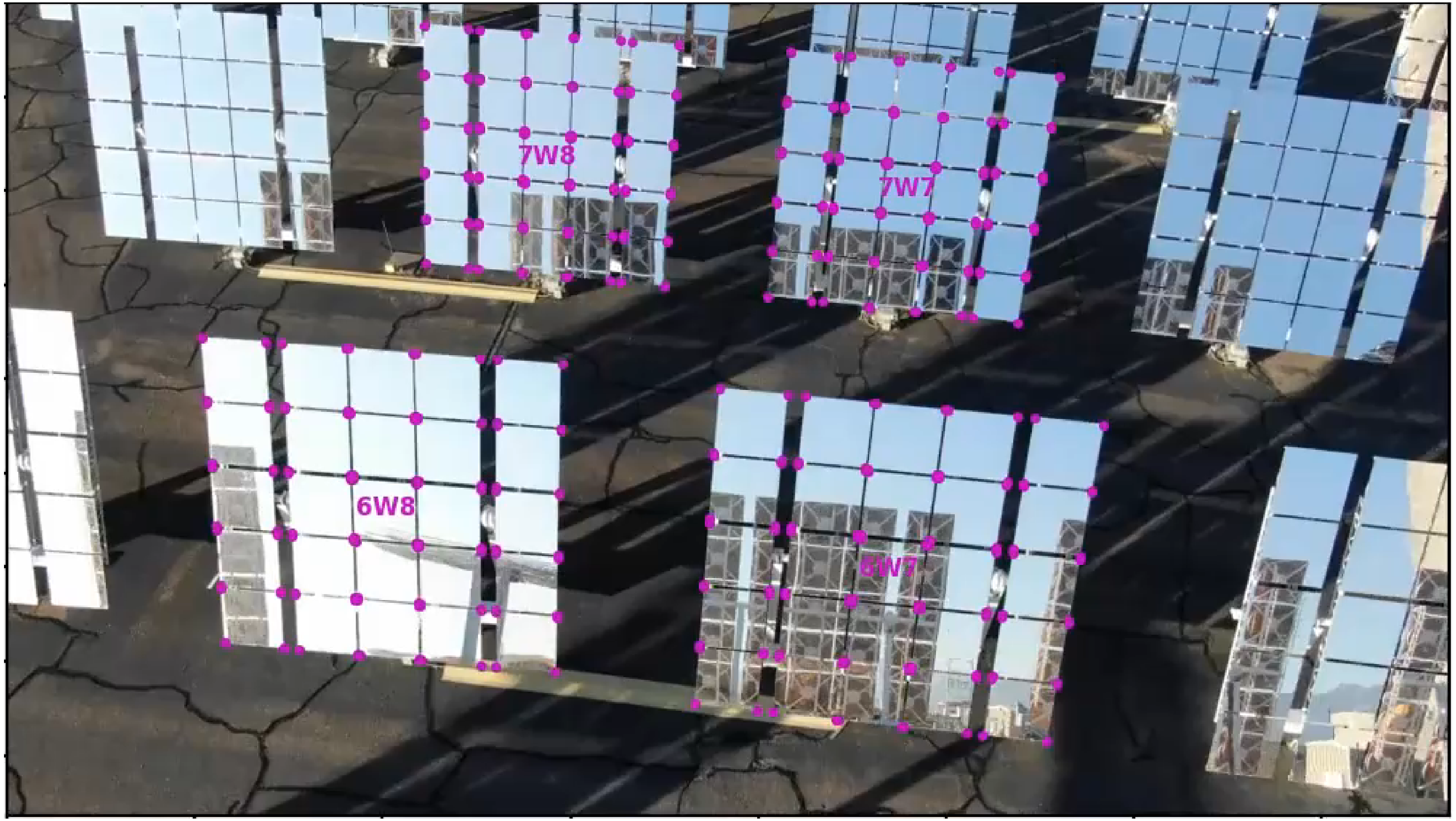

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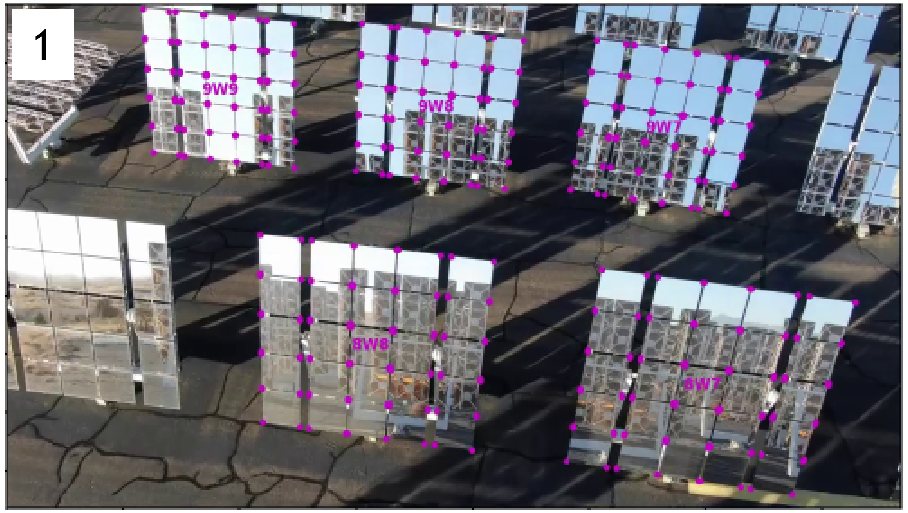

