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Calibration and Characterization Systems in Solar Concentration Plants: Field Expertise, Conclusions, and Lessons Learned

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October 18th, 2023

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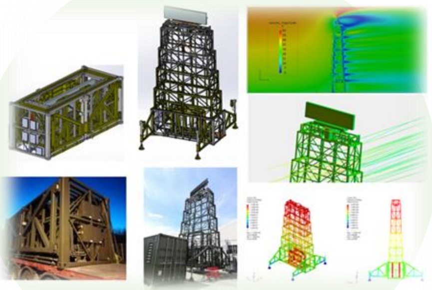
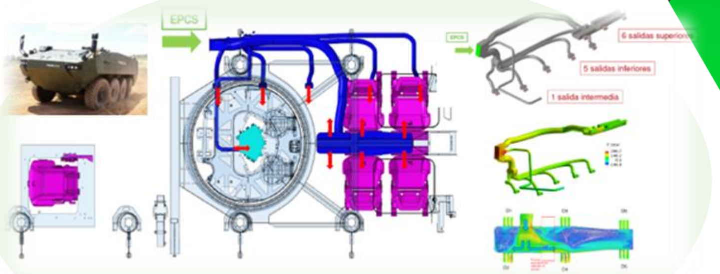
Company with Scientific and Innovation DNA
More than 25 years making Real Industrial Innovations…


RENEWABLE ENERGY



INDUSTRY



DEFENSE

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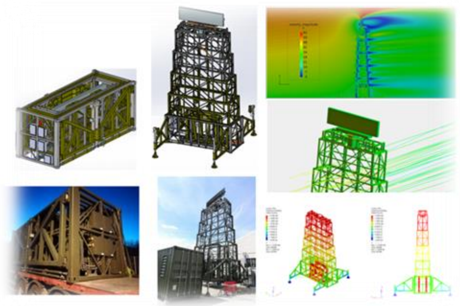
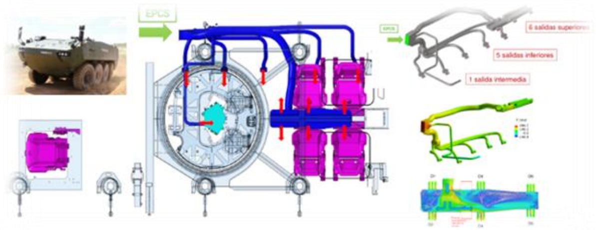
40 Patents in Solar Energy and Hydrogen. Executed projects worldwide.

TEWER DIVERSIFICATION

RENEWABLE ENERGY

- CONCENTRATED SOLAR POWER
- GREEN HYDROGEN (PHOTO-THERMO CATALYSIS H2 PRODUCTION)
- PHOTOVOLTAIC SOLAR POWER
- OTHER PROJECTS / TECHNOLOGIES





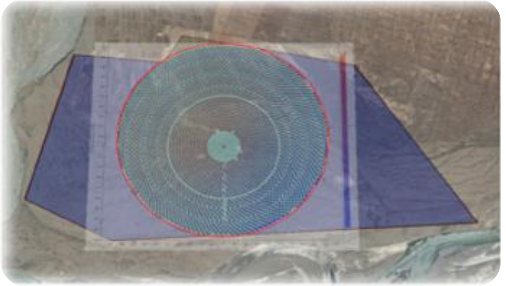
INDUSTRY & DEFENSE

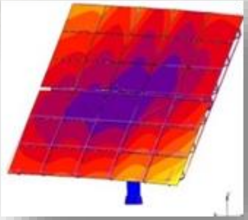
- ELECTROMECHANICAL SYSTEMS
- MECHATRONICS
- COOLING SYSTEMS
- MANUFACTURING AND ASSEMBLY PROCESSES
- ENGINEERING SERVICES

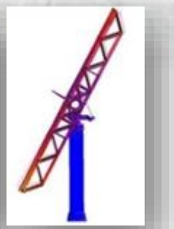
TEWER MULTI-TECHNOLOGY PARTNER

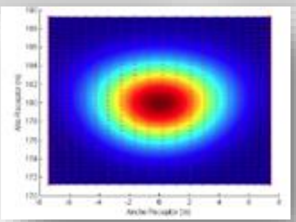
TECHNOLOGICAL BASES. CSP.

FROM FEASIBILITY PHASE TO DETAILED DESIGN



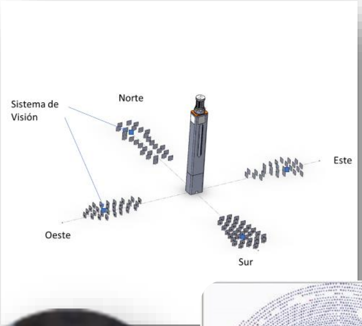


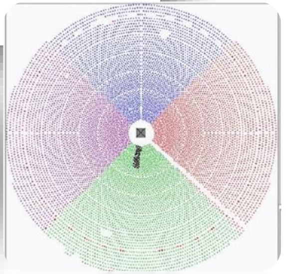




TURNKEY PROJECTS SOLAR FIELD ASSEMBLY AND COMISSIONING

SPECIFIC TECHNOLOGICAL SERVICES





PROPRIETARY TECHNOLOGY

OUR EXPERIENCE IN ALL THE VALUE CHAIN OF CSP TECHNOLOGY HAS BEEN APPLIED IN MULTIPLE PROJECTS OVER THE WORLD (CRESCENT DUNES, GEMASOLAR, CERRO DOMINADOR)

