DRONE-BASED QUANTIFICATION OF SOILING LOSSES FOR PARABOLIC-TROUGH COLLECTOR PLANTS

Rome, 10th Oct 2024

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30TH EDITION SolarPACES CONFERENCE

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  - Principles
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MOTIVATION

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Motivation

- CST[1] is strongly affected by soiling[2]
  - Regular cleaning not taking into account the current soiling losses is expensive in terms of human and natural resources[3]

➢ To optimise cleaning schedule[4] **representative soiling characterisation is of high interest[5]**
  - When to clean?
  - Where to clean first?

- State of the art measurement of soiling:
  - Portable reflectometer, TraCS, Avus[6,7]
  - To measure at several locations within the plant either high installation costs or significant effort necessary

- <u>Image based soiling measurement</u>[8]
  - High spatial resolution, portable and potential for low labour cost

UAV next to a PTC

[1] Lovegrove(2021) [2] Conceição(2022) [3] Merrouni(2020) [4] Cohen(1999) [5] Wolfertstetter(2018)
[6] Fernández-García (2017) [7] Heimsath(2018) [8] Wolfertstetter(2022)

PRINCIPLES OF OPERATION

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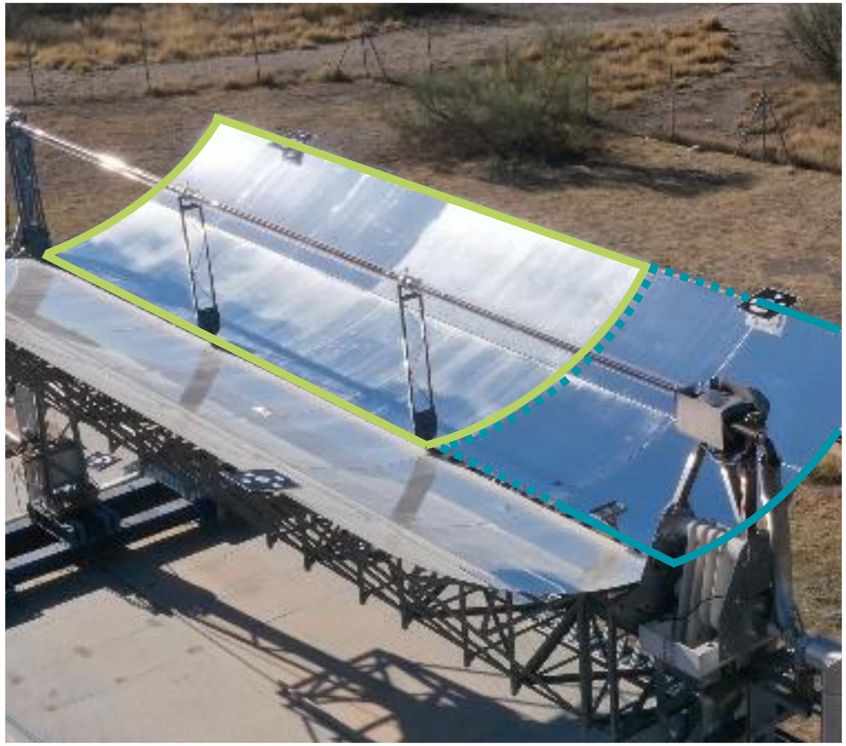
Principles of operation

- Soiling loss $= 1 - \frac{reflectance_{soiled}}{reflectance_{clean}}$
- Strong soiling e.g. by bird droppings is detected with AI method and set to 0% reflectance (not todays topic)
- Measure soiling effect of fine particles on collector:
  - Particles increase the brightness of the collectors in images
  - Use images of a clean collector to determine brightness without soiling for all other collectors
  - Use images of a soiled collector with known soiling loss to convert the brightness increase to a soiling loss for other collectors
- Reflected + scattered light captured by the camera
  - $RGB_{soiled} \propto Brightness = \boxed{\boxed{Reflected_{clean}} + Scattered_{particles}}$

