

Scalable HeliOstat calibRation sysTem (SHORT) – How to calibrate your whole heliostat field in a single night

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Marcelino Sanchez

msanchez@cener.com

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1.- Introduction and context

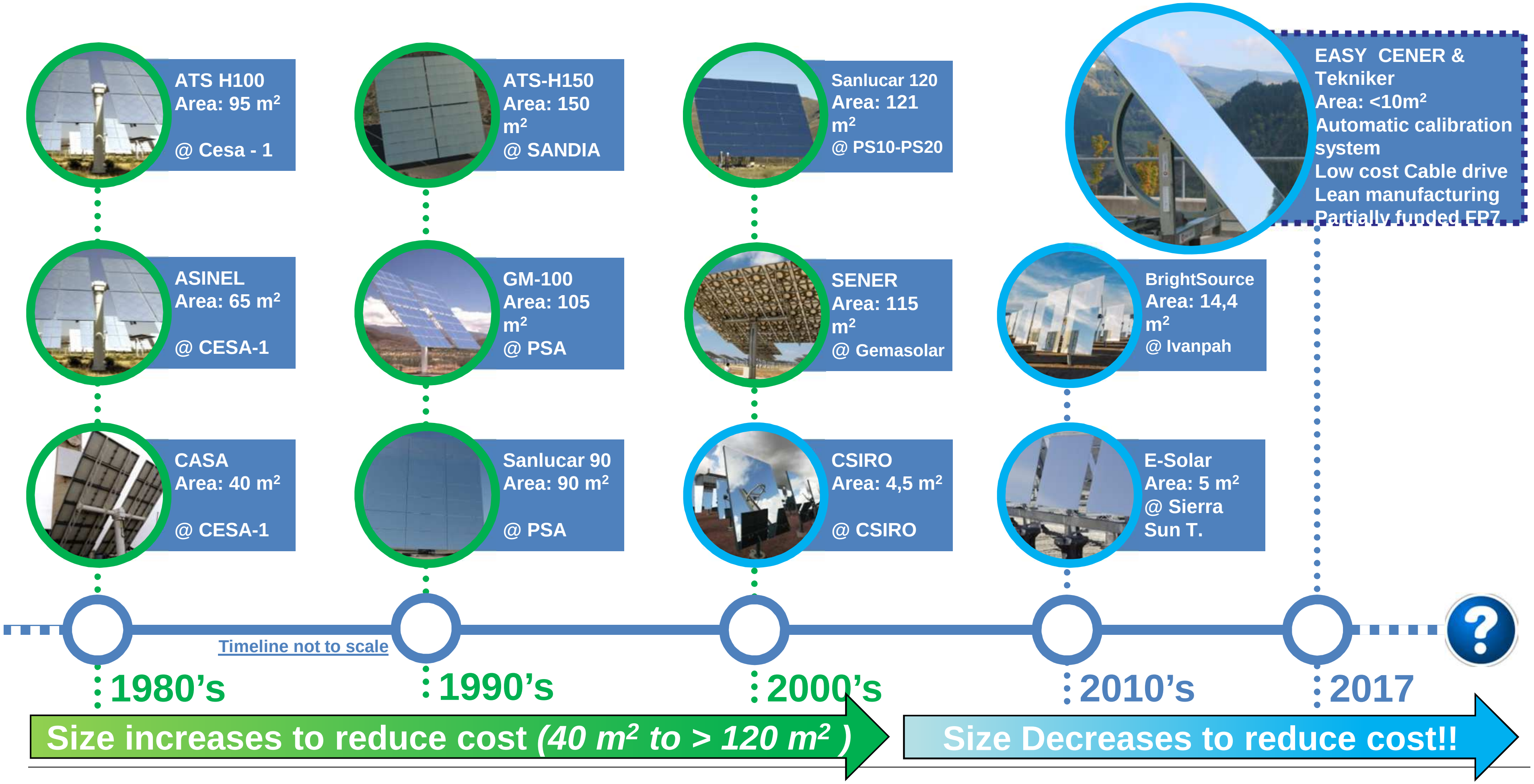
Technology trends

- While current installed CSP capacity is dominated by parabolic trough systems, data from the CSP Today Global Tracker shows that solar towers account for nearly half of global capacity under construction and 70% of projects under development.

Status	Tower (MWe)	Parabolic Trough (MWe)
Operation	651	4,218
Construction	891	943
Development	3,558	1,469
Source: CSP Today Global Tracker (as at March 2017)		

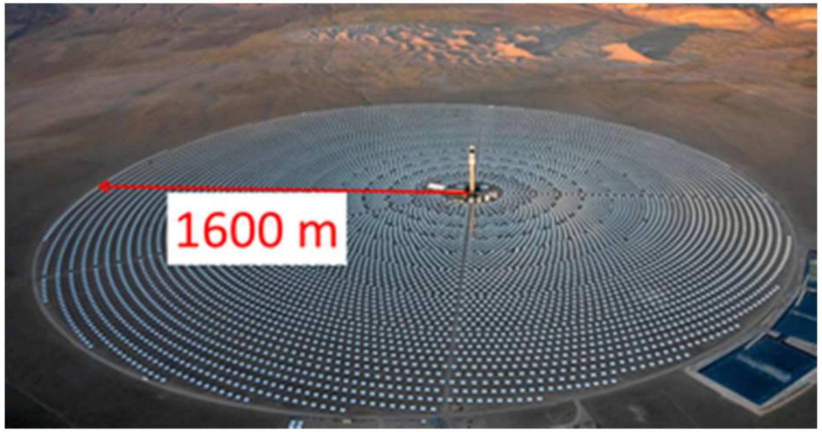
Global CSP capacity: Solar towers vs. parabolic trough

Heliostats designs and evolution



Solar heliostat fields trends

Current trend field size increase



GEMASOLAR (2011)
- **Heliostats: 2,650 @ 120 m^2**
- **Aperture: 304,750 m^2**
- **Power: 20 MW**
- **Storage: 15 h**

CRESCENT DUNES (2015)
- **Heliostats: 10,347 @ 115.7 m^2**
- **Aperture: 1,197,148 m^2**
- **Power: 110 MW**
- **Storage: 10 h**

Sept 2017. **DEWA awards AED14.2 billion largest CSP project in the world with a record bid of USD 7.3 cents per kW/h to generate 700MW.** The project will have the world's tallest solar tower, measuring 260 meters. Power 200 MW??

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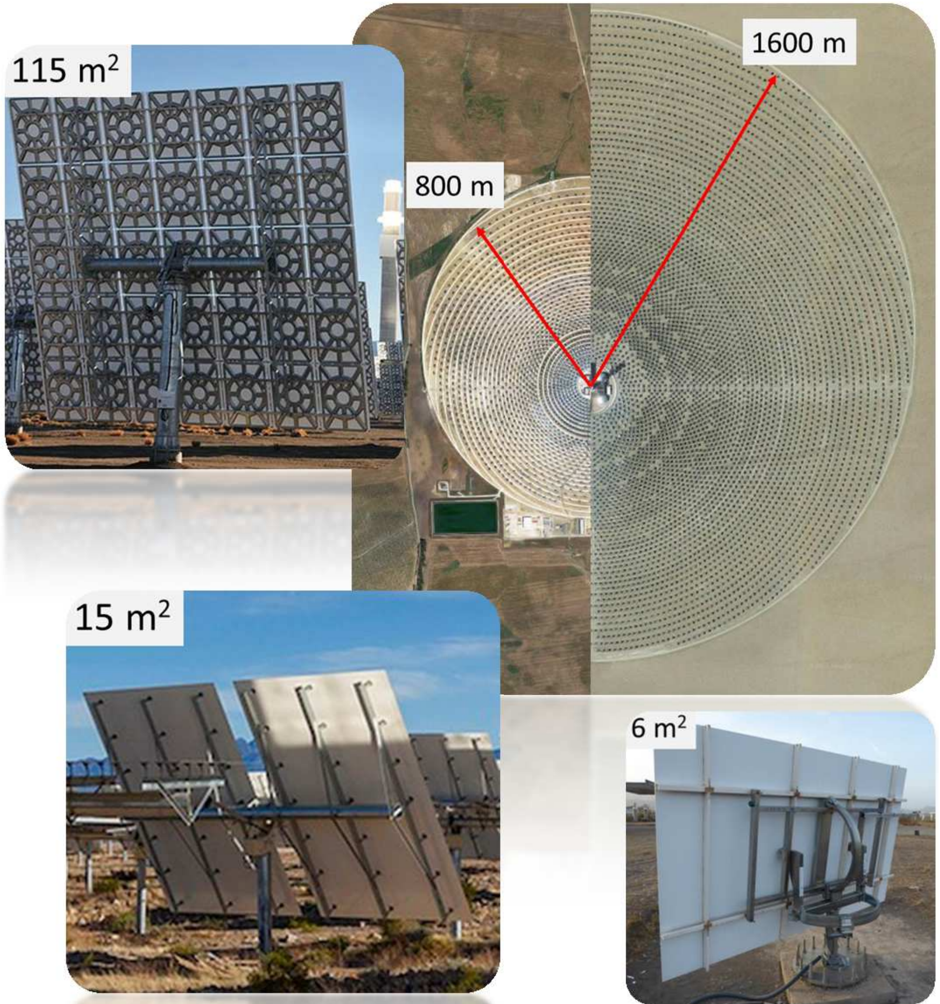
1. Introduction and context

