TOP Alignment Methodology

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Relevance/Objective

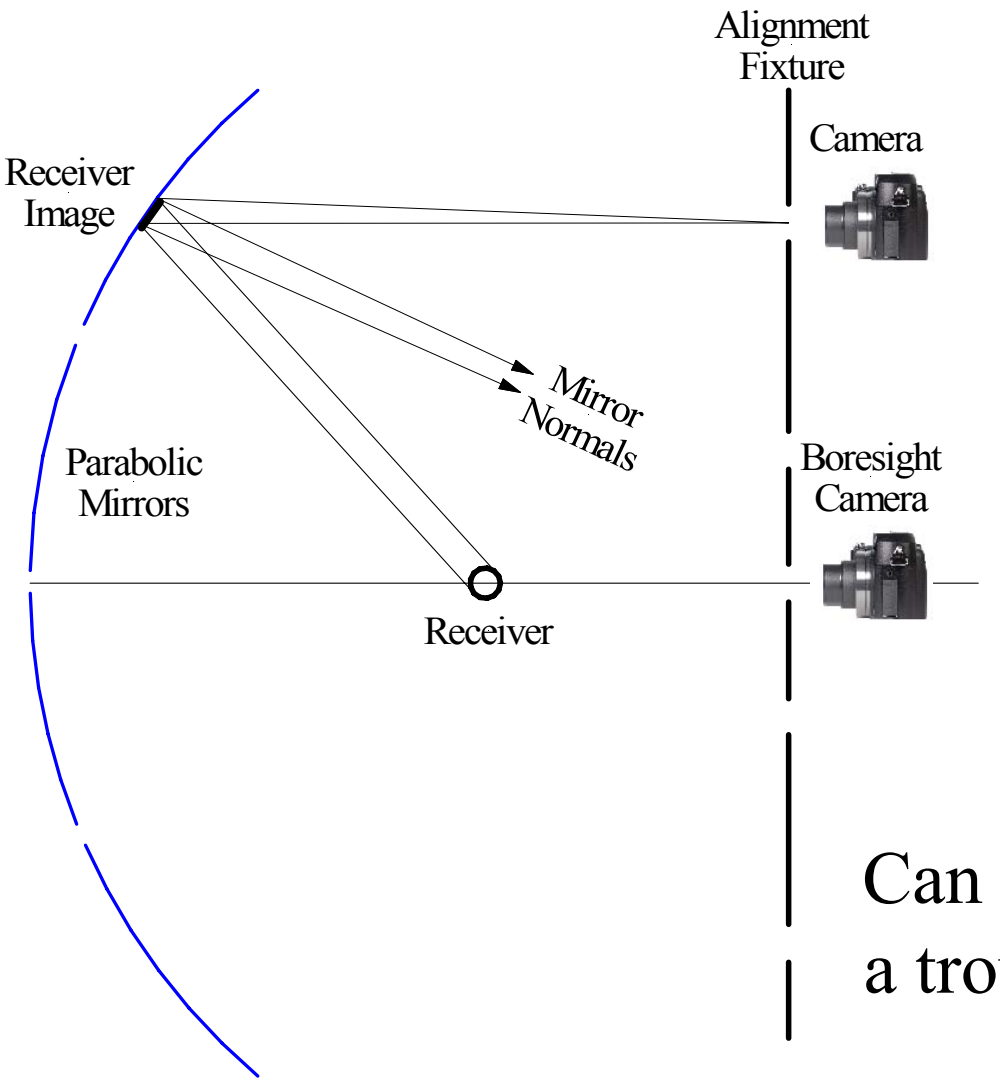
- Develop an optical evaluation approach for parabolic trough power plants
  - Rapid and cost effective
  - Improve the performance of existing power plants, suitable for quality control during plant construction, or routine maintenance
- Reduce the cost of parabolic trough solar power
  - Increase optical intercept of trough plants
  - Increase aperture with same receiver size of new plants
  - Increase concentration ratios/collection efficiencies
- An objective is to evaluate the optical alignment of existing trough power plants
  - If appropriate, improve alignment and measure benefits
  - License of the technology to trough developers and/or plant operators

Mirror Alignment – The Ideal Solution*

- **Simple to setup and implement**
- **Minimum of sophisticated hardware**
- **Not require receiver removal**
- **Not require sun or other restrictive weather conditions**
- **Not require line-of-sight to distant observer or light source**
- **Permit accessibility to mirrors for adjustments**

*Richard B. Diver, 1995, "Mirror Alignment and Focus of Point-Focus Solar Concentrators," Proceedings of the 1995 ASME/JSME/JSES International Solar Energy Conference, Maui, HI.

