Drone-Based Quantification of Soiling Losses for Heliostats in Solar Power Tower Plants

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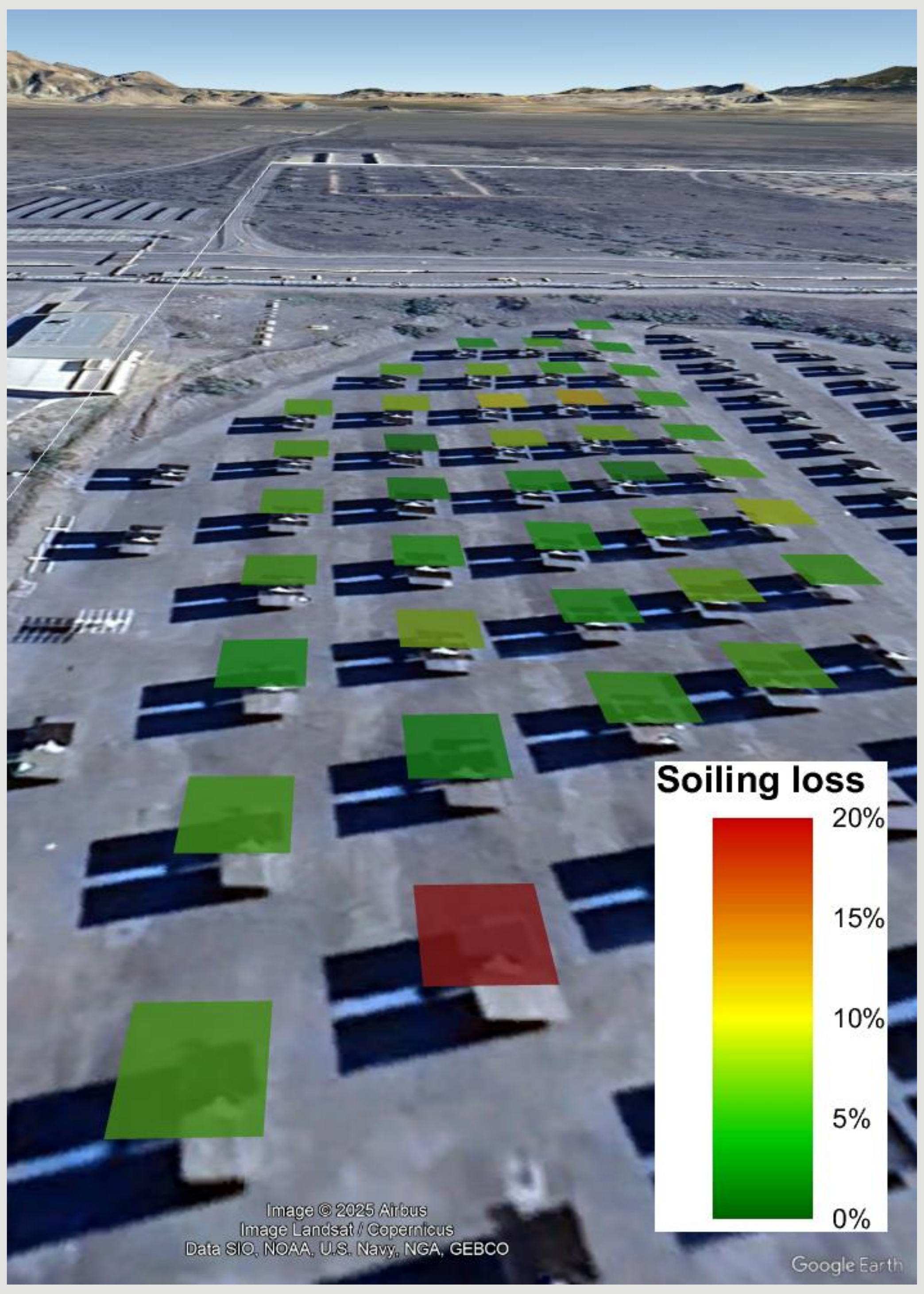

Fig. 1 Google Earth overlay indicating the averaged soiling loss per heliostat in a section of the CESA-1 at CIEMAT's Plataforma Solar de Almería.

Motivation

Figure 1 shows the evaluated soiling losses of concentrators in the CESA-1 heliostat field at the Plataforma Solar de Almería (PSA). Soiling [1] is a key challenge for concentrating solar technologies, as it significantly reduces the efficiency of the plant [2]. However, regular cleaning without taking actual soiling losses into account is costly and consumes both human and natural resources [3]. Therefore, a representative characterization of the amount of soiling [4] is crucial for scheduling cleaning timing and areas efficiently [5].