CSP PROPRIETARY TECHNOLOGY

HELIOSTATS	PHOTON *HELIOSTAT FAMILY* ***Smart and autonomous small dimensions heliostats*** *without wiring or foundations. Tested in PSA CIEMAT.* ATH146 ***146 m² reflective surface heliostat****. Tested and validated in PSA CIEMAT.*
PARABOLIC TROUGH	ATT10 ***High aperture PTC with optimized performance – cost*** *to be installed and validated in PSA CIEMAT in Autumn 2022* ATT6 *Already validated* ***PTC with 5.7 m aperture and excellent cost – performance ratio***
SOLAR FIELD ASSEMBLY PROCESSES	*Proprietary assembly and canting processes for both parabolic trough and heliostats solar fields*
FACETS	***Different facet solutions developed and patented by Tewer****.* ***High quality and low-cost solar reflectors.*** *Used for both internal products and for third party products.*
CHARACTERIZATION AND CALIBRATION SYSTEM	***Automatic solar field calibration system*** *that allow the complete optical characterization of the solar field (tower technology) as well.*






RESEARCH & DEVELOPMENT (R&D)

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Project PHOTON

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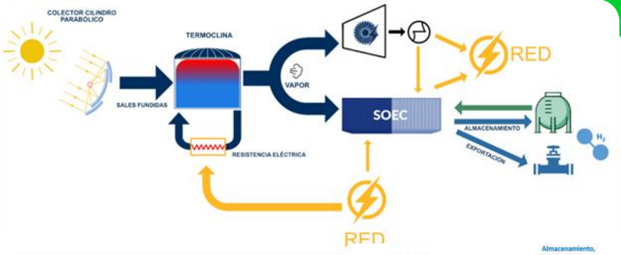
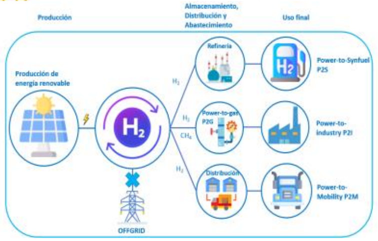


High performance Solar Reflector for CSP Industry
AUTO-RST SMEI PHASE II GRANT

European Commission

Financiado por la Unión Europea
NextGenerationEU

CDTI
@CDTIoficial



SI-CO

CSP CONCENTRATED SOLAR POWER

CSP ERA-NET has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 838311.

PROYECTO NEOSOLAR

White HYdrogen PHOTOcatalysis Power (PhotoHy)

tewer INGENIERÍA

High Thermal Inertia CAVity Receiver (THICAV)

Funded by the Horizon 2020 Framework Programme of the European Union

UNIVERSITY WEST

PROCADA

THICAV project

PROMES

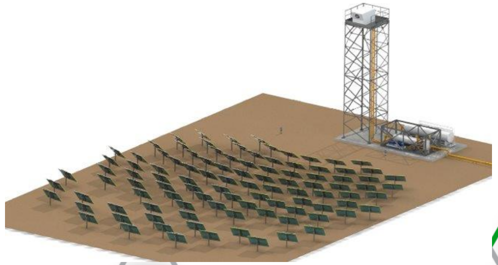
CNRS

LEIA

soLar field mEasurements to Increase performAnce

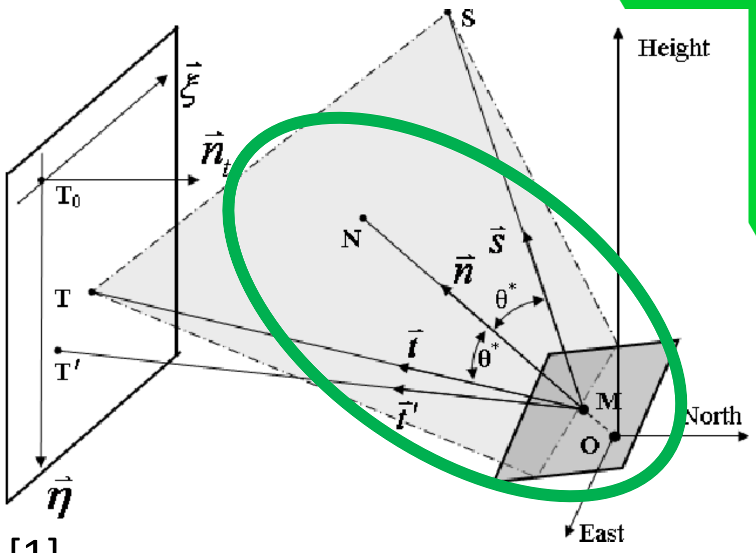
cspservices · acciona · DLR · tewer · PSA · CENER · SIEMENS energy

European Commission



UNDERSTANDING THE IMPORTANCE OF CALIBRATION SYSTEMS

Each heliostat is aligned individually in such a way that the overall surface normal bisects the angle between the sun's position and the aim point coordinate on the receiver.



[1]

Due to various tracking error sources, achieving accurate alignment **≤1 mrad** for all the heliostats with respect to the aim points on the receiver without a calibration system can be regarded as **unrealistic**.

→ A calibration system is **necessary** not only to improve the aiming accuracy for achieving desired flux distributions but also to reduce or eliminate spillage.