Theoretical Overlay Photographic (TOP) Alignment Approach



Alignment fixture - a pole with accurately established camera offsets

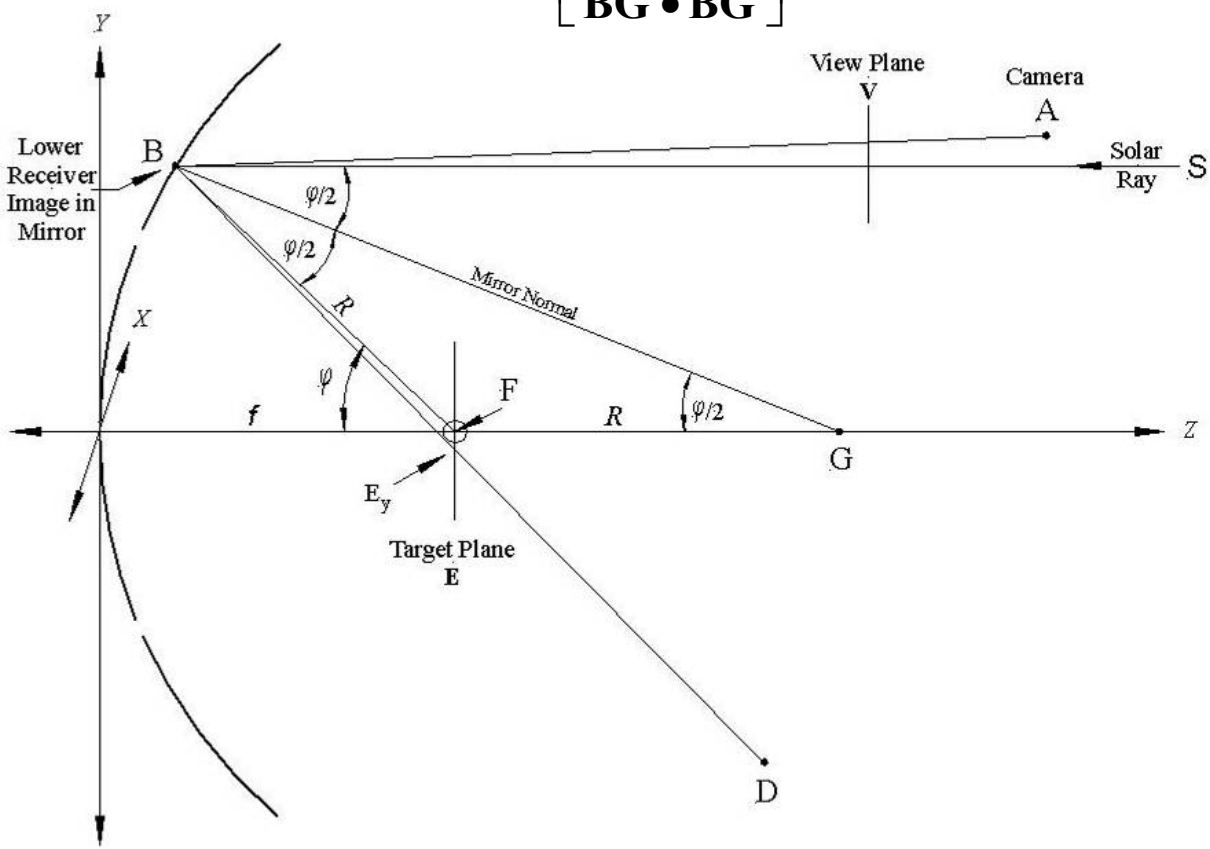
Fixture position established by "boresight" centering of receiver on center mirrors

Can be used between rows of a trough plant

TOP Alignment Theory

- Vector algebra used to calculate position of top and bottom edges of receiver in mirrors as seen from a know location
- Projection theory calculates mirror corner and receiver edges as seen by a camera in the same location
- Calculated theoretical image overlaid on photograph and compared

$$\mathbf{BD} = 2\left[\frac{\mathbf{BA} \bullet \mathbf{BG}}{\mathbf{BG} \bullet \mathbf{BG}}\right]\mathbf{BG} - \mathbf{BA}$$



TOP Alignment Derived from Dish Alignment Methods

- Accurate alignment critical for dishes
  - Avoid hot spots & melted metal
- TOP alignment similar to the approach used on Remote Dishes
  - Theoretical color target mounted on engine
  - Dish, receiver and observer bore sighted with sight aids
  - Overlay image on dish
  - Adjust mirrors accordingly
- Accurate alignment with no “hot spots” on receiver

Summary of Activities

- TOP alignment proof-of-concept experiments
  - Characterize stock LS-2 module at Sandia
  - Compare before and after TOP alignment with Distant Observer
- Development of field deployment TOP alignment system
  - Build and test a trailer mounted fixture suitable for commercial LS-2 trough power plants
  - Develop data acquisition and image analysis software utilizing National Instruments (NI) Vision image processing and analysis software for LabVIEW™
- Evaluate the optical alignment of commercial plants
  - Saguaro 1 MWe trough plant near Tucson, AZ used for system testing
  - Align limited number of mirrors and evaluate change in performance
  - Evaluate Florida Power SEGS plants in Kramer Junction, CA and other facilities