In addition to measurement methods such as portable reflectometers, TraCS or Avus, which involve high installation costs or considerable effort, **image-based soiling measurements** [6] offer a promising alternative. They enable high-resolution, portable, and labor-cost-effective measurement of soiling in the field.

The work presented here introduces a drone-based method, including physical principles and measurement procedure, and shows an detailed evaluation of data recorded at the PSA.

Principles of operation

The soiling loss of a mirror is defined as:

$$\text{Soiling loss} = 1 - \frac{reflectance_{soiled}}{reflectance_{clean}}$$

Fine dust particles on the collectors alter the appearance of the mirror surface by scattering light. This makes soiled mirrors appear brighter than clean ones. To make use of this effect, reference images of a clean mirror section of the collector are used as a basis for determining brightness without soiling. Images of a soiled mirror with known soiling loss are then used to convert the change in brightness into a quantitative soiling loss for all other collectors.

The camera captures both the reflected light and the light scattered by the particles:

$$RGB_{soiled} \propto Brightness = \boxed{Reflected_{clean}} + \boxed{Scattered_{particles}}$$

For image pre-processing, the images (Fig. 2) are radiometrically linearized and the collector section is orthogonalised and masked so that several images from different perspectives can be combined (Fig. 3).

The calibration process is divided into two steps:

I Determine brightness without soiling	II Convert brightness increase to soiling loss
• RGB values of cleaned section from several images extracted to a sky map • Sky brightness modelling enables transfer from calibration time to evaluation time	• Brightness increase changes with scattering angle and DNI • Several images with different observation angles per pixel • Calibration function to convert brightness increase into a soiling loss is obtained

The reference measurements for this were recorded with a D&S 15R-USB reflectometer, operated with a red light source at 660 nm and an acceptance angle of 12.5 mrad. Using the five reflectance measurements (s. □ in Fig. 4), the calibration function (Fig. 5) is calculated as a function of the scattering angle $f(\theta)$.

The validation with further reference measurements that were not used for calibration is shown in Fig. 6.
By applying the method to the entire evaluable mirror surface, the soiling loss of entire heliostats can be determined (Fig. 7) or facet-wise averaged (Fig. 8).

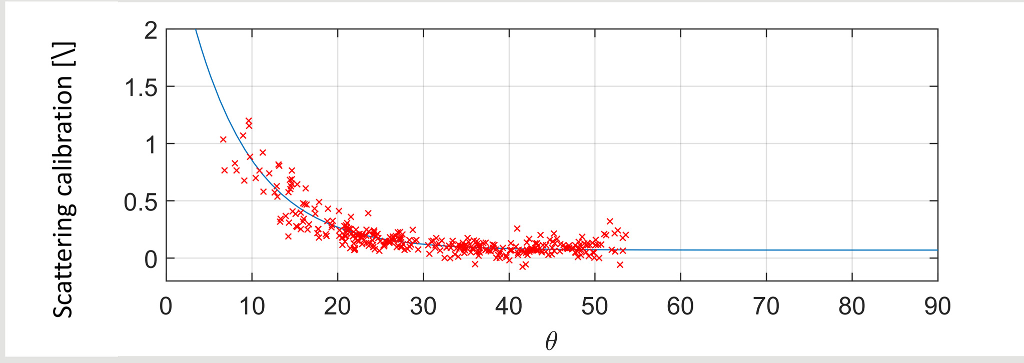

Fig. 5 Fit function of scattering properties (—). Values (x) were extracted from pixels at the position of the calibration measurements.