[1] Gu, M. and Wang, Z. (2015) Study on the General Accurate Azimuth-Elevation Tracking Angle Formula for Heliostat and Its Applications. Advances in Energy and Power Engineering 3(5), 123-138. doi.org/10.12677/aepe.2015.35019

SOURCES OF OPTICAL ERRORS

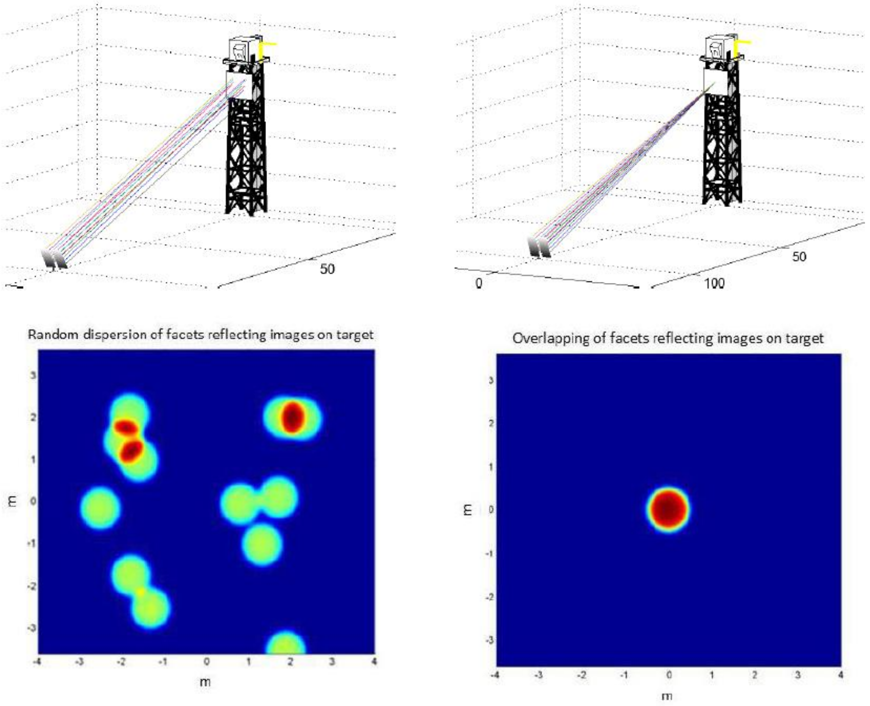


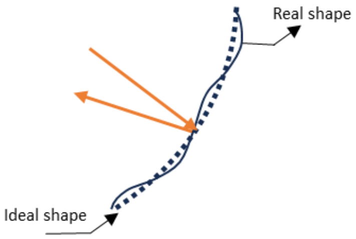
Figure 12: Simulation of heliostat image on target before (left) and after (right) canting (Source: [Monterreal2014]).

Heliostat mirror facet alignment involves two actions:

- ✓ Focusing
- ✓ Canting

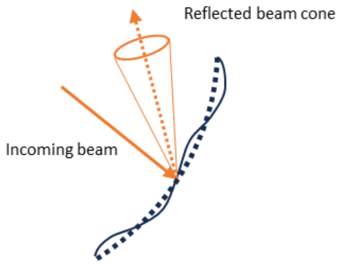
Good heliostat alignment leads to **reduced spot size and spillage losses at the receiver**; as a result, **annual power** intercepted by the receiver **is maximized** [2].

OTHER ERROR SOURCES



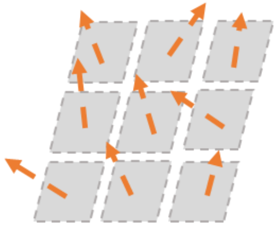
Surface Slope Error

Deviation of the rays due to slight ripples presented in the mirror shape



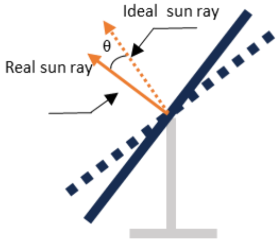
Beam Quality

Actual flux density distribution of the reflected heliostat beam on a target



Canting Error

Misalignment between mirror facets enlarges and defocuses the beam



Tracking Error

Deviation of the heliostat actual orientation from the desired orientation

[2] STAGE-STE Project (2014). State of the Art in Heliostats and Definition of Specifications. Survey for a low cost heliostat development.