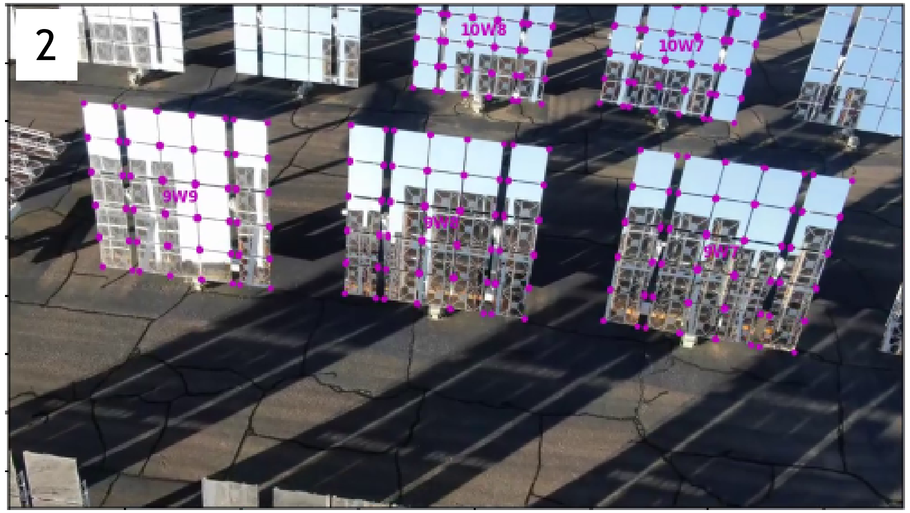

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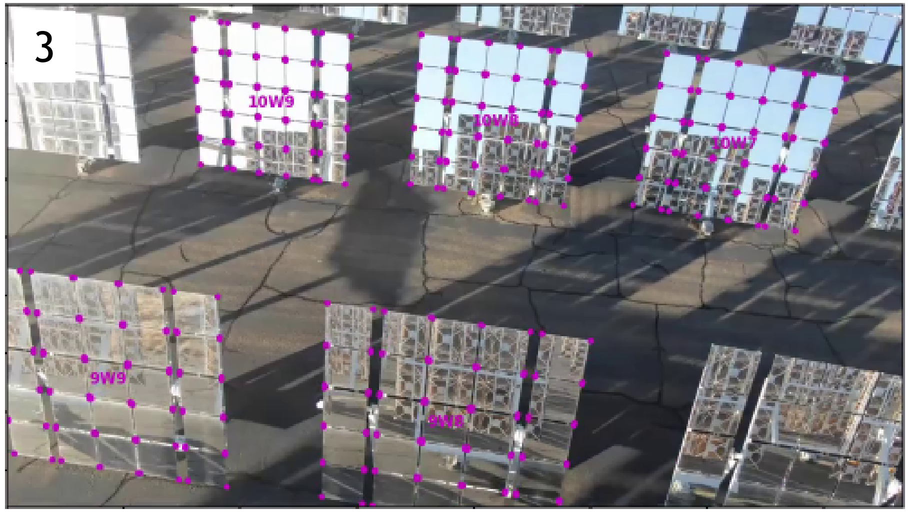