Linearised images

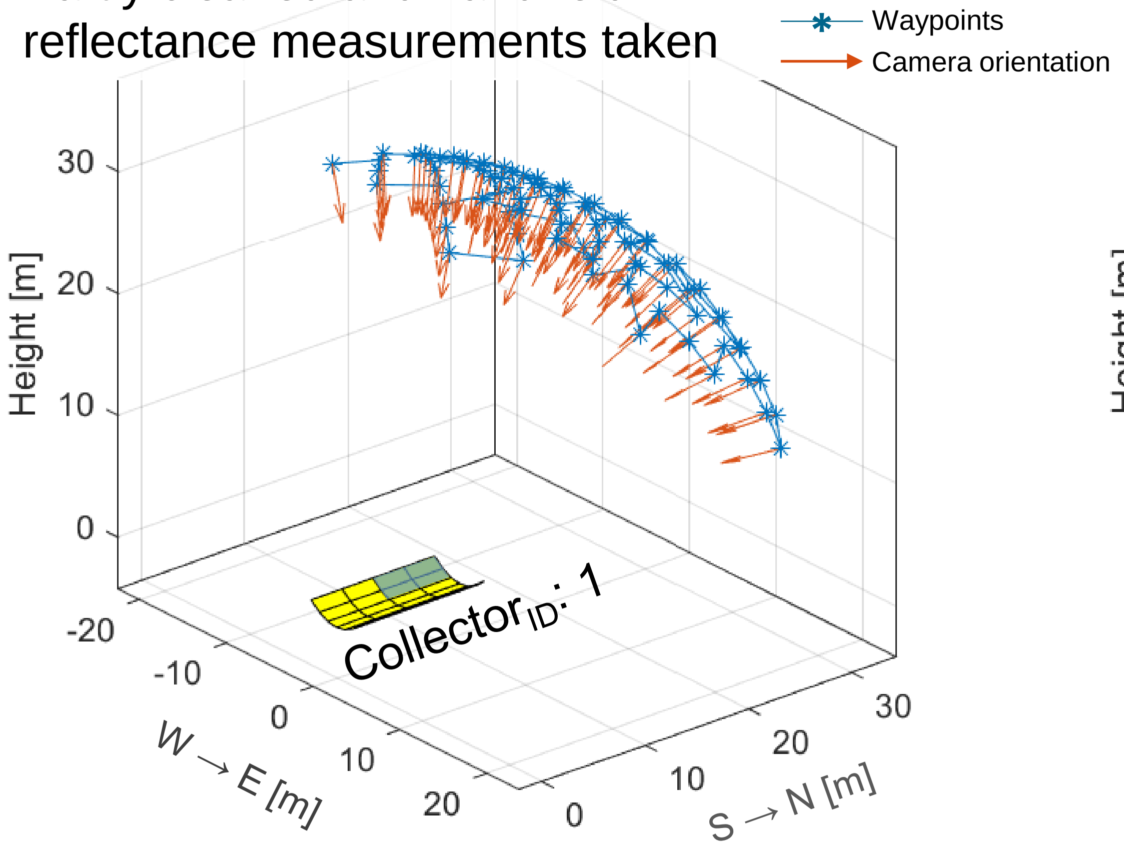


Cleaned and soiled area of a parabolic trough collector, Image taken at CIEMAT's Plataforma Solar de Almería

Principles of operation
- flight planning -

Calibration Flight

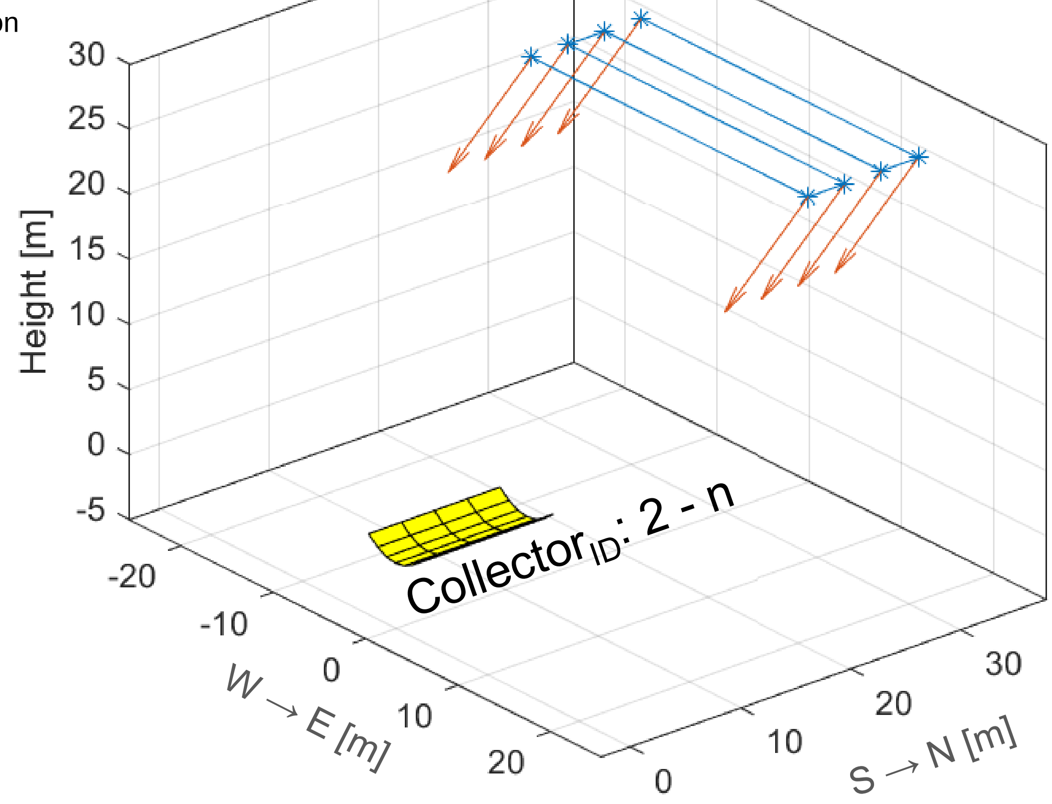
Partly cleaned and handheld reflectance measurements taken