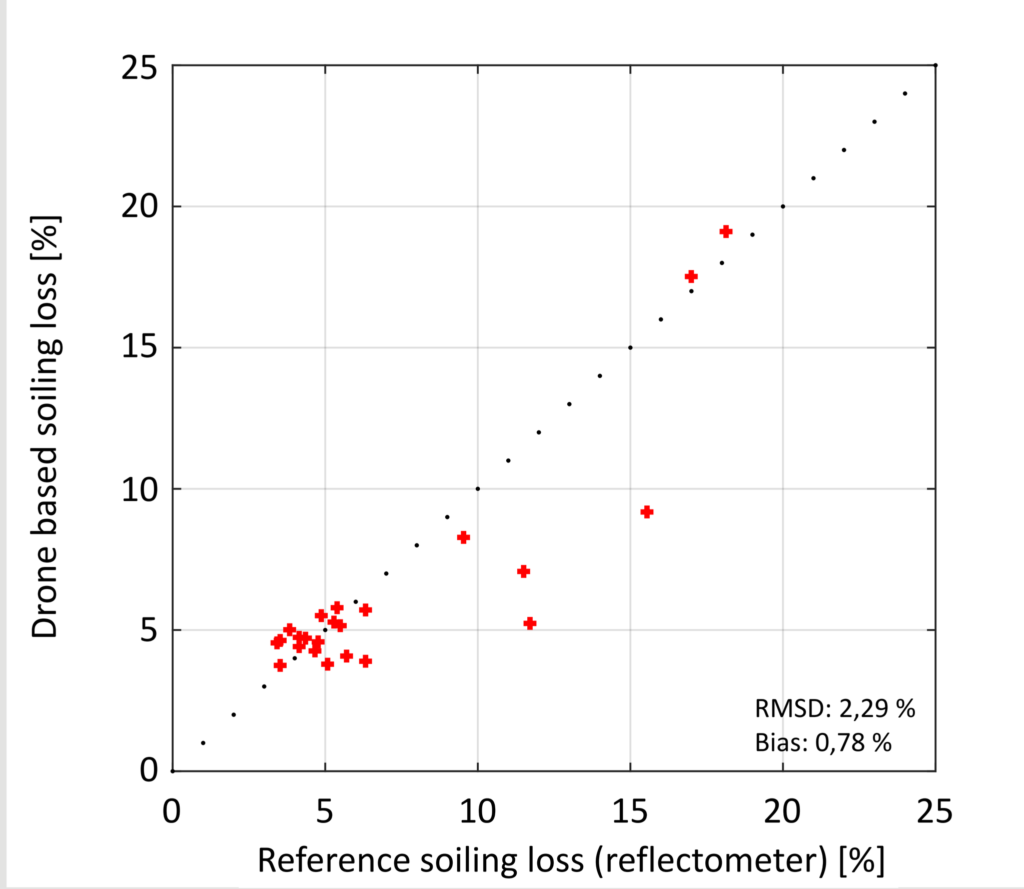

Fig. 6 Validation results of drone based soiling loss compared to reference soiling loss.

Summary

The developed method for determining soiling losses is based on physical measurement principles, has been successfully validated on heliostats, and shows promising results. With just a few manual calibration measurements, it can already be applied to entire power plants and can be further optimised for automated operations, e.g. with docking stations for drones.

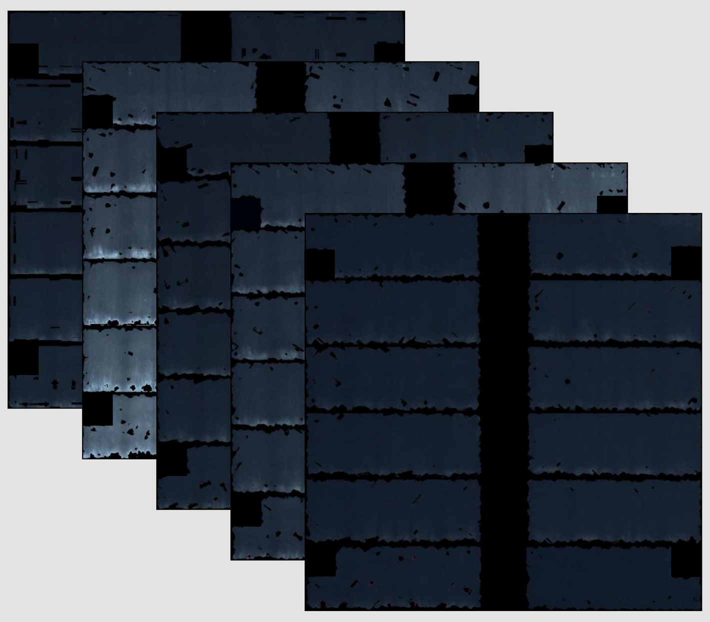

Fig. 3 Pre-processed images of the same collector from different perspectives.