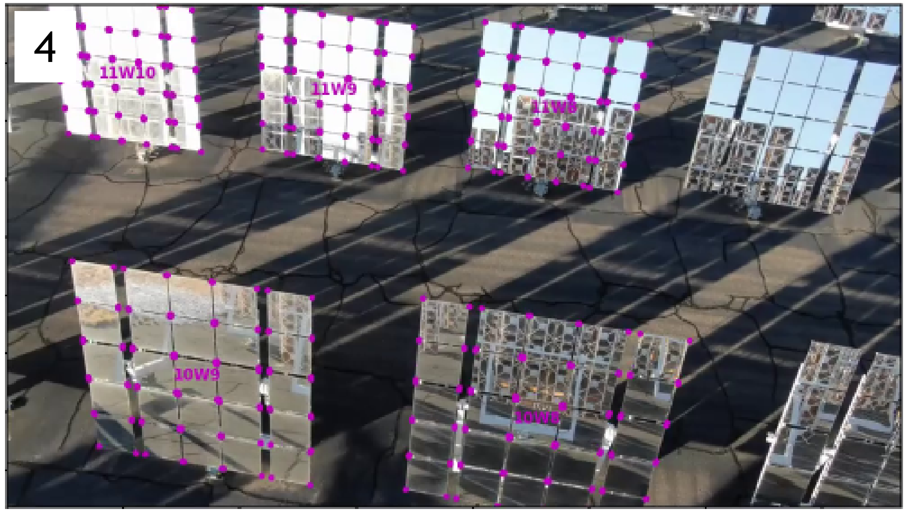

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Envisioned Applications

Tracking and labelling gives us a series of circumscribed individual image sequences with individual heliostats, and even individual facets, identified.

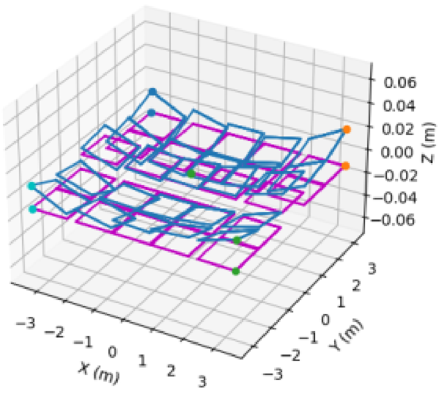
Envisioned applications:

- Indexed review, by heliostat.
- 3-d reconstruction.
- Damage detection.
- Degradation detection.
- Identify heliostat changes after storm events.
- Optical error measurement, supporting field calibration, heliostat performance assessment.

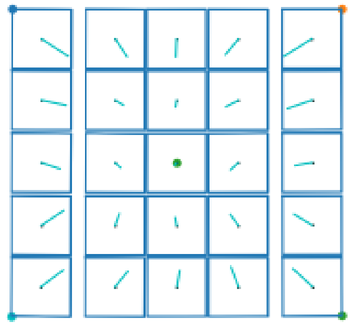
<u>Example: 3-d Reconstruction</u>

<u>Example good output:</u>

7W5



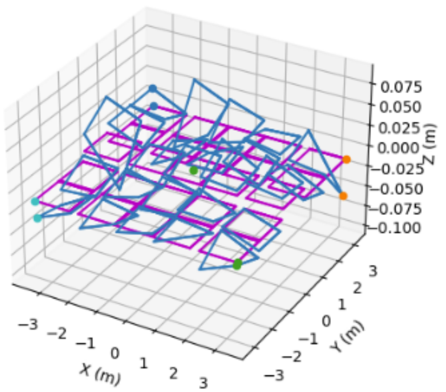
7W5



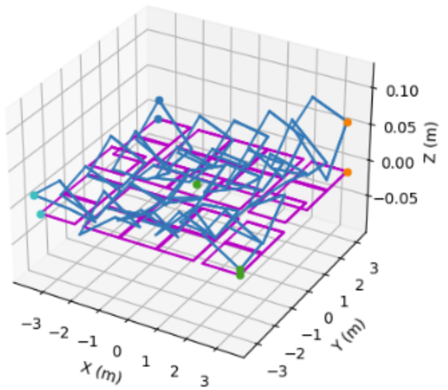
Top View, Surface Normals

<u>Example poor output:</u>

9E9



14E3



Work in progress.

Conclusion

Method is:

• Robust.	→	We successfully executed 45 flights over an active heliostat field. Flight planning and operation procedures are robust. Video processing code still under development, sometimes brittle.
• Fast.	→	Scanned all of NSTTF solar field in less than 20 minutes. Flight paths compatible with higher speed.
• Non-intrusive.	→	No changes to solar field operation are required.
• Avoids high flux.	→	Low altitude avoids high flux concentration. Excessive temperatures avoided in all flights.
• Collects rich data.	→	Typically over a hundred annotated views of each heliostat.
• Supports automated analysis.	→	Planning and post-processing code almost completely automated. Work continues toward full automation, additional capability.

… Still work in progress!