Planned calibration flight

Evaluation Flight

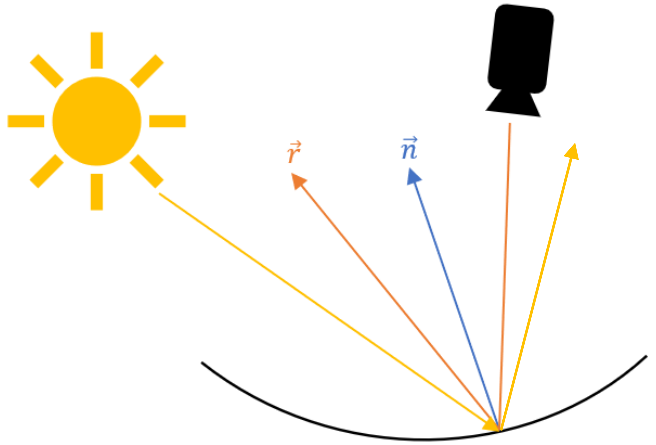
Any other collector



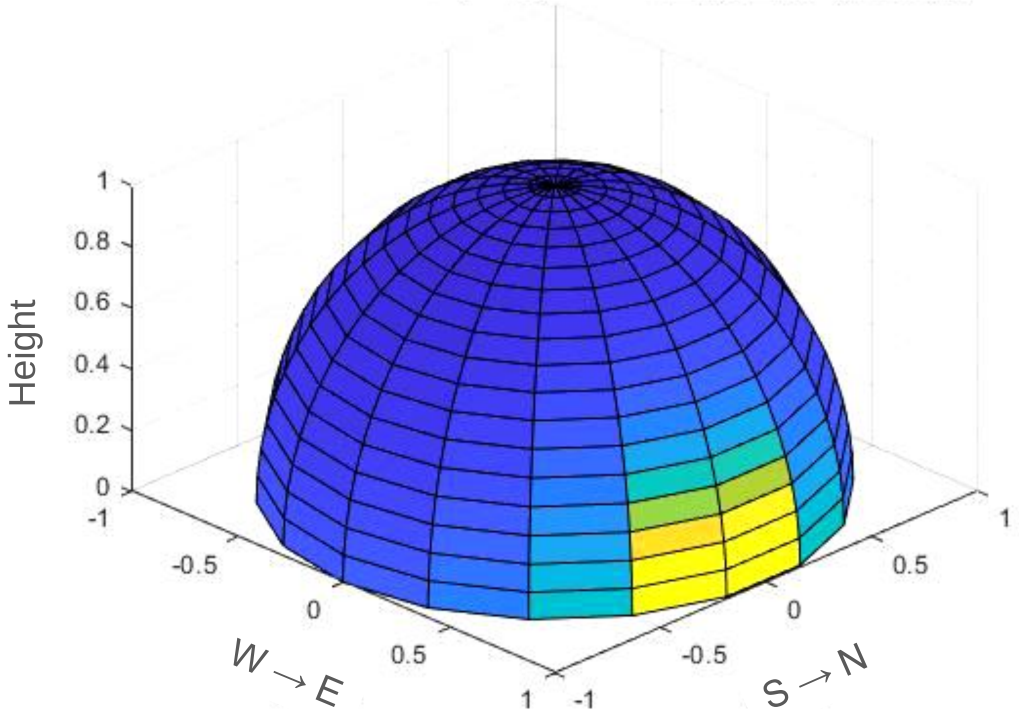
Planned measurement flight

Principles of operation
- how to determine brightness without soiling -

- RGB values of cleaned section from several images with different reflection vectors $\vec{r}$ are extracted to a sky map
- Images of mirrors to be evaluated might be taken at a different time compared to images of the cleaned mirror section
- Transferability from calibration time to evaluation time
  - Sky brightness modelling[9]
- Compare brightness of same sky position at relevant timestamps
  - $V_{Sky} = \frac{Sky\ brightness_{evaluation}}{Sky\ brightness_{calibration}}$



Schematic illustration of the soiling measurement



Simulation of the sky brightness on a dome with radius 20m, centered on the mirror

[9] Perez(1993)