- **Large number of heliostats:**
  - Smaller heliostats
  - Bigger plants
- **Pressure to reduce costs:**
  - Relax requirements
  - Reduce the need of long term stability
  - Simplify installation
- **Need for:**
  - Quick heliostat installation
  - Guarantee final accuracy on field
  - Applicable for large distances between heliostat and tower

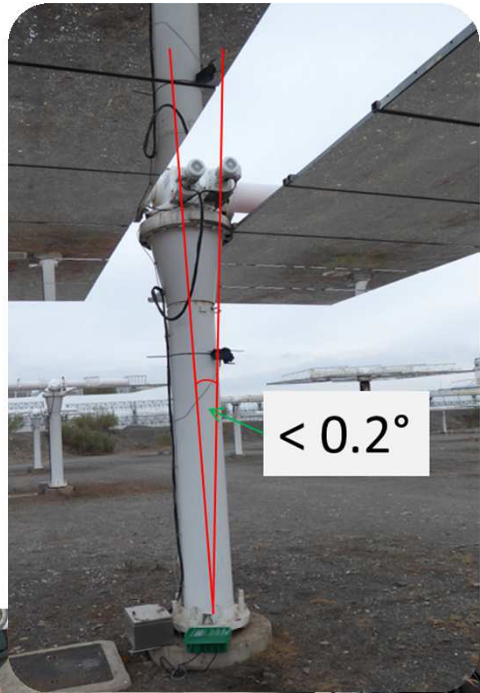


Current State

Combination of (one-time) manual adjustment with flux verification.

- **On construction:**
  - Make sure heliostat axis are properly aligned
  - Measure inclinations
  - Adjust orientations (screws)

- **Drawbacks:**
  - Very difficult to repeat later on
  - Labor intensive
  - Difficulties to guarantee final accuracy



Current State

❑ **During operation:**

- Reflect sun onto target
- Use camera to detect flux center
- Measure deviations
- Calculate angular offset and introduce as offset correction

