Laser Scanning for Optical Assessment of Heliostat Fields

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Background

Critical Technology Gap: Maintaining clean and aligned heliostat mirrors is crucial for concentrated solar power (CSP) plant performance. A lack of systematic evaluation of reflectance and mirror misalignment hinders heliostat technology advancement [1,2].

Figure 1. The Faro Focus S70 laser scanner captures a 3D point cloud of the front of a heliostat.

Proposed Method

We propose a solution using advanced laser scanning technology to tackle these challenges with high spatial resolution and fast acquisition speed:

- Cleanliness Assessment: Detects backscattered laser intensity from soil and dust to determine mirror cleanliness.
- Heliostat Orientation Determination: Uses point cloud processing, smart filtering, and paraboloid fitting to enable adjustment of facets (canting) and aiming directions (tracking).

Figure 2. At the Thémis solar plant of PROMES-CNRS (Targassonne, France), canting errors in a heliostat were quantified and corrected using terrestrial laser scanning, improving the solar flux distribution at the receiver's target.

Cleanliness Assessment

Principle

The backscatter power depends on the target mirror's retroreflection level, the laser beam's incident angle, and the distance between the scanner and the heliostat mirror. Therefore, the influence of distance (d) and incidence angle (θ) must be modelled to relate the detected power to the specular reflectance. Measurements can be transferred to a reference distance (d_{ref}) and incident angle (θ_{ref}) by canceling their influence on the backscatter power.

$$\Phi_{\mathrm{b},d_{\mathrm{ref}},\theta_{\mathrm{ref}}}(d,\theta) = \Phi_{\mathrm{b}} \frac{f(d_{\mathrm{ref}})g(\theta_{\mathrm{ref}})}{f(d)g(\theta)} \eta_{\mathrm{ext}}$$

For considering the influence of external factors (e.g., temperature), normalizing the scan intensity (η_{ext}) is necessary