STATE-OF-ART OF CALIBRATION SYSTEMS

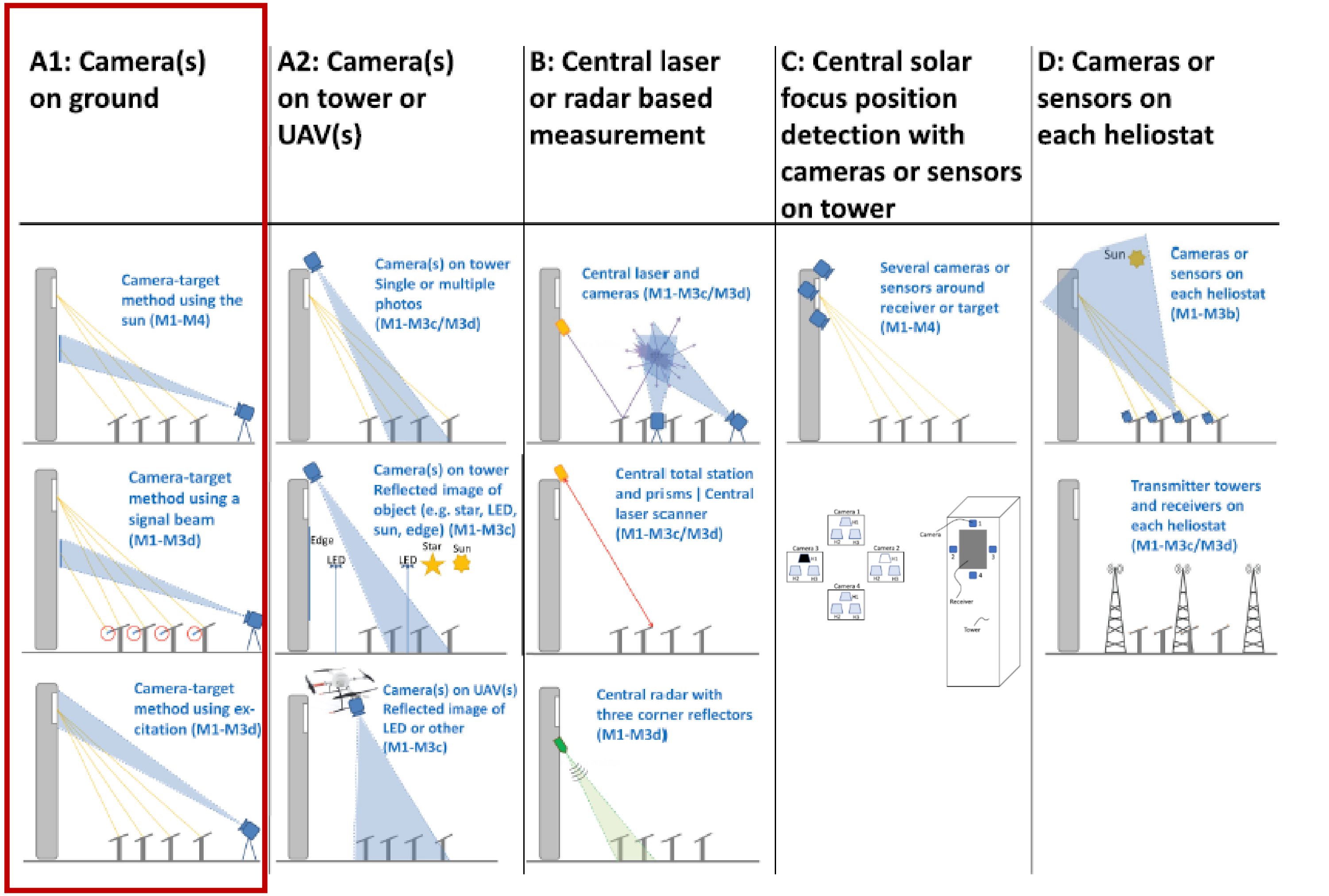


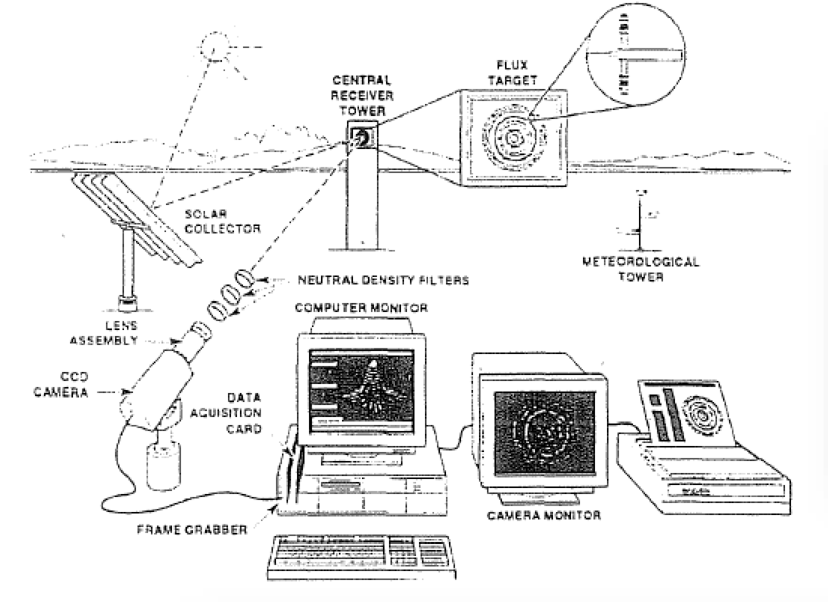
Fig. 6. Visualisation of the resulting calibration system classes according to the classification criterium *Location, type and number of measuring devices or sensors* (Röger et al., 2018) (modified and translated into English).

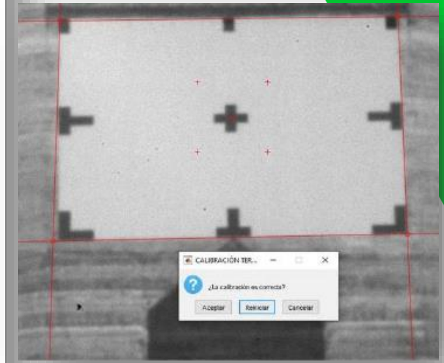
[3] Sattler et al. (2020). Review of heliostat calibration and tracking control methods. Solar Energy 207, 110-132. doi.org/10.1016/j.solener.2020.06.030.

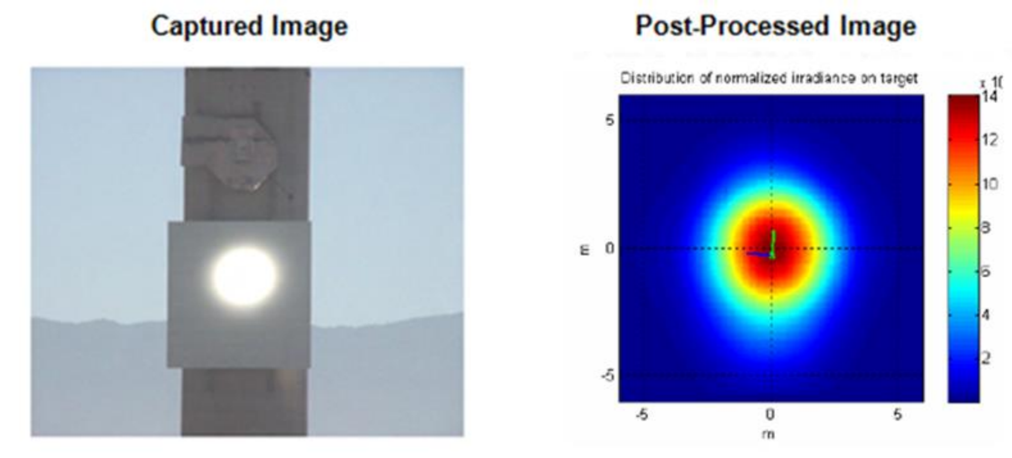
CAMERA-TARGET METHOD USING THE SUN

A calibration is done by:

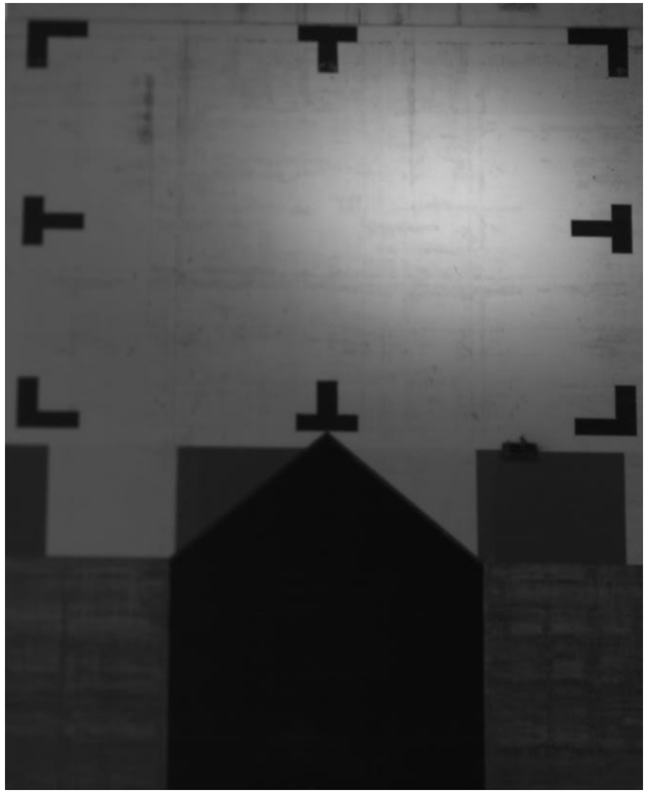
1) Sequentially moving individual heliostats out of the receiver focus onto a white Lambertian target screen underneath the receiver.
2) Capturing the solar focus on the target screen using a camera on the ground.
3) Using image processing software to detect the centroid solar focus position on the target and comparing it to a reference position. By comparison of the solar focus position with the desired reference position, a pointing error can be computed (offsets).
4) The measured pointing error is usually stored in a database and can be used as sampling data for an error model.