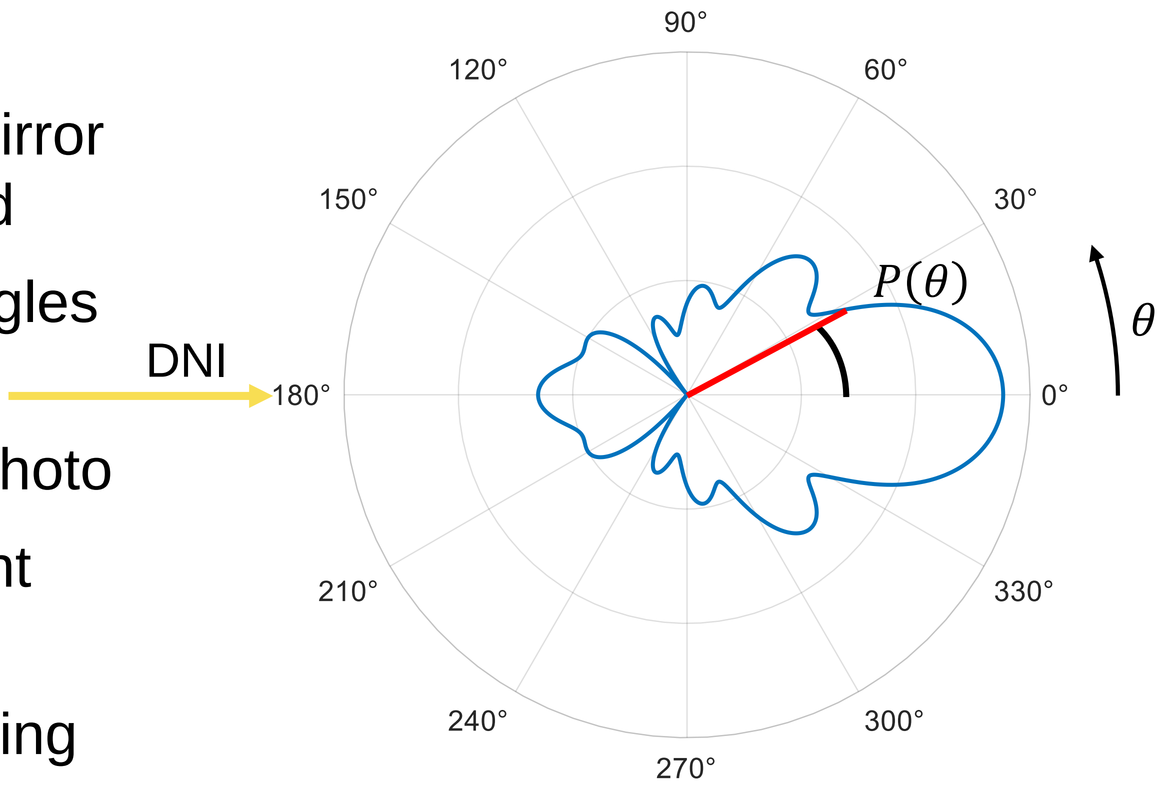
Principles of operation
- how to convert brightness increase to soiling loss -

- Brightness increase mainly depends on soiling loss, but also on scattering angle and DNI
- Different DNI and sun incidence angles on mirror in calibration and evaluation to be considered
- Several images with different observation angles on each pixel

➢ Scattering angle varies with time, pixel and photo

➢ DNI during calibration and measurement flight must be known

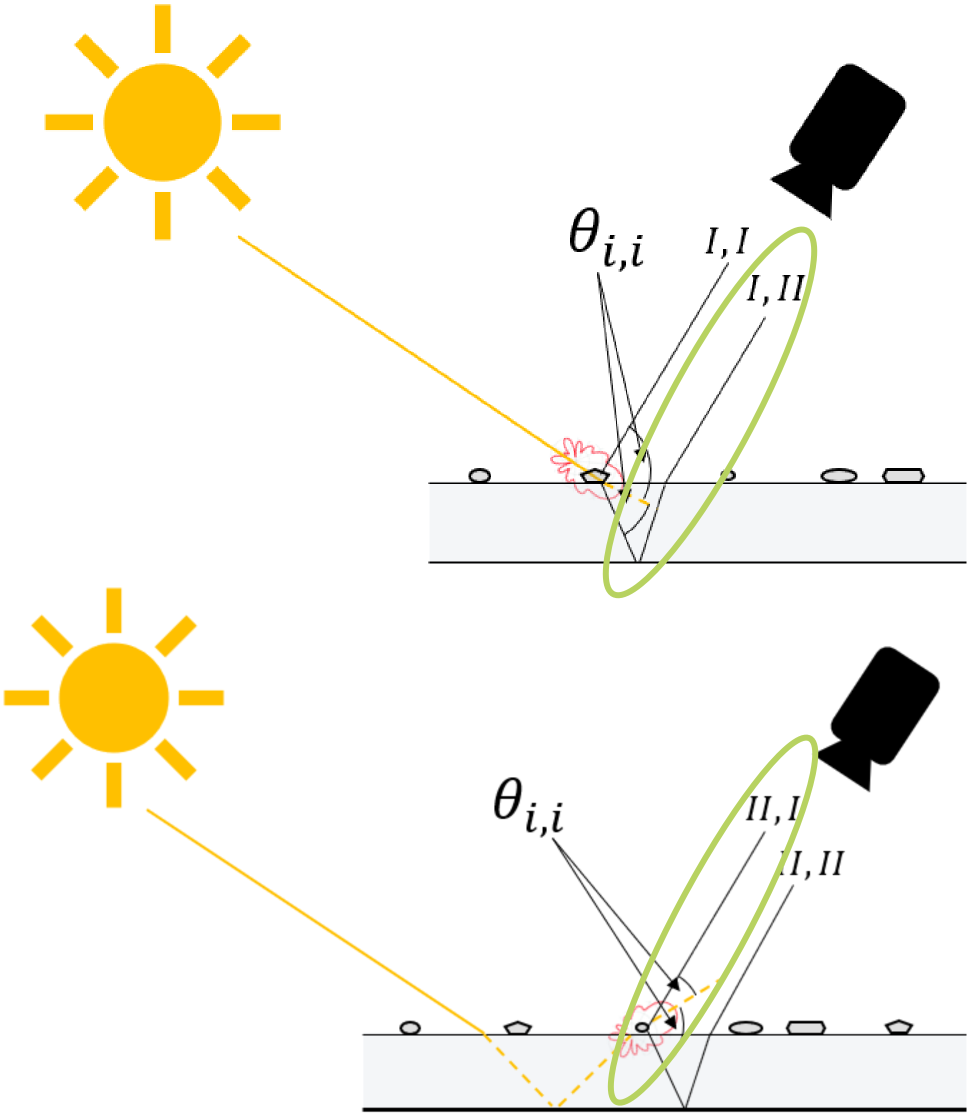
➢ For each pixel and photo the relevant scattering angle must be known



Logarithmic phase function of Mie scattering

Principles of operation
- how to calculate scattering angle from geometry -

- 4 light path ways identified (with scatter angles $\theta_{I,II} = \theta_{II,I}$ and $\theta_{I,I} = \theta_{II,II}$)
- Only paths with $\theta_{I,II} = \theta_{II,I}$ are relevant as the forward scattering is much stronger than the sideways scattering
- No consideration of multiple scattering
- Scattering angle can be derived from geometry
- Calibration factor that converts brightness increase into a soiling loss is obtained as a function of the scattering angle



Schematic illustration of scattered light path ways

EXAMPLE MEASUREMENT

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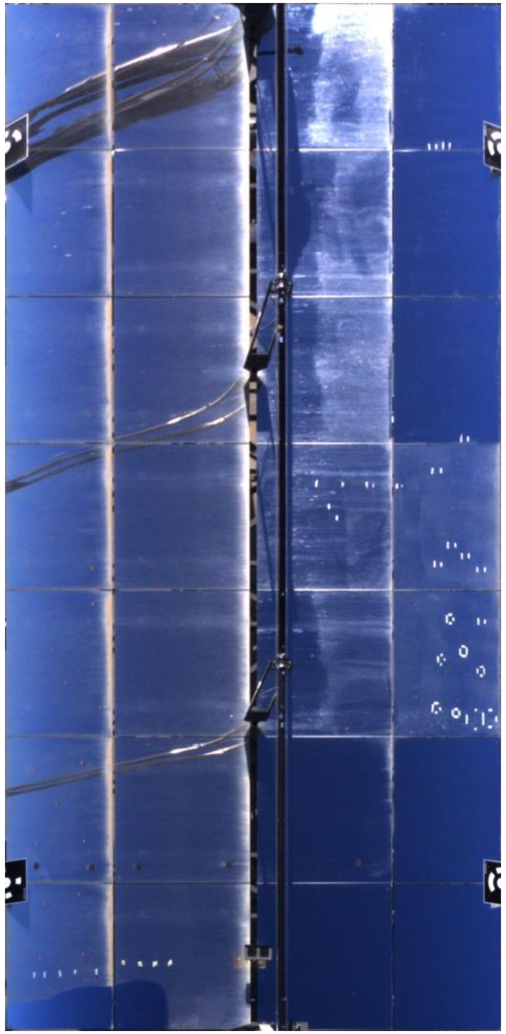
Example measurement
- image preprocessing -