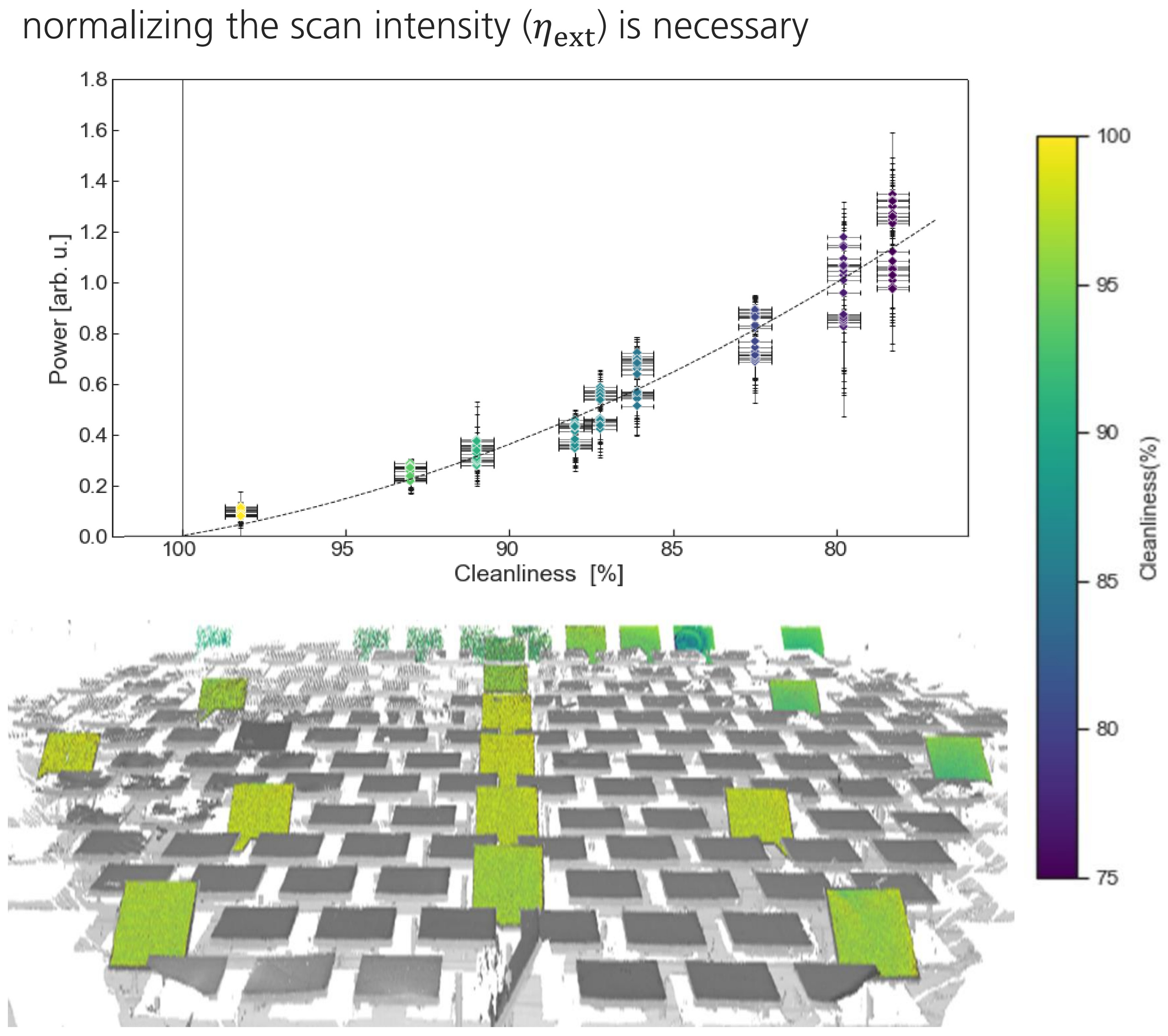

Figure 3. Upper: Detected power for different scanner-mirror distances and inclinations after transformation to reference conditions as a function of cleanliness measured with the pFLEX reflectometer [3]. Lower: Digital representation of a 3D scan of the IMDEA energy solar field with the spatially resolved cleanliness of the heliostats shown as color map.

Outcomes

Calibration measurements with artificially soiled mirrors and extensive field measurements established a correlation between backscatter power and cleanliness (Fig. 3, upper). We performed the first spatially resolved cleanliness measurement for a heliostat field (Fig. 3, lower), successfully validating the measurement principle.

Determination of Heliostat Orientation

Principle

The captured point cloud of the heliostat field is processed, filtered and fitted with the following steps:

1. Paraboloid fit of the heliostat surface and coordinate transformation.
2. Removal of outliers based on residual thresholds, center-of-mass and RGB filters..
3. Iterative fit of the cleaned point cloud for refinement of the heliostat coordinate system (Fig. 4, left).
4. Automatic segmentation of the point cloud into modules, fit of module with planes and calculation of normal vector angles to the z-axis (Fig. 4, right).

Outcomes

The accuracy of laser scanning for heliostat canting error correction was validated by the enhanced flux distribution after realignment of modules (Fig. 5). Despite a mean absolute error of around 8 mm for the surface fitting, the large number of points measured and the iterative filtering result in uncertainties in the identified facet tilt angles between 0.03 and 0.10 mrad. **Thus, laser scanning in heliostat fields offers fast and accurate evaluation of cleanliness and orientation, marking a substantial advancement in solar field quality control and enables corresponding efficiency increases.**

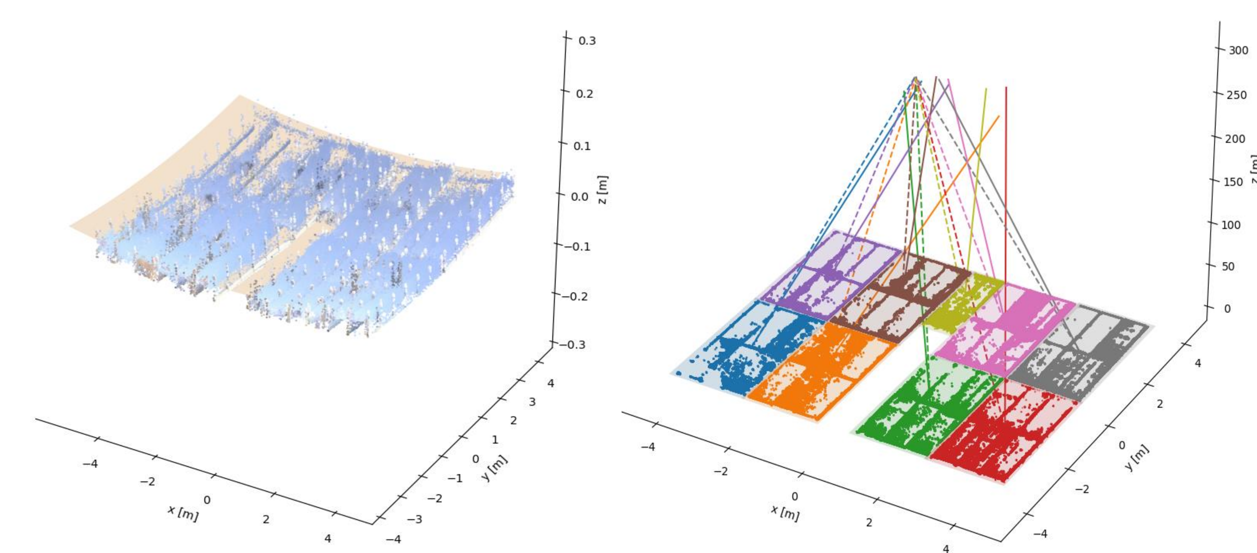

Figure 4. Left: Filtered point cloud for the heliostat surface (blue) and paraboloid surface fit (orange). The parameters of the fit were used for a subsequent automatic segmentation of the point cloud into nine modules. Right: Point cloud of the measured heliostat after segmentation into nine separate modules, fitted with individual planes. The continuous lines show the direction of the normal vector for each plane, while dashed lines represent the ideal design normal vectors. The deviation between continuous and dashed lines indicate the canting errors of the modules (note the compressed scale in z-axis compared to the xy-plane).

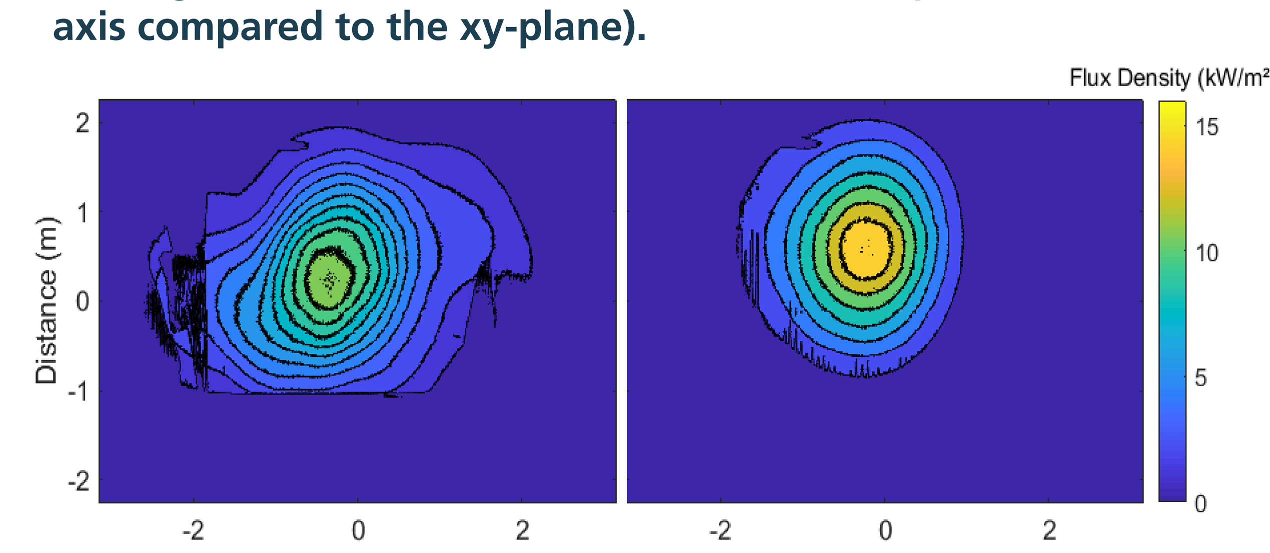

Figure 5. Measured solar flux density at the target on the tower before (left) and after adjustment of the canting angles based on the laser scanning results (right). At similar DNI, the integral power within the flux measurement area was increased from 23 to 30 kW (+30%), and the peak flux density from 8 to 16 kW/m² (+100%). The estimated size of the focal spot was decreased from over 4x2 m² to less than 2x2 m² due to the heliostat module orientation adjustment made based on the laser scanning measurement.

[1] G. Zhu et al., "Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power". Golden, CO: NREL, 2022.
[2] A. Heimsath et al., "The effect of soiling on the reflectance of solar reflector materials – Model for prediction of incidence angle dependent reflectance and attenuation due to dust deposition". Solar Energy Materials and Solar Cells, 2019.
[3] pFLEX - Portable Soiling/Cleanliness Handheld Reflectometer. PSE Instruments GmbH 2022. https://www.pse.de/test-equipment/thermal-collectors/sensors/pFLEX-portable-handheld-reflectometer/.

The work was supported by the German Federal Ministry for Economic Affairs and Climate Protection (BMWK) under contract 03EE5065A. The support is gratefully acknowledged. The authors of this publication are responsible for its contents.

Federal Ministry for Economic Affairs and Climate Action