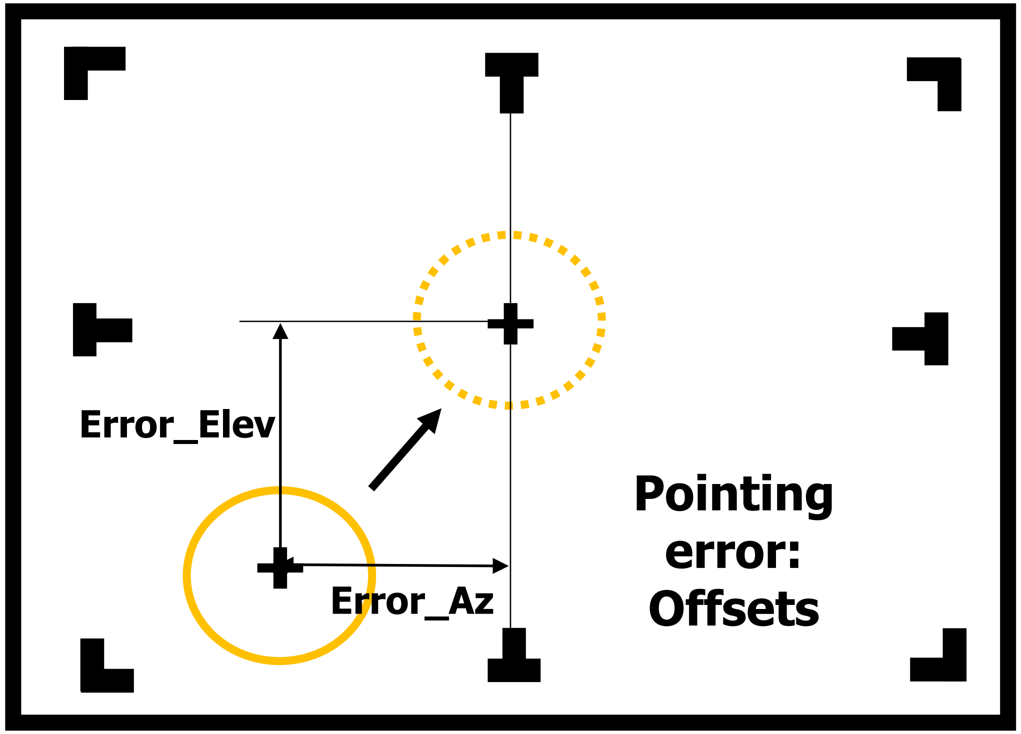






CAMERA-TARGET METHOD USING THE SUN



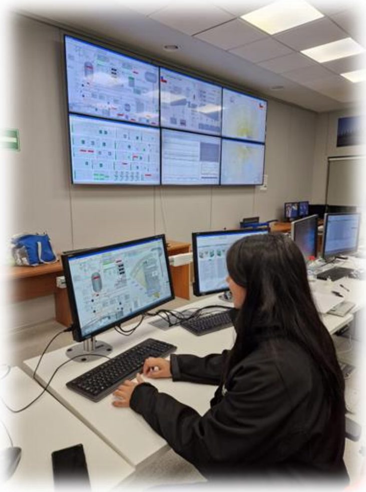


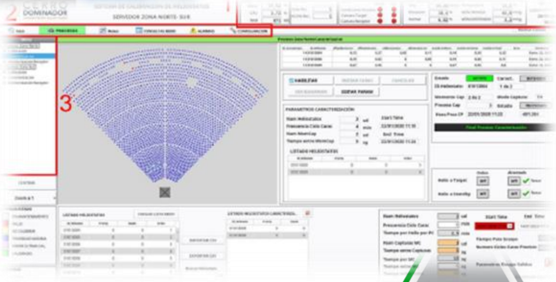
Pointing error refers to the difference in position between the reflected image of the sun and the intended position

CAMERA-TARGET METHOD ON GROUND USING THE SUN

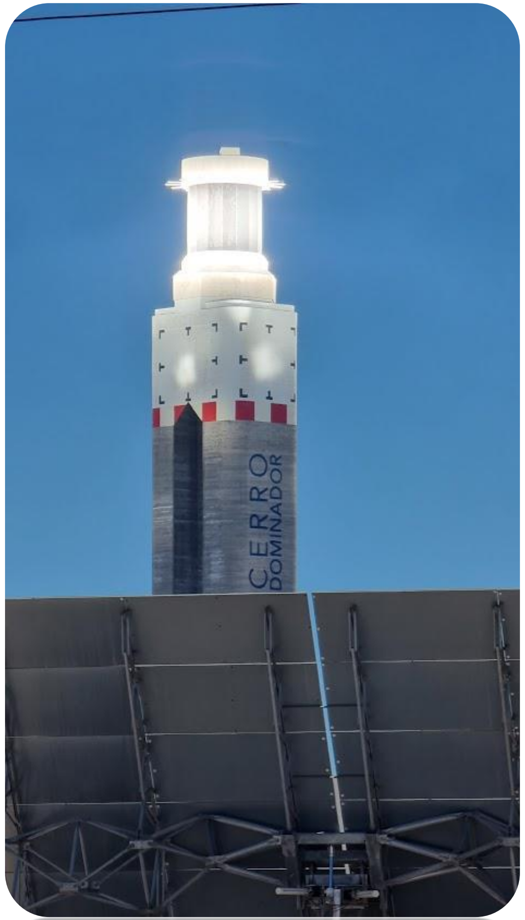
<u>Advantages</u>:

- ✓ The camera-target method is currently the state-of-the-art method with the largest track record, delivering very accurate heliostat orientation data with accuracies around 0.1 mrad (fine calibration), however this also depends on the heliostat movement system's tolerance.
- ✓ The camera-target method uses a simple setup with relatively **<u>low-tech components</u>**, i.e., a white Lambertian target, a camera and a computer for image processing.
- ✓ Measuring an individual heliostat's solar focus directly on the target delivers a highly accurate feedback signal.





CAMERA-TARGET METHOD ON GROUND USING THE SUN

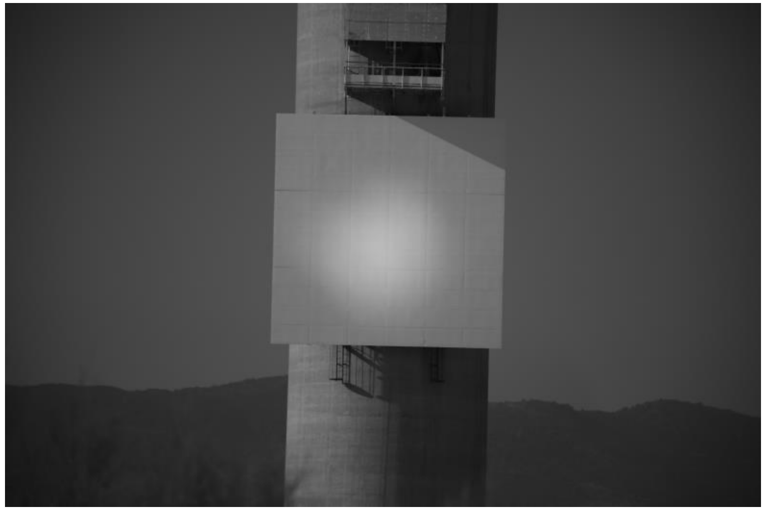


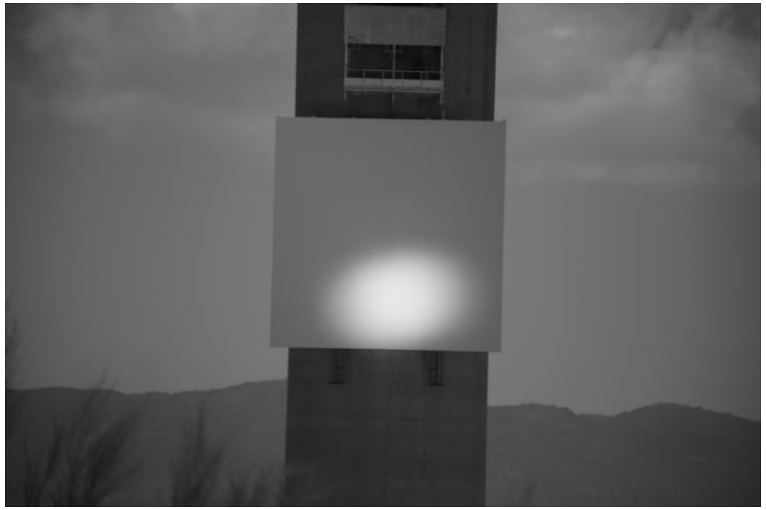
Limitations:

- With a high number of heliostats, the calibration process needs a lot of time.
- There is certain initial effort necessary for a coarse pre-calibration of the heliostats to focus on the calibration target.
- Heliostats far away from the target require a more complex algorithmics and procedure to calibrate them due to their lower energy flux density per area.
- The method can only be applied during sunny periods with direct solar irradiance.
- The system requires a fully deployed control system of the solar field with a robust communication architecture.

