Cloud shadow maps from whole sky imagers and voxel carving

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DLR - Institute for Solar Research
Overview

• Motivation and Introduction

• What we do
  • Hardware: @ Plataforma Solar de Almeria (PSA)
  • Approach: voxel carving with whole sky imagers

• Results:
  • Proof of principle and validation with shadow cameras
  • Sensitivity analysis

• Outlook
Motivation for creating shadow maps

Optimize energetic & financial yield & plant life time (our focus)

- CSP (Concentrating Solar Power) plant operation involves e.g.
  - In tower plants: mirror focus control (avoid fast temperature changes of receiver, avoid overload dumping with dynamic aim-point selection)
  - In trough plants: Individual heat transfer fluid mass flow in different parts of the solar field
- ...

- Good plant operator decisions need **spatially resolved DNI data**
  - Live data and nowcasting
  - Shadow maps are the basis for this

Andasol parabolic trough plants
Solution

highly temp. and spatially resolved irradiance maps (nowcasts and live information) from cloud camera system

Example for challenges:
- High variability
- Complex cloud formation/motion

Captured at PSA
2014-05-28, 10:00 - 17:00
investigate all components of a camera system that creates live and nowcasted shadow and irradiance maps:

- Camera system and validation network and create data
- Processing software:
  - Segmentation, classification
  - Cloud geo-location (3D)
  - Creation of shadow maps (later irradiance maps)
  - Nowcasting
  - Validation

Focus so far:
- Geo-location (3D)
  - 4 cameras: voxel carving
- Verification of the system
  - Measured shadow maps from elevated shadow cams (to be combined with irradiance measurements)
  - Sensitivity analysis for camera setup geometry
Cloud height from LIDARs

Automatic solar trackers with pyrheliometer + Rotating Shadowband Irradiometers (inside PSA & 2km south)

Exposure series every 30/15 seconds since 01/2014

2 Mobotix Allround M25

Mobotix Q24

pyranometers

Automatic solar trackers with pyrheliometer

Image: Google, CIEMAT, DLR
1. Step of evaluation → Segmentation
Voxel carving with WSI

- Back-projection of detected clouds view cone
- Intersection of view cones = cloud
Shadow map calculation

- Back-projection of detected clouds view cone
- Intersection of view cones = