Review of Alternative Soiling Assessment Techniques

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Introduction

WP 3 of the ongoing "**Soiling measurement guidelines**" project, funded by SolarPACES is reviewing the **state-of-the-art on alternative soiling measurement methods**.

Alternative methods go beyond the established use of hand-held reflectometers to improve the spatial and temporal resolution of measurements.

Although this work focuses on applications relevant to CST, **PV-related work is also in scope** to cover all potentially useful techniques in solar technologies.

Methods classification

Category 1 - **Upgraded reflectometer methods**:

- Address limitations of hand-held reflectometers by upgrading the devices and/or its packaging. Focus is on autonomous operations.

Category 2 - **Camera-based methods**:

- Use cameras and image processing to obtain information for potentially large fractions of a solar field.

Category 3 - **Alternative measurement sensors**:

- Measure soiling based on light-scattering and attenuation effects in dedicated devices.

Category 4 - **Multi-parameter indirect methods**:

- Exploit multiple environmental sensors and information sources to build mathematical models able to determine soiling.

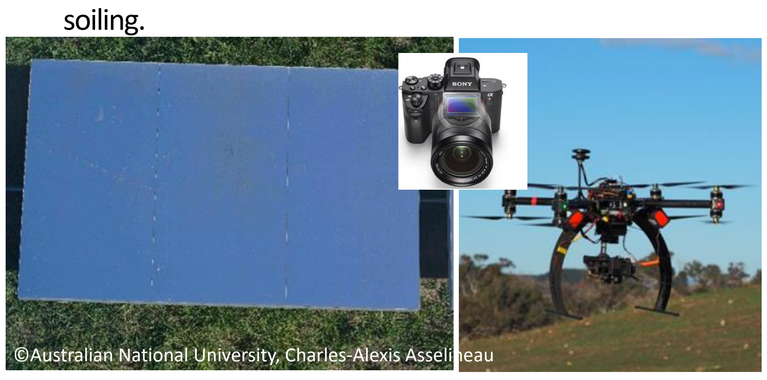
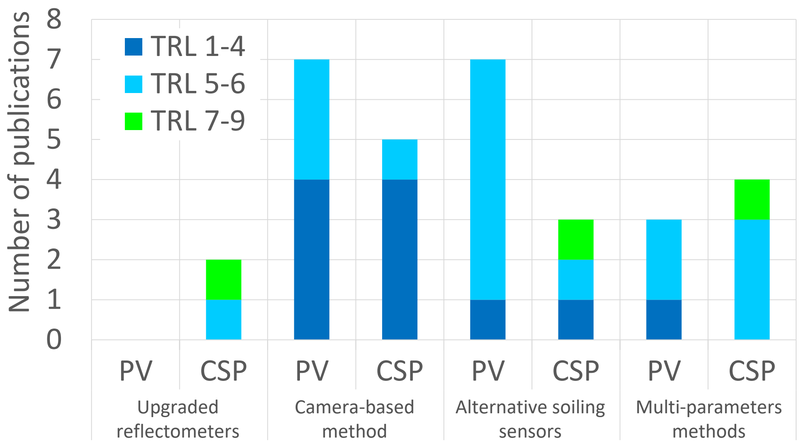


Fig. 1: Category 2 – Camera based method with drone

Observations

- Most recent publications are on camera-based methods (14).
- Publications scattered across many fields and journals/conference proceedings.
- Not many peer-reviewed publications on alternative methods for CST (14).

Fig. 2: Classification of the studies identified in this review by indicative TRL.



Review statistics

- 32 studies reviewed and classified and regrouped into 2 tables, one for CST and one for PV.
- Very active research in PV: many new studies since the start of this WP.
- 4 applications:
  - **O&M**: support for cleaning schedules.
  - **Yield estimation**: higher accuracy measurements needed.
  - **Site assessment**: autonomy requirements.
  - **Soiling R&D**: develop understanding of soiling deposition and scattering.
- Classification of the work in indicative TRL levels (Fig. 1).

Fig. 3: Category 1 – AVUS Instrument

Fig. 4: Category 4 – Protinus 1000 Dust Monitor Station

Knowledge gaps

Standardization:

- **Lack of standardization in the reporting of soiling measurements, related uncertainty metrics and nomenclature**. Lack of standardized test cases, and samples for methods development. Lack of knowledge about existing CST standards.