Drone footage of a parabolic trough taken at CIEMAT's PSA

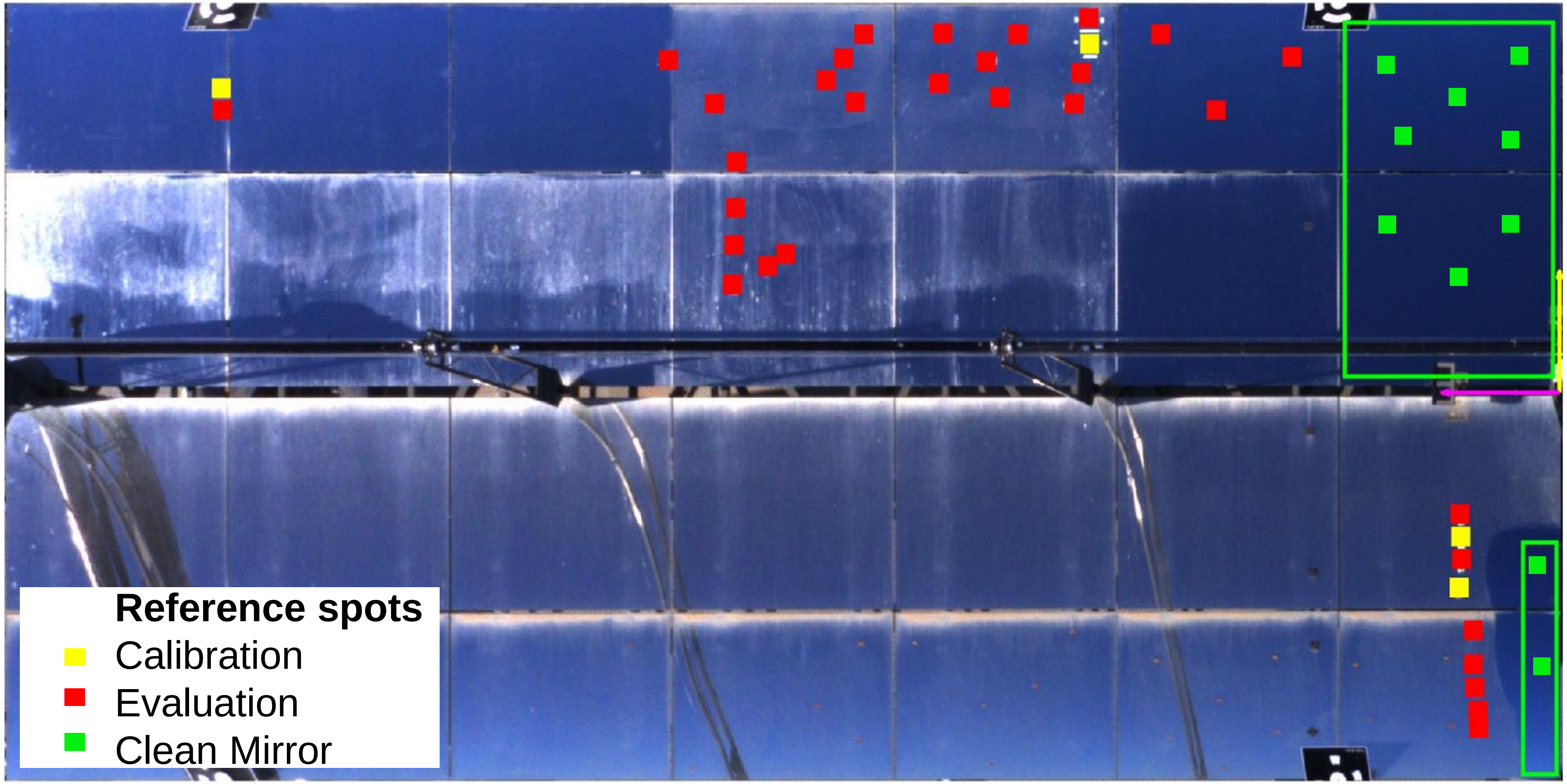


Orthogonalised RAW image

Filtered image

Gaps are covered by combining multiple images.

Example measurement
- reference measurement spots -



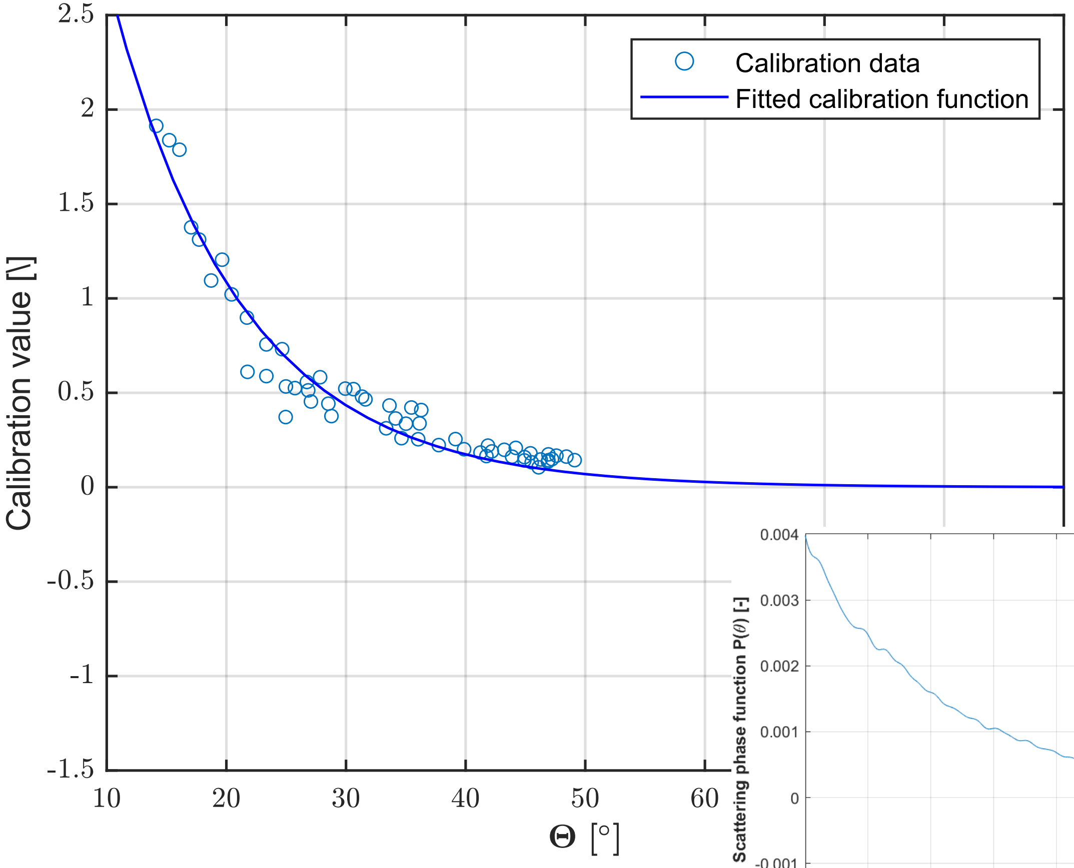
Reference measurement spots on a parabolic trough collector

- Used device: D&S 15R-USB
  - Acceptance angle 12.5 mrad
  - Light source emitting red light (660 nm)
  - Calibrated with test mirror

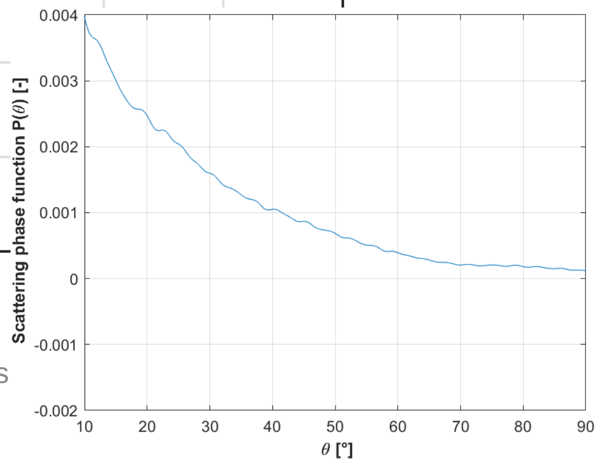
Devices and Services portable specular reflectometer 15R-USB
Source: devicesandservices.com

Example measurement
- from brightness increase to soiling loss -

- Calibration
  - Calculated calibration values using handheld reflectance measurements
  - Fit a calibration function $f(\theta)$
- Evaluation
  - Use this function to convert brightness increase to soiling loss for the full power plant
  - Transfer to soiling losses at 15° incidence angle



$f(\theta)$ with calibration values as circles



Scattering phase function $P(\theta)$ over scatter angle θ

RESULTS

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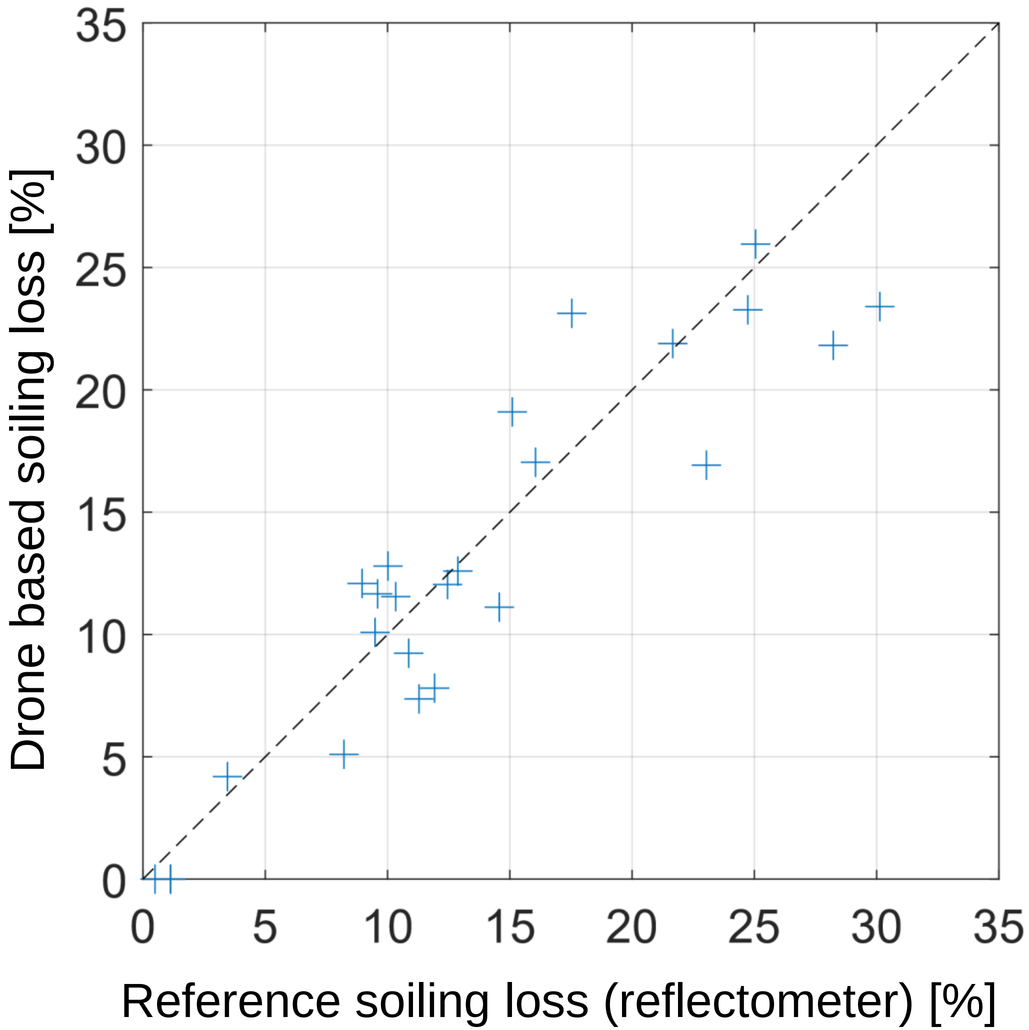
Results
- validation -