Proof of Concept

- TOP alignment proven
  - Tested on LS-2 module at Sandia
  - One middle (boresight) position
  - Four alignment positions centered on mirror rows
- Nikon D-70 digital camera
- Error analysis indicates better than 1 mrad accuracy feasible
  - Mirror slope error ~ 2 mrad
  - Inherently aligns mirrors to the receiver
  - TOP measurements near center of mirrors are representative of alignment

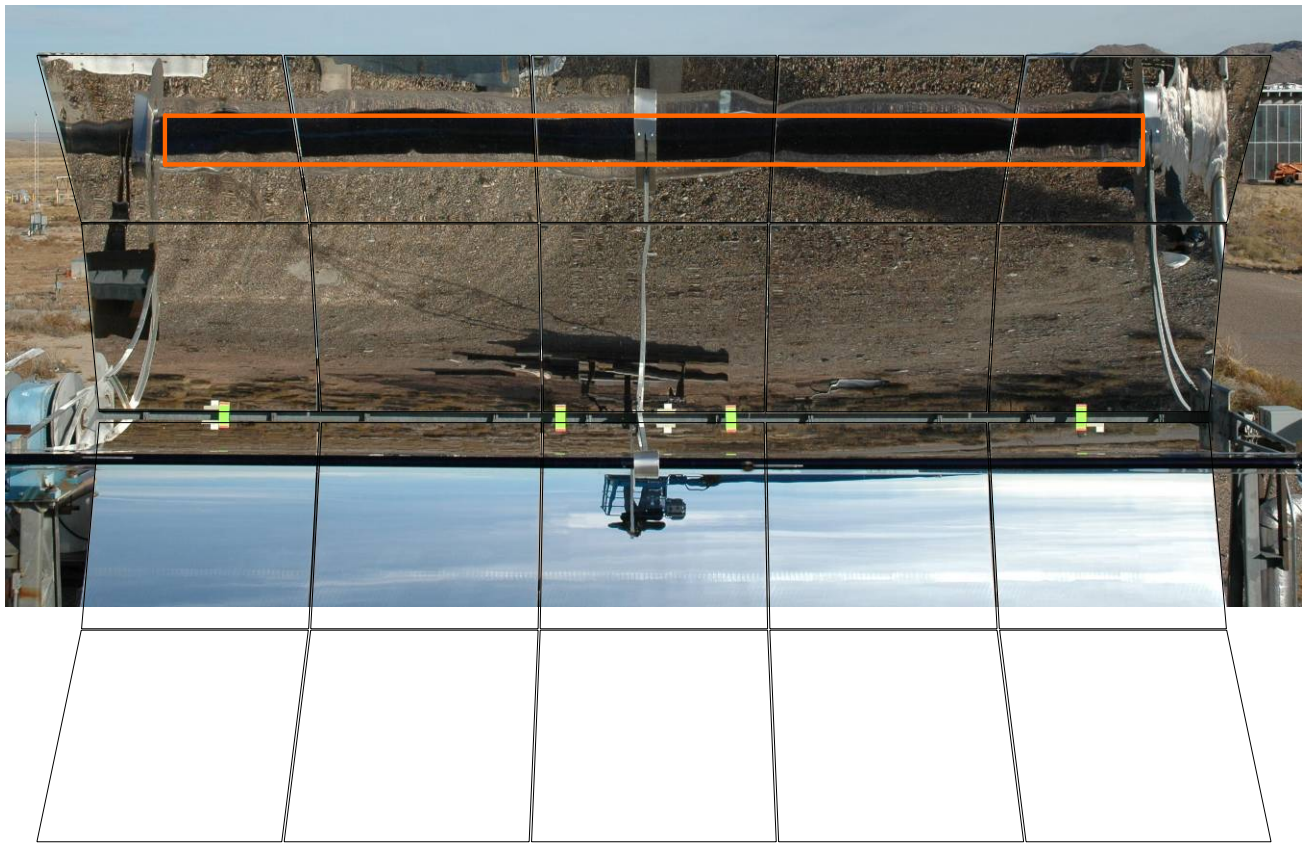
Proof of Concept

Distant Observer Before 79 ± 2%

TOP Alignment Top Row - Before

Theoretical trough and receiver image overlaid on carefully surveyed photograph

TOP Alignment Top Row - After

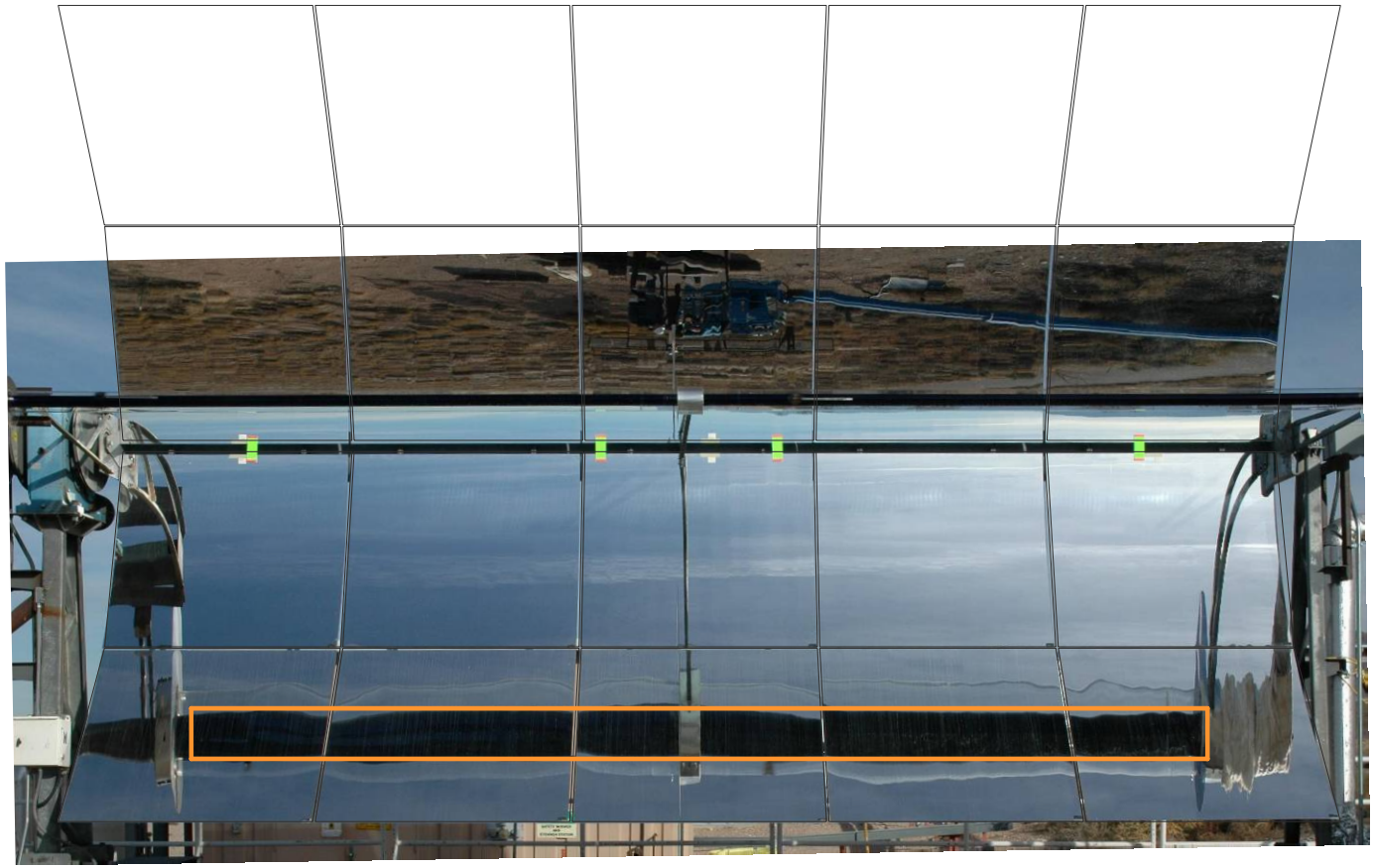


Mirror alignment adjusted to match actual and theoretical images

TOP Alignment Bottom Row - Before