❑ **Drawbacks**

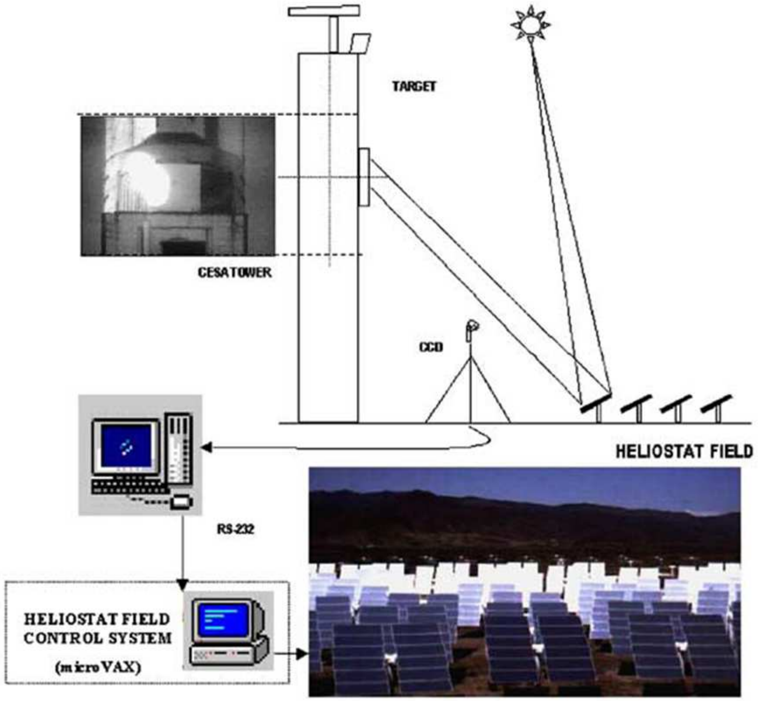
✓ One heliostat at a time

✓ Takes a very long time for large fields

✓ Not fully applicable to **long distance heliostats** where:

- o Reflected image has very low power density
- o Size of reflected image could be bigger than the white target.
- o **Impossible to accurately determine actual aiming point.**

✓ Final accuracy of this methodology depends on heliostat features such us (facet quality, heliostat size and position).

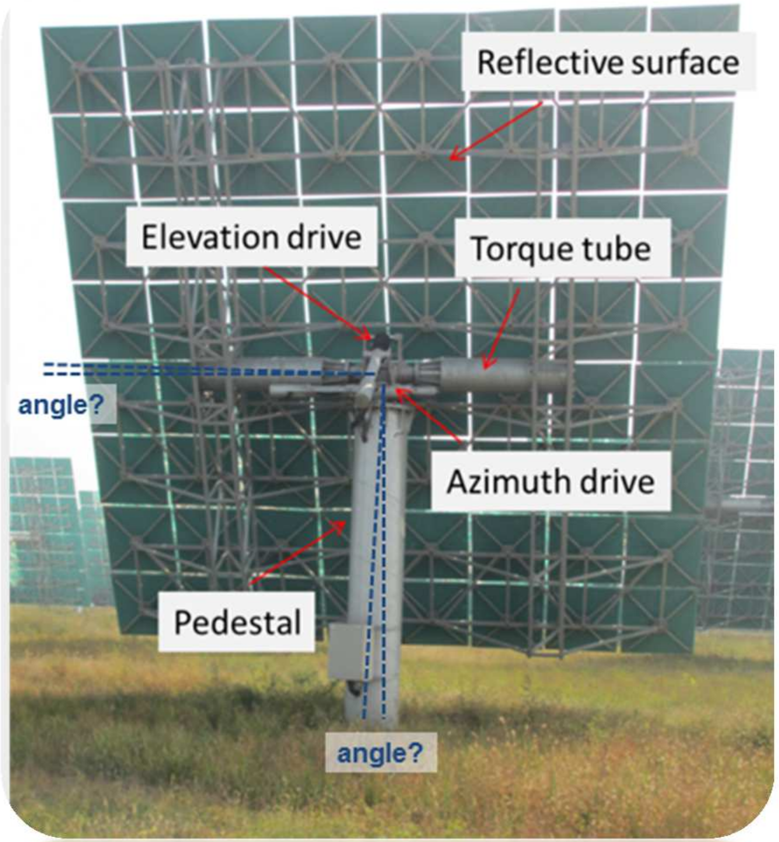


Berenguel et al. 2004

2.- SHORT approach

Goals

- ❑ Identify heliostat actual configuration
  - ✓ Axes orientations
  - ✓ Angular offsets
  - ✓ Facet orientation
  - ✓ Exact position
- ❑ Automatic process
- ❑ Accurate
- ❑ Fast (Parallel)