- Statistical Evaluation
  - $R^2 = 0.922$
  - $RMSD = 0.032$
  - $Bias = -0.0073$

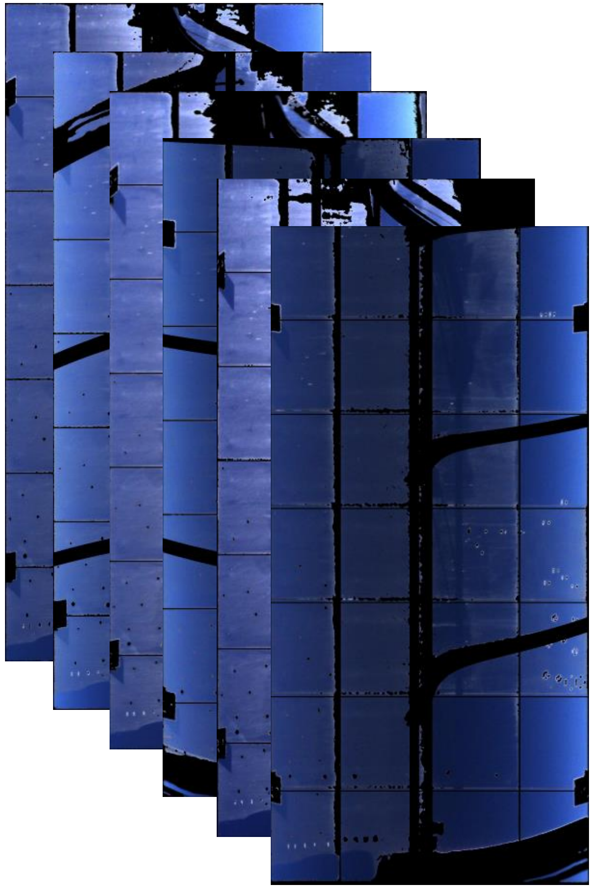
- Good selection of calibration points covers even spots with high soiling levels well



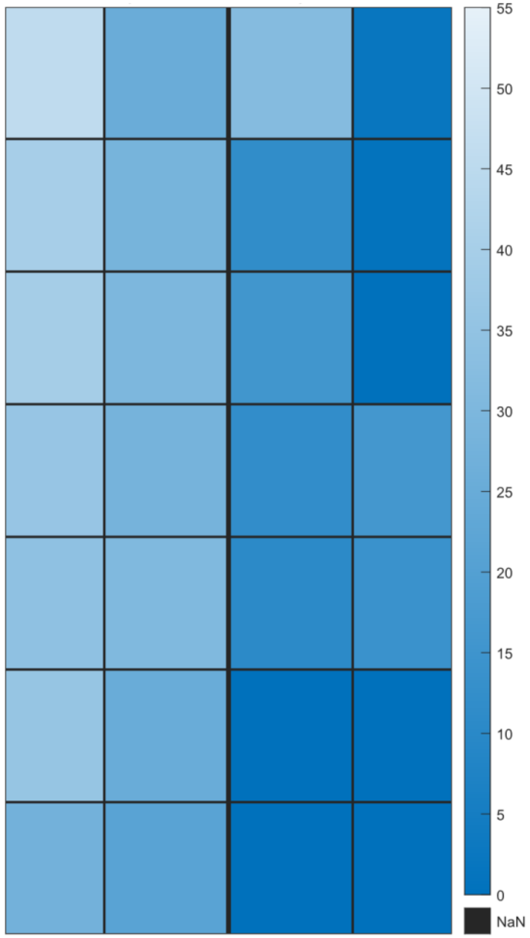
Results for cleanliness over reference cleanliness

Results
- evaluation -

- Applying the calibration function to the entire evaluable mirror
- Linking multiple images to the collector's overall result



Several masked images of the same collector



Averaged soiling loss per facet [%]

SUMMARY

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Summary

- Physical measurement principles shown to determine soiling on mirrors
- Processes include brightness modelling, calibration and image processing
- Method validated on PTC and shows promising results
- Calibration requires only a few manual measurements, esp. at heavily soiled mirror sections
- Already applicable to entire power plants
- Predefined flight routes
- Automation of flights, e.g. with a docking station for drones

Skyport
Source: Skycharge GmbH

OUTLOOK

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Outlook

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

DLR

Further research

- Application on heliostat fields
- Increasing robustness further
- Simplifying procedures by providing predefined calibration
- Conversion to other moving machines or static cameras

Acknowledgements

- We thank the German Federal Ministry for Economic Affairs and Climate Action for funding the AuDroMon (03EE5128A) project.

Literature

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THANK YOU FOR YOUR ATTENTION

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Imprint

Topic: **SolarPACES Conference 2024**
Drone-Based Quantification of Soiling Losses for Parabolic-Trough Collector Plants

Date: 2024-10-10

Author: Rone Yousif et al.

Institute: Institute of Solar Research

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