Note slanted receiver image in middle mirror

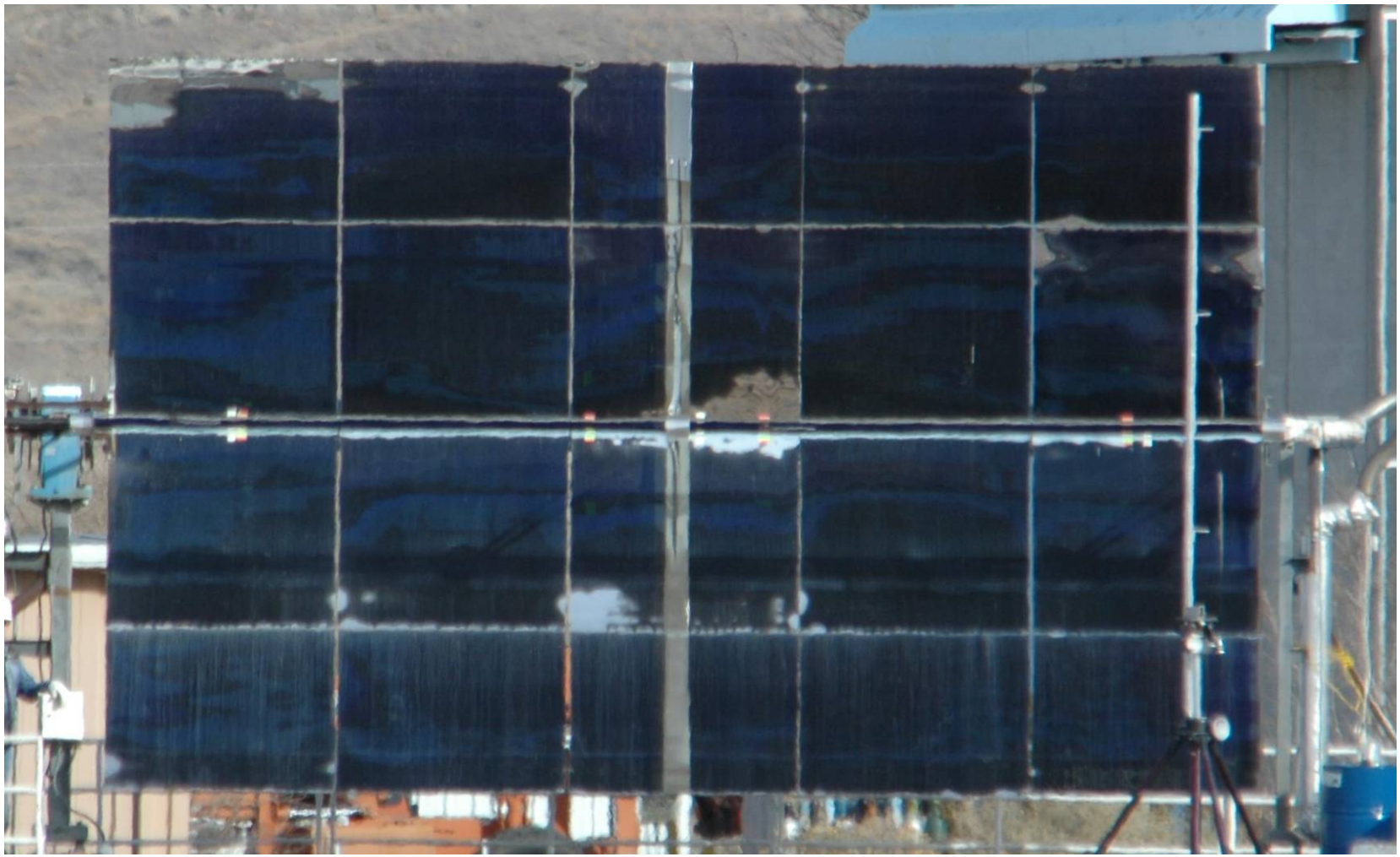
TOP Alignment Bottom Outer Row - After



Accommodates four point mounts

Proof of Concept

Distant Observer After 92 ± 2%



TOP Alignment - Practical Field Implementation

- Trailer mounted fixture towed through field
  - Troughs pointed horizontally (± 1°)
  - Stop when cameras frame module
  - Distance to trough guided by ultrasonic distance measurement
  - Raise or lower to boresight fixture as needed, level, take images, move on
- Field crew installs/removes sight gages
- Post-process data and align later
  - Image analysis software utilized to analyze images and generate adjustment instructions
  - Possibly align while trough operates
  - Quality control alignment check as appropriate

Field Deployment System