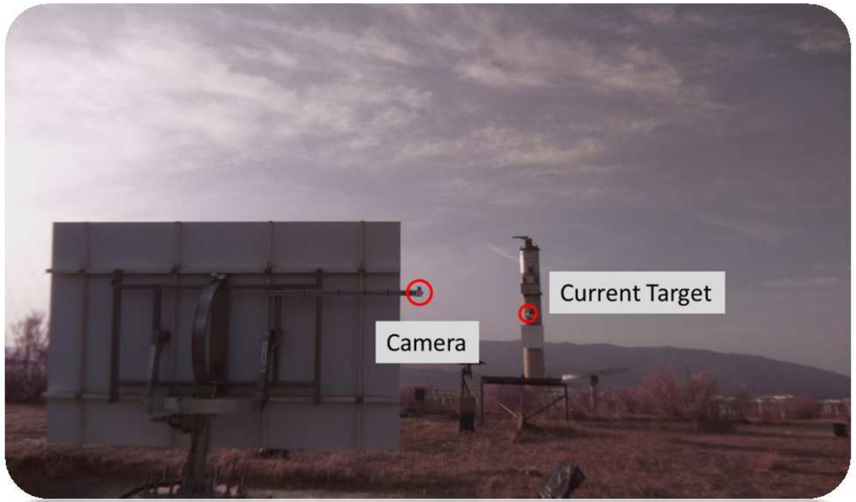
Final goal

- ❑ Eliminate current drawbacks

- ❑ Attach a camera to each heliostat
- ❑ Rigid connection to facet structure
  - ✓ No specific position or viewing direction required
  - ✓ Possibly looking sideways or backwards
- ❑ Low-cost camera (mobile devices)

Methodology

- ❑ Camera observes **targets with known locations:**
  - ✓ Lights, sun, moon
  - ✓ Anything identifiable (artificial or natural)



Moon

Methodology (artificial vision system)

- Storage known positions of targets
  Iterative process → heliostat moves to find targets:
- For each position
  - ✓ Automatically detect target in image
  - ✓ Store target ID
  - ✓ Store encoder values
- Repeat for several targets and heliostat orientations



Methodology (Kinematic model)

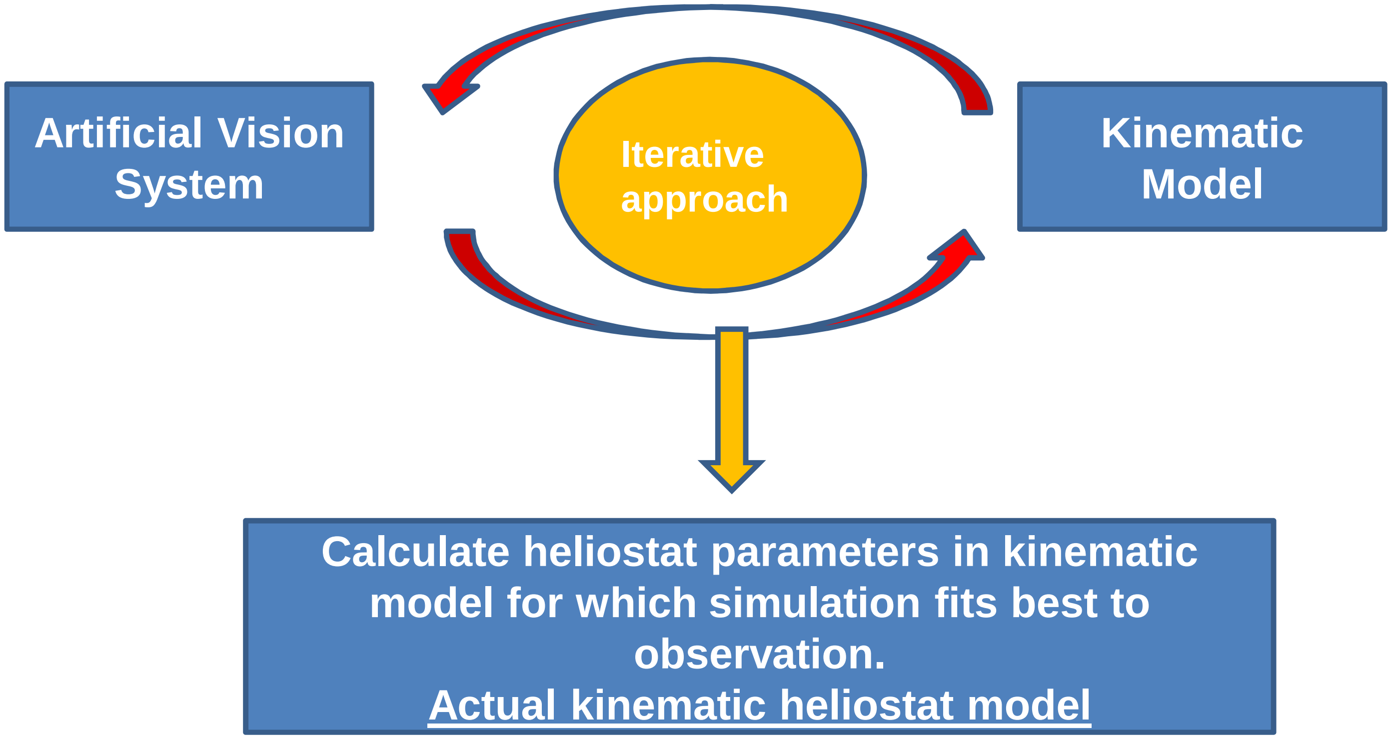
- Model the kinematic behavior of the heliostat
- Predict orientation according to encoder values
- Simulate capture of targets
- Model predicts the image position of a target