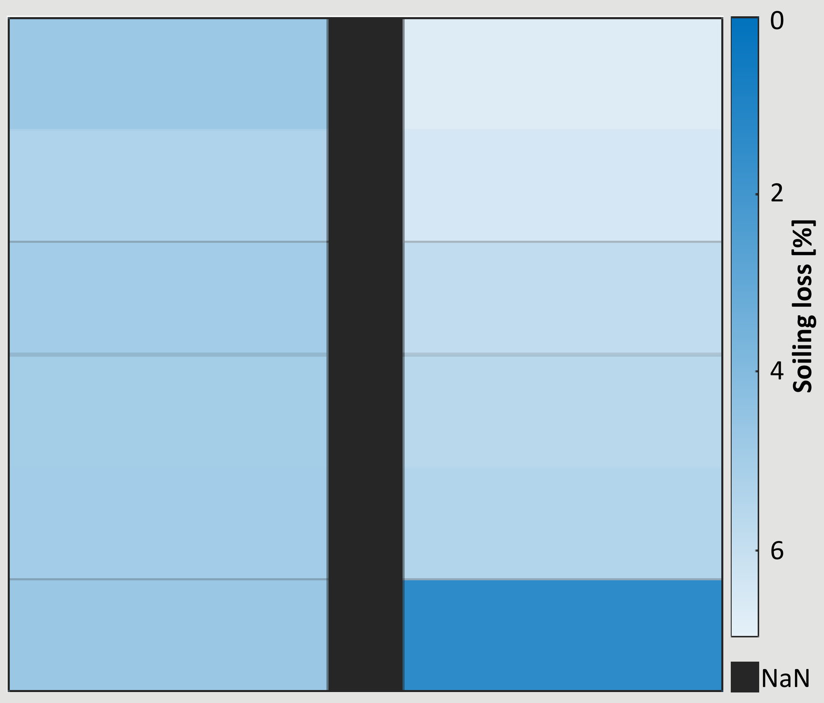

Fig. 8 Averaged soiling loss per facet.

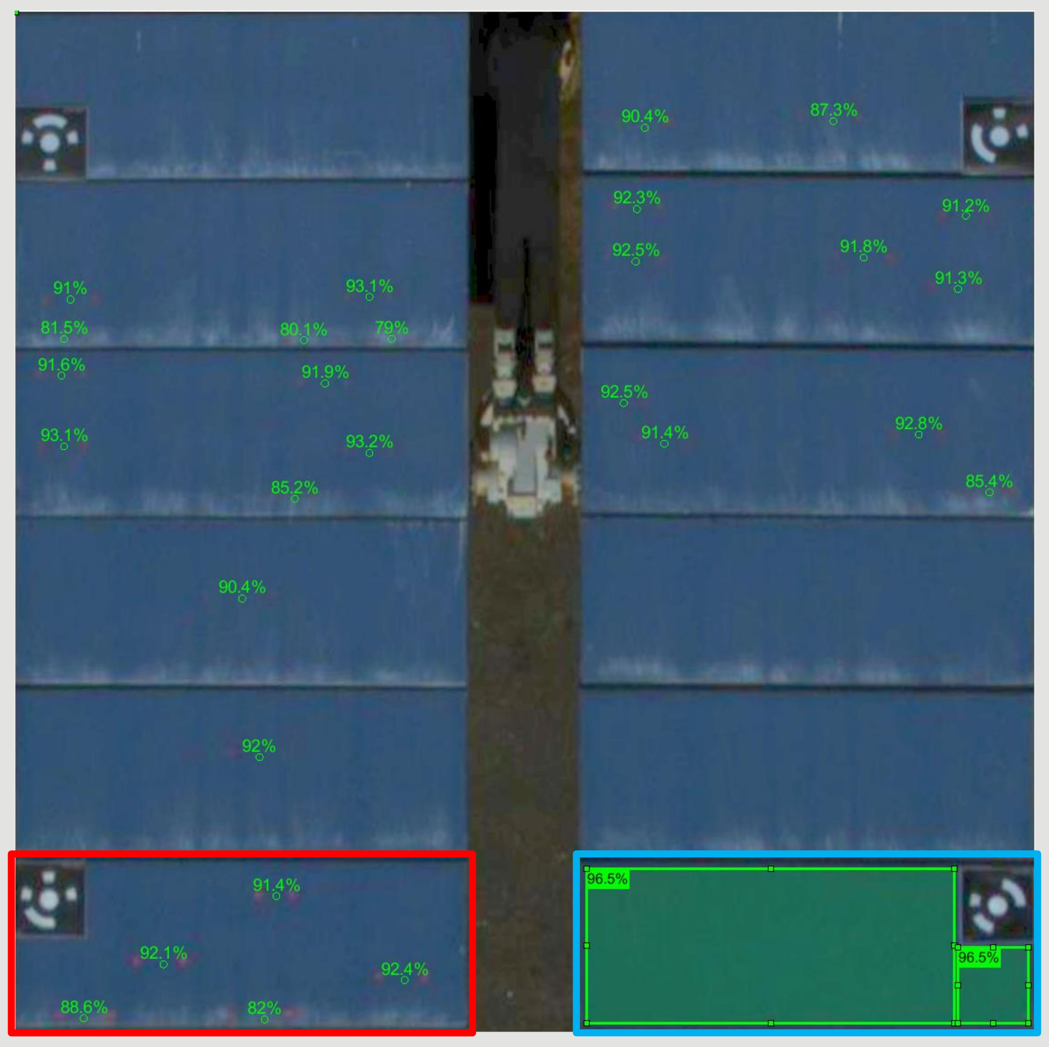

Fig. 4 Heliostat with a cleaned facet (□) and reference measurements for validation and calibration (□) with their reflectances and postions on the mirror marked in green.