- Remotely actuated fixture moves up or down 9 inches for bore sighting
- Fixture can rotate 360º
- 5 digital video cameras (2 megapixels each) for acquiring images
- 2 ultrasonic meters
  - horizontal distance between fixture and trough
  - vertical distance between fixture and trailer bed
- Two stepper motors/clinometers self level fixture

- Controllers, DAQ, and camera hubs inside weather tight electrical cabinet mounted on fixture
- DAQ operated from Dodge Caravan minivan
- Two 12 Volt marine batteries supply all power needs
- Toolbox on trailer for storage of tools, batteries, and misc. equipment

Field Deployment System

TOP Alignment fixture has three positions

Image taking position

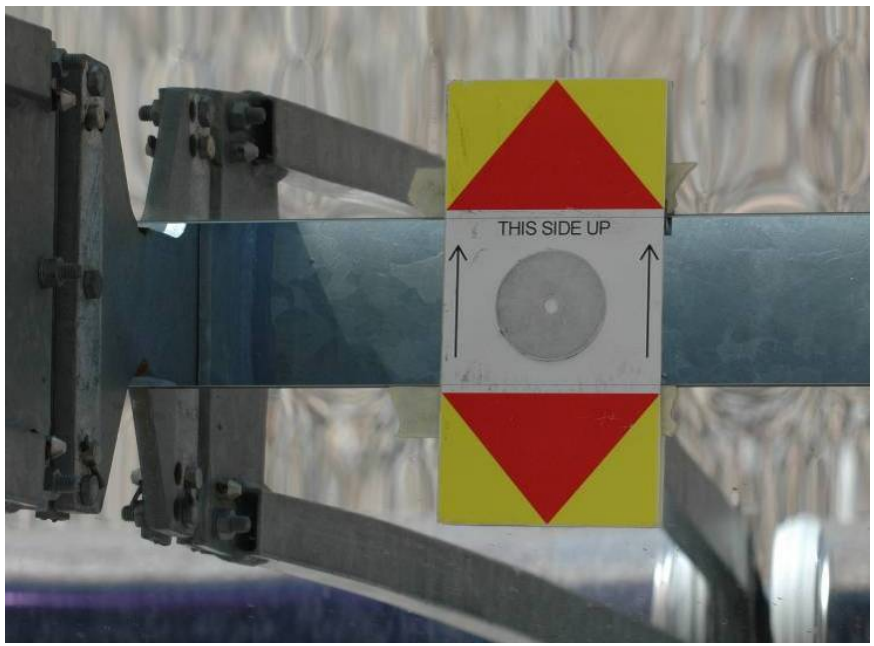
Takes less than 1 hour to change between image taking and travel positions