$$\begin{pmatrix} u \\ v \end{pmatrix} = f\left(\alpha_{Azimuth}, \alpha_{Elevation}, X_{Target}; Model\right)$$

- **The Kinematic model "evolves"** from a generic heliostat model **to the actual model of the heliostat under calibration, including** accurate real values of heliostat parameters such us **axes orientation and position**

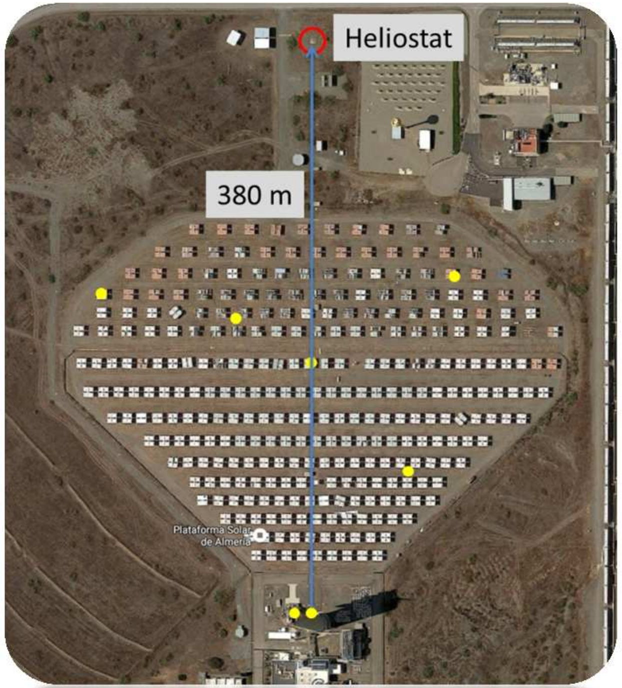
3.- Experimental results

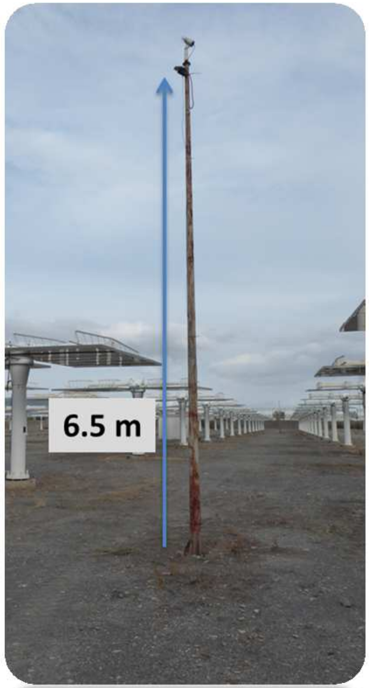
Methodology (Calibration)