Fig. 2 Drone footage of heliostats. Image taken at Plataforma Solar de Almería, Spain (owned by the Spanish research centre CIEMAT). Source: DLR.

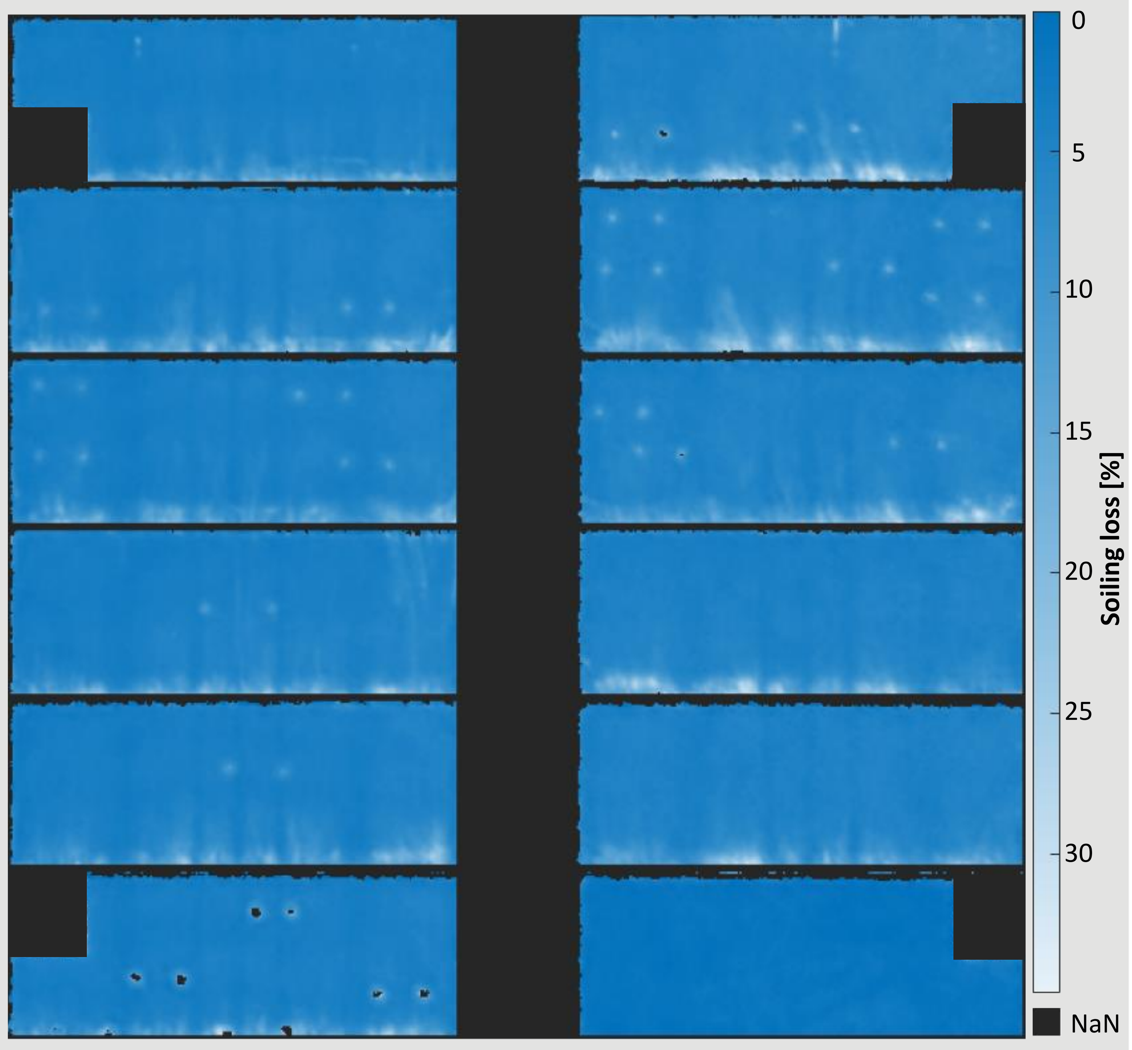

Fig. 7 Pixelwise determined soiling losses of the heliostat from Fig. 4.

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