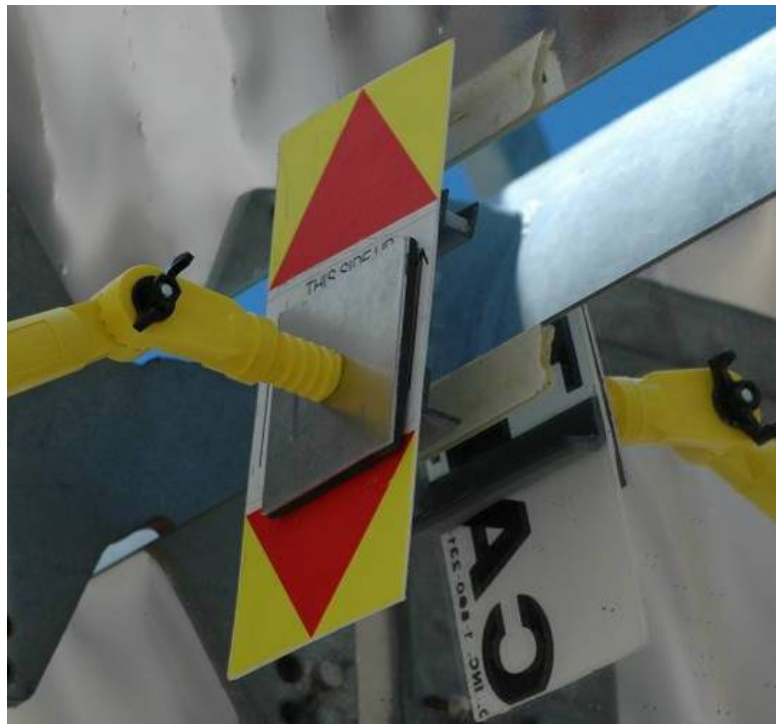
Travel position

Hydraulically actuated “limbo” feature for going underneath crossovers (~ 20 sec to change)

Boresight Gauge Installation

- Boresight gauge installed from the ground
- One person installs one boresight gauge per module in a row
- Another person follows trailer removing boresight gauges
- Both ride back with fixture to beginning of next row





Procedure for Acquiring Images

1: Stop with cameras centered on trough module

2: Raise or lower fixture to boresight center camera on receiver and boresight gauge

3: Level camera fixture using self leveling program

4: Acquire and store images from all cameras

5: Store data from the two ultrasonic meters

6: Drive to next module

Field Deployment System

Field Deployment System Testing at the Arizona Public Service 1 MW_e Saguaro plant

- Shakedown testing March 2006 and October 2006
  - Numerous fixture and software issues identified
  - One half of plant photographed in October
  - ~70 sec/module demonstrated
- Additional trip planned
  - Faster rate (<60 sec/module)
  - Improved image quality
  - Characterize structural defections and address module-to-module alignment
  - Align at least 1 Solar Collector Array (12 modules/drive)