3. Experimental results

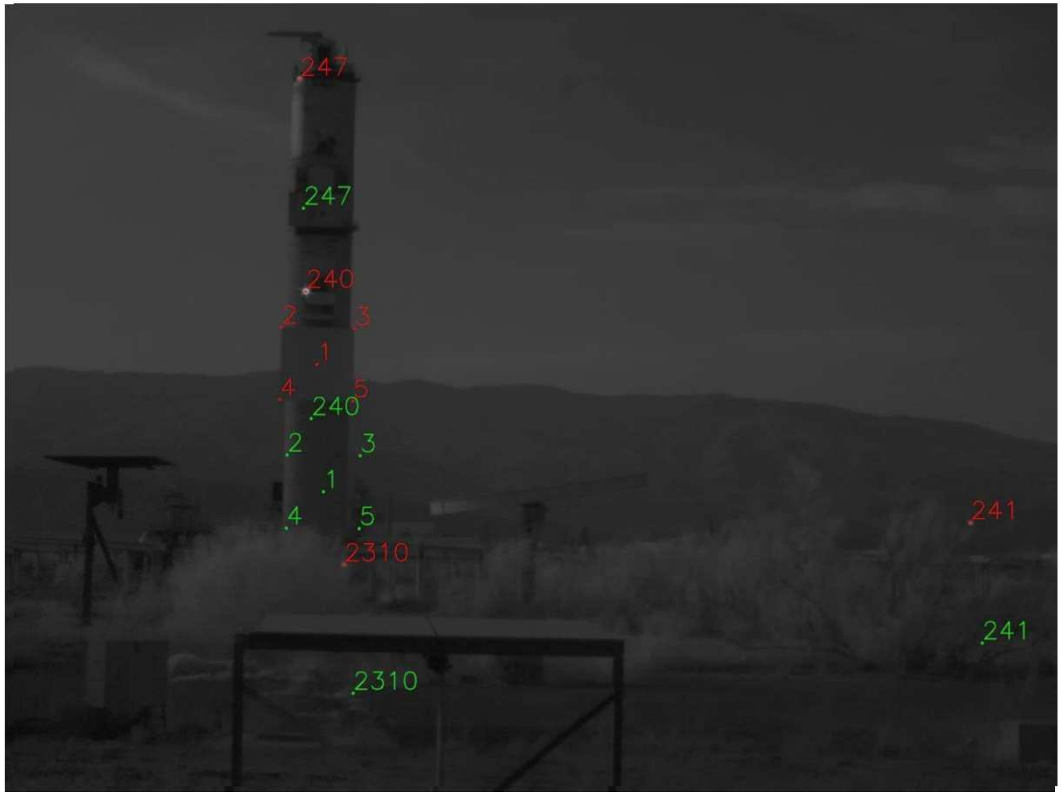
- Tested at PSA in October 2016
- 7 IR targets throughout the solar field
- 53 observations for calibration (additional for evaluations)
- Multiple observations of the same target under different orientations





3. Experimental results

- Precise knowledge how the heliostat is moving
- RMS error of 0.22 mrad in movement prediction



Intermediate kinematic model
(heliostat parameters iterative adjustment)

Initial kinematic model

Final kinematic model
(Actual heliostat parameters)

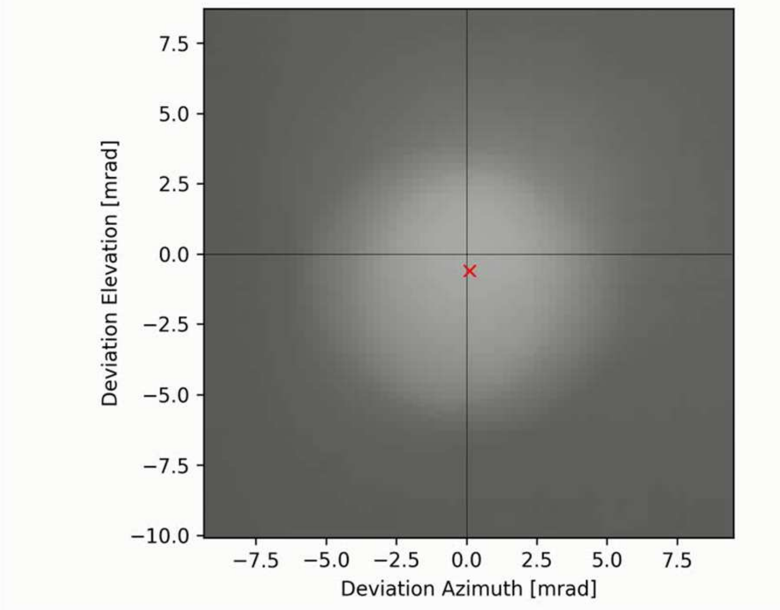
Calibrated model

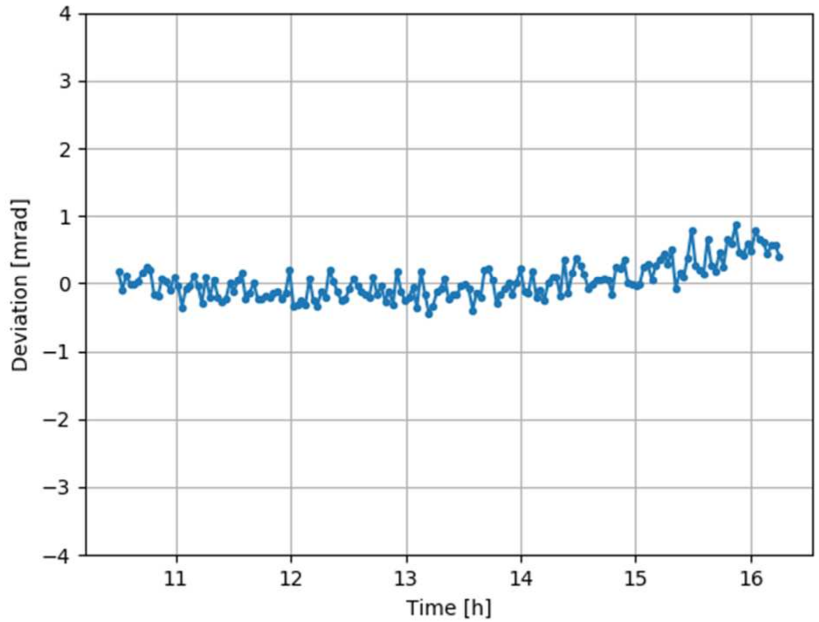
Red: Correct position

Green: Model estimation

3. Experimental results

- Once the actual kinematic model of the heliostat is calculated by SHORT
- Heliostat can be moved into desired orientation



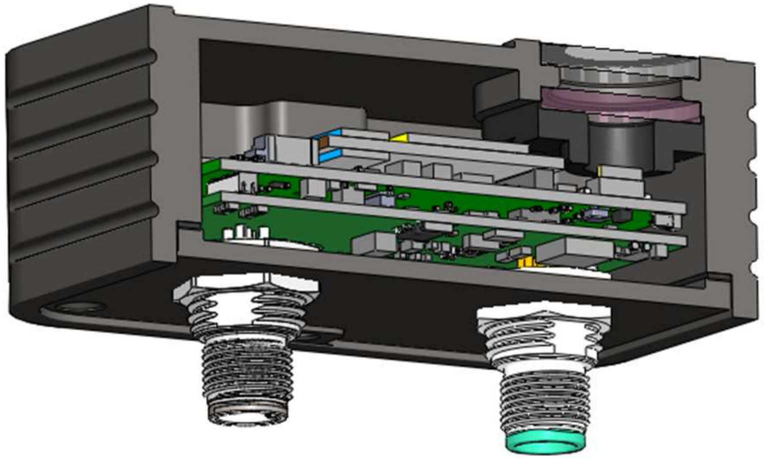


Results on a real heliostat tested at PSA (heliostat tracking evaluation all day long)

- Evaluation of tracking accuracy (sun tracking)
- 0.6 mrad tracking error (RMS) for the tested heliostat

N. Custom hardware development

- Functionality: Calibration and (optionally) motion control of heliostat
- Highly flexible software architecture
- Traceability of operations supported by a database
- Specs:
  - A7 processor for running high level algorithms on Linux
  - M4 processor for real time motion control
  - Integrated calibration camera and IR filter
  - Integrated motor drivers (azimuth & elevation actuators)
  - Communication buses (RS485, ETH) for plant management and integration with large heliostats



4.- Conclusions

4. Conclusions

Scalable HeliOstat calibRation sysTem (SHORT) has been presented:

- SHORT is based on an **automatic parallel calibration** using a **camera attached** to each heliostat
- SHORT has been **validated on field** making test at PSA facilities
- SHORT **calibrates** not only heliostat axes orientation but **the actual kinematic model of each heliostat**
- The **accuracy** of SHORT is **independent of heliostat features and position on field**
- **Experimental** results show **SHORT errors below 0.3 mrad (rms)**
- Calibrate a heliostat takes less than an hour **(heliostat field calibration takes few hours)**
- SHORT **can be applied at night** avoiding any interference with ordinary plant operation
- **SHORT is fast, easy, robust and accurate and can be applied to any heliostat field**

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Thank you for your attention!!!
Marcelino Sánchez msanchez@cener.com
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