SOME EXAMPLES

As sunspot shapes vary during the day and different optical qualities could be obtained for different daytimes, the evolution of the optical accuracy during the day should be analysed.





Reflected flux on the target

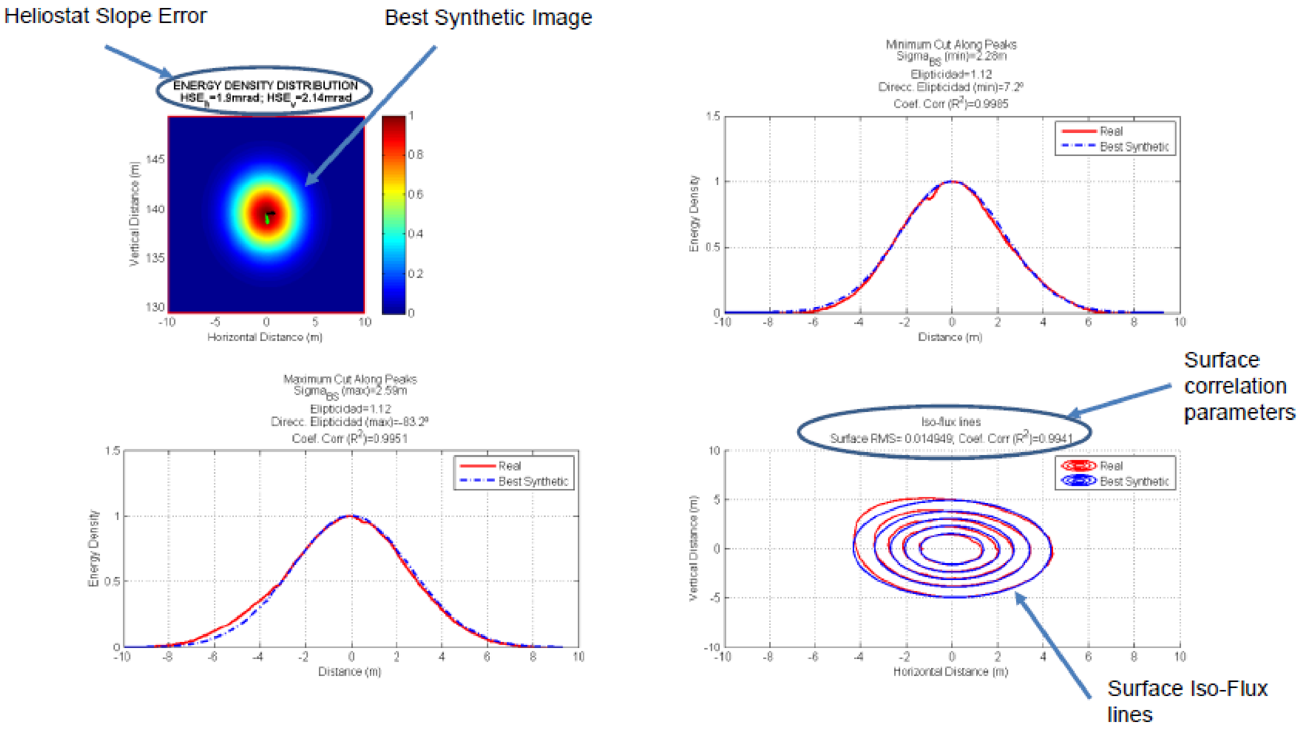
↓

Tracking Error Characterization Systems

OTHER FEATURES OF THE SYSTEM

To study the optical quality of the heliostat (Tracking Error and Slope Error), a reflected solar flux analysis system is necessary. In this regard, the TEWER calibration system has the additional advantages:

- **It enables the option of calculating the Slope Error** of the heliostat after each successful calibration.
- Since azimuth and elevation angles of the heliostat and Sun are registered, it also **allows integrating a characterization system** by sequentially calibrating a single heliostat at different positions throughout the day.



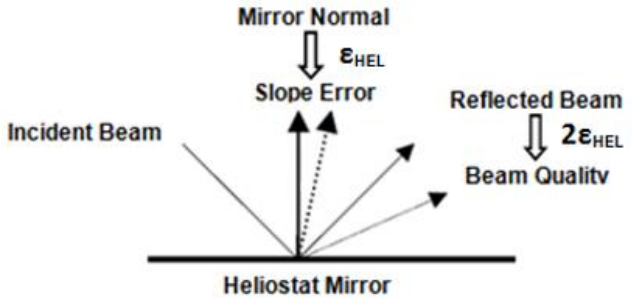
SLOPE ERROR CALCULATION

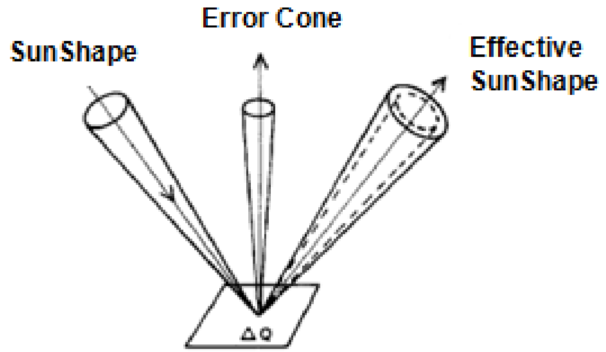
Heliostat Error Slope (ε_{HEL}):

Standard deviation (1σ) of a normal probability distribution that includes the deviations of the normal vector to the reflecting surface of the heliostat with respect to that corresponding to an ideal reference surface, free of optical errors.