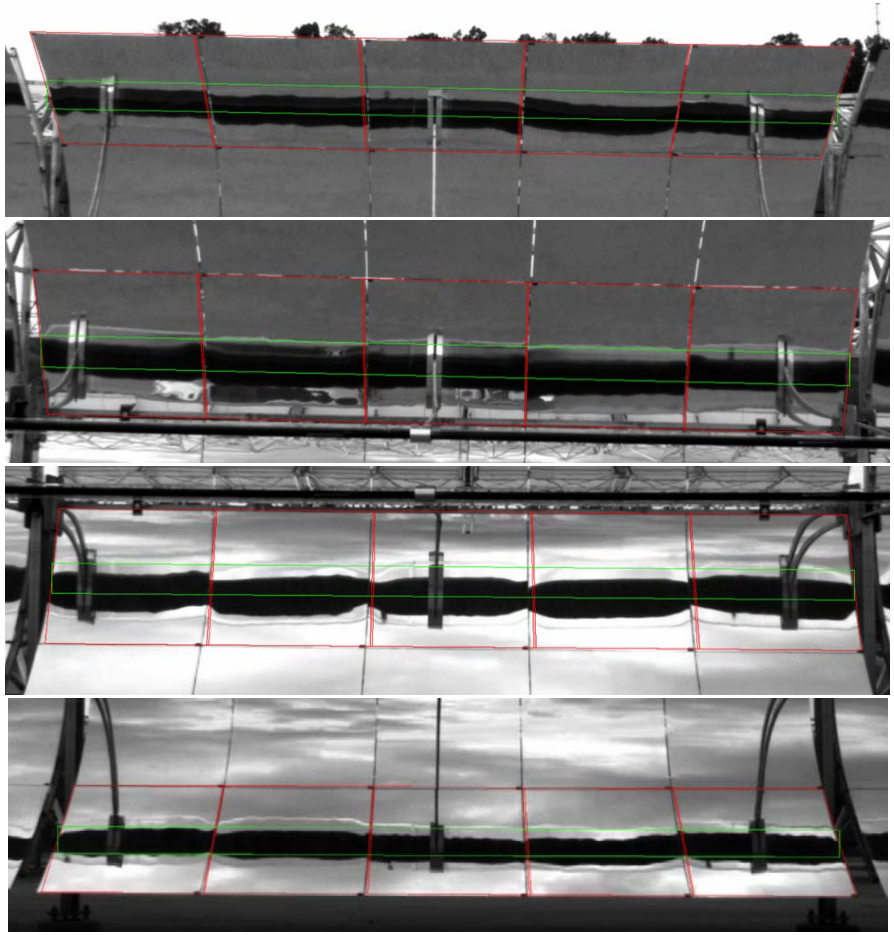
Field Deployment System

Current status of Software development

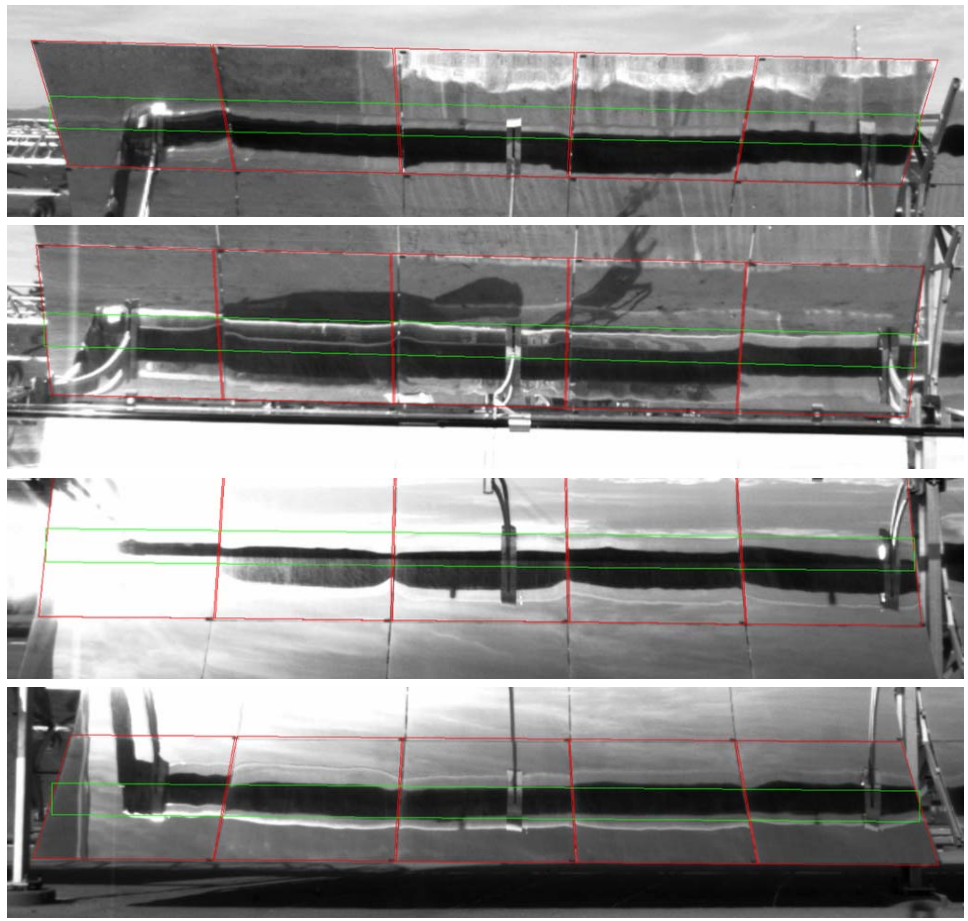
- Software written in LabVIEW Vision
- DAQ software essentially complete
- Software for analyzing images ~70% complete
  - Image analysis hampered by wide range of lighting conditions
  - Overlays are semi-automatic – operator determines mirror edges
- Database management still being developed