Reflectometers and ground truthing:

- Virtually **all CST relevant methods rely on hand-held reflectometers for calibration.** Ground truth of hand-held reflectometers is being addressed in WP2 of this project, however, **reflectometers are typically not able to provide ground truth for large areas and high-resolution coverage** (potential TRL progression issue).

Fig. 5: Category 3 – TraCS instrument installed on Kipp & Zonen sun tracker Solys 2

Category specific:

- Category 1: Limited work ongoing in this category.
- Category 2: Lack of understanding of radiometry and image data in existing works.
- Category 3: Sensors developed for PV should be validated for CSP applications to be used confidently.
- Category 4: Estimations come from sensors in different places and with different frequencies. Significant lack of physics in the models developed lead **to large and unknown uncertainty**.

Yield estimation and accuracy:

- **Lack of methods accurate and precise enough to be relevant to yield estimation** (estimated about 1 % absolute reflectance uncertainty).

Table 1. Selected information for the 14 CST studies identified in this review.

Reference title	Type	Single measurement resolution	Single measurement coverage	Measurement frequency	Mobility
Bern et al. (2018): FREDA - An automated field reflectance and degradation assessment system for central receiver systems	Camera-based methods	Medium (dm^2)	Very large (>10 m^2)	Seconds	Stationary
Heimsath et al. (2019): Monitoring of soiling with the AVUS instrument – Technical and economic assessment	Upgraded reflectometer method	High (cm^2)	Small (~cm^2)	Minutes	Stationary
Heimsath et al. (2018): Automated monitoring of soiling with AVUS instrument for improved solar site assessment)	Upgraded reflectometer method	High (cm^2)	Small (~cm^2)	Minutes	Stationary
Ferreres et al. (2023): Terrestrial Laser Scanning for Fast Spatially Resolved Cleanliness Assessment of Heliostat Fields	Alternative measurement sensors	High (cm^2)	Very large (>10 m^2)	Minutes	Surface transport
Wolfertstetter et al. (2014): Monitoring of mirror and sensor soiling with TraCS for improved quality of ground-based irradiance measurements	Alternative measurement sensors	High (cm^2)	Small (~cm^2)	Seconds	Stationary
El Gallassi et al. (2023): Novel technique for soiling measurement on concentrated solar plants using night-time image analysis	Camera-based methods	Very high (mm^2)	Large (~m^2)	Seconds	Surface transport
Wang et al . (2019): In-situ reflectivity monitoring of heliostats using calibration cameras	Camera-based methods	Low (m^2)	Large (~m^2)	Seconds	Stationary
Bonanos et al. (2020): Characterization of mirror soiling in CSP applications	Multi-parameters indirect methods	High (cm^2)	Small (~cm^2)	Minutes	Stationary
Smestad et al. (2023): Variability and associated uncertainty in image analysis for soiling characterization in solar energy systems	Alternative measurement sensors	Very high (mm^2)	Small (~cm^2)	Days	Stationary
El Boujdaini et al. (2022): The effect of soiling on the performance of solar mirror materials: Experimentation and modeling	Multi-parameters indirect methods	Medium (dm^2)	Medium (dm^2)	Minutes	Stationary
Conceição et al. (2018): CSP mirror soiling characterization and modeling	Multi-parameters indirect methods	High (cm^2)	Small (~cm^2)	Minutes	Stationary
Picotti et al. (2018): Development and experimental validation of a physical model for the soiling of mirrors for CSP industry applications	Multi-parameters indirect methods	High (cm^2)	Small (~cm^2)	Minutes	Stationary
El Ydrissi et al (2023): Dust InSMS: Intelligent soiling measurement system for dust detection on solar mirrors using computer vision methods	Camera-based methods	High (cm^2)	Small (~cm^2)	Minutes	Stationary
Rafique (2024): Field Deployable Mirror Soiling Detection Based on Polarimetric Imaging	Camera-based methods	Very high (mm^2)	Large (~m^2)	Seconds	Surface transport

References

[1] F. Wolfertstetter *et al.*, "Recommendations for reflectance measurements on soiled solar mirrors," 2022.

Next steps

- Executive summary input to an updated SolarPACES Guideline: "Recommendations for reflectance measurements on soiled solar mirrors" [1].
- Review article publication.
- Share bibliography.

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