The Heliostat Slope Error includes the effects of undulation (small-scale surface deviations), surface slope error (structure deformations due to wind, temperature and gravity effects) and edge errors (all sources of possible optical errors that can be modeled using a Gaussian distribution).

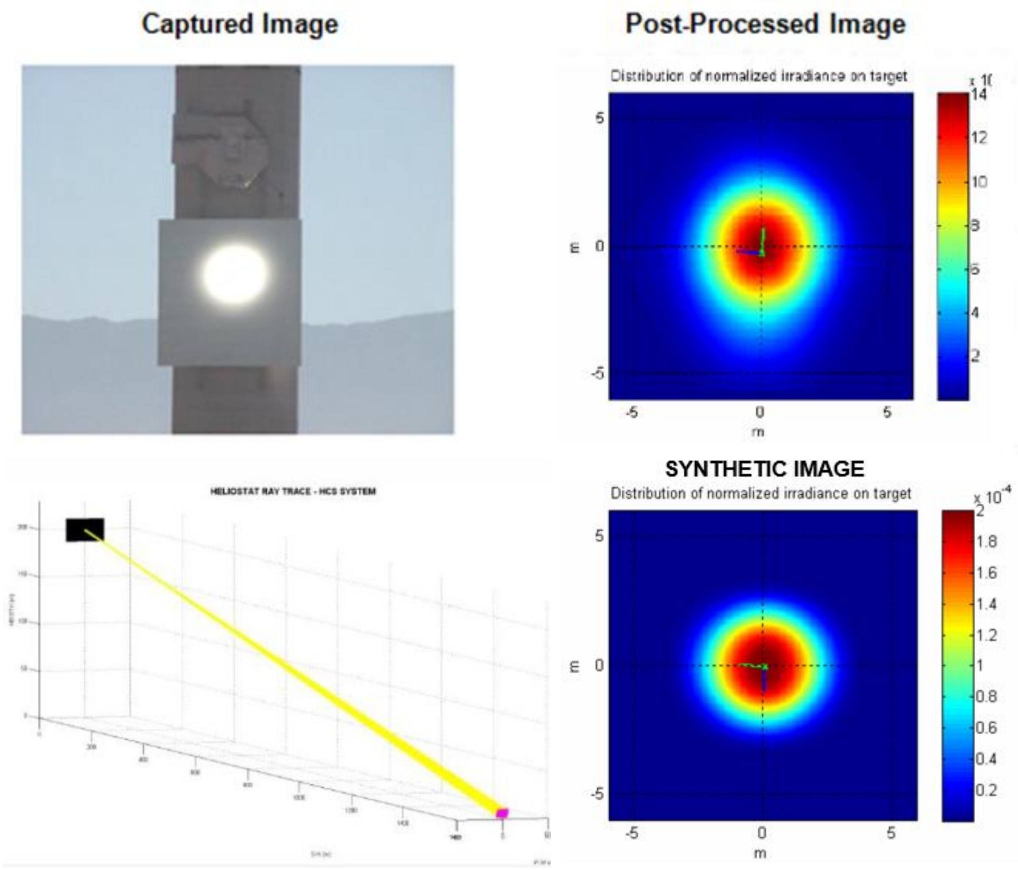
$$Beam\ Quality = 2 \times Heliostat\ Slope\ Error$$





SLOPE ERROR CALCULATION

The Slope Error of the heliostat is calculated by comparing the flux intensity distribution reflected by the heliostat that intercepts the target (**Real Beam Shape**), with the theoretical flux distribution calculated with a mathematical model (**Synthetic Beam Shape**).



The comparison and adjustment of the parameters inherent to the heliostat allow the evaluation of the Slope Error, differentiated for each of the evaluated heliostat axes σ_H and σ_V, which best represents the shape of the real beam of the heliostat (Real Beam Shape).

FURTHER SYSTEMS BEING DEVELOPED BY TEWER

LEIA
soLar field mEasurements to Increase performAnce

European Commission

Development of a calibration method using a new solar sensor deployed on the heliostat structure to enabling a low-cost calibration without a target.

- A new Solar Sensor will be designed by TEWER to perform offset calibration and tracking corrections. A collimating-type sun sensor will be used, and the implementation of fuzzy logic in sensing the sun position will be used to make possible to use cheaper photosensors to reach the required accuracy and resolution.

- The use of this type of sensor provides a **great advantage** in the performance of the solar field and calibration cost, considering that **the solar field could be calibrated simultaneously in a big group of heliostats without using the target**.

- The use of this sensor also **provides information about the heliostat offset and tracking degradation**.

LESSONS LEARNED AND CONCLUSIONS

Factors to consider when the calibration system is being conceived:

- ✓ Importance of the correct engineering of the system in terms of the definition of the cameras.
- ✓ The geometry and position of the targets in accordance with the plant layout and receiver geometry.
- ✓ The algorithm and its intelligence to calibrate without problems during operation, adapting and adequately treating the diversity of thousands of different heliostats’ reflection shapes on the target, considering real operational conditions such as wind gusts.
- ✓ Importance of correctly characterizing the Slope Error and the Tracking Error with tests that provide sufficient information to interact with the plant's pointing strategy.

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Thank you for your attention

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