Field Deployment System

Sample Overlays



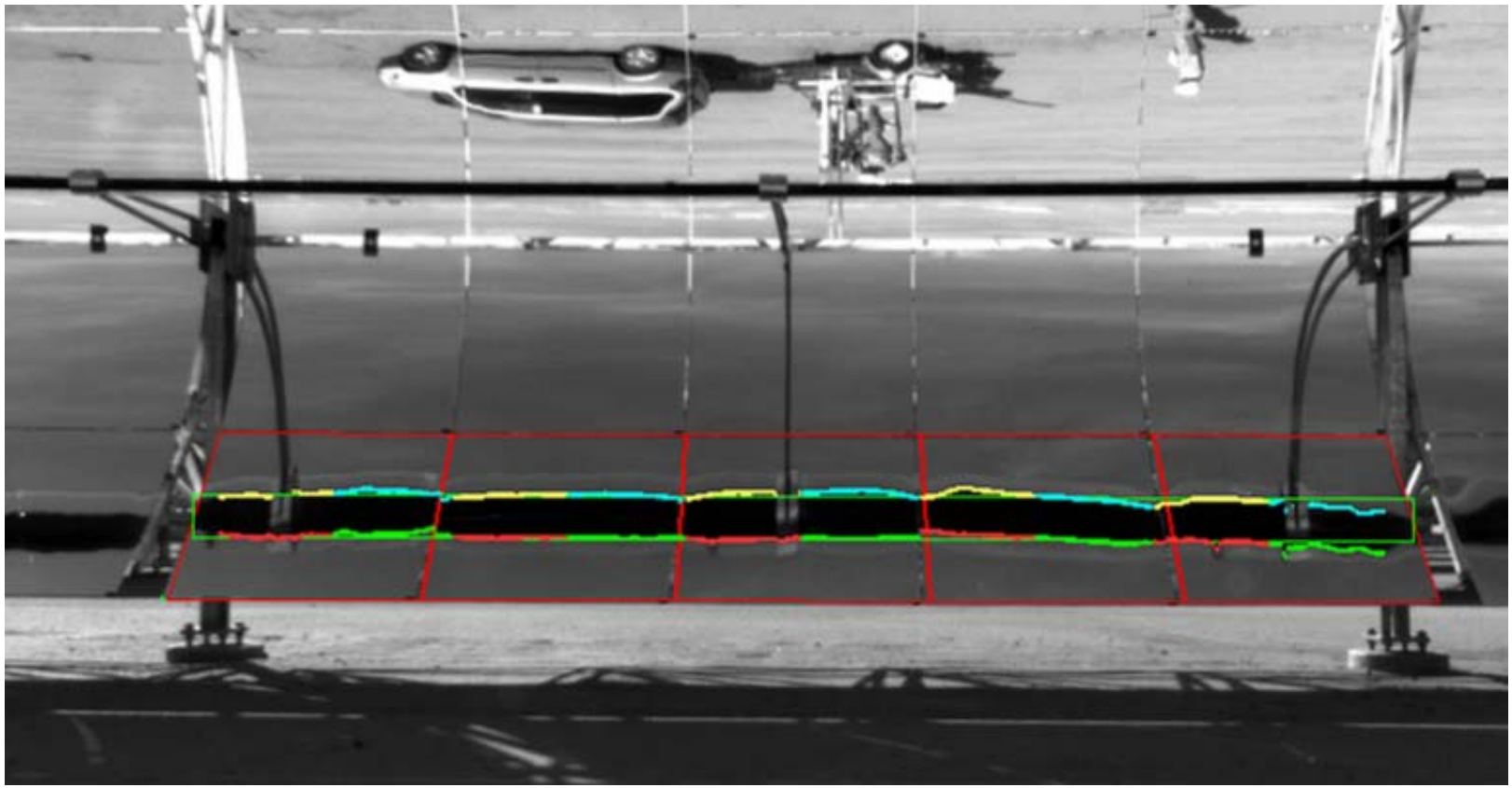
Module 4B3N



Module 6A6S

Field Deployment System

- TOP overlays of bottom row APS Saguaro module 6A6S
- Average number of pixel displacements (left and right) used to determine mount adjustments



Field Deployment System

TROUGH ALIGNMENT SCA: 6D3N

Instructions: East Facing View

	11N		12N		13N		14N		15N	
Row 1										
Row 2										
Row 3										
Row 4										

- Program creates worksheets that specify adjustment instructions
- Utilize same nomenclature currently used by plant operators/developers

Budget History

TOP Alignment Budgets

TOP Alignment	Total Value
FY05	$50K
FY06	$425K
FY07	$275K
Grand Total	$750K

Accomplishments

- Invented a practical approach for optically aligning trough mirrors
  - Inherently aligns mirrors to receiver
  - Better than 1 mrad alignment error
- Demonstrated the TOP Alignment at Sandia
  - Compared with Distant Observer approach
- Developed and tested field deployment system
  - Addresses requirements of commercial trough power plants
  - 70 sec/module demonstrated
  - Beginning to create alignment instructions
- Module-to-module alignment approach invented
  - Approach consistent with TOP Alignment references
  - Module and mirror alignment simultaneously addressed

Future Directions

- Refine and test TOP field deployment system
- Field test module-to-module alignment approach
- Align at least one solar collector array
- Characterize alignment of SEGS plants at Kramer Junction
- If appropriate, align statistically significant number of modules and quantify benefits
- Transfer/license to industry
- Apply overlay approaches to heliostats and parabolic dishes

Summary

- Derived from years of parabolic dish alignment experience
- Meets requirements of an ideal system
- Potentially significant impact
- Accurate and inherently aligns the mirrors to the receiver
- Simple, practical, straight forward for old or new installations, or O&M needs
- Method proven and viable for full development
- Refinement of hardware, software, and methodologies under development
- Interest by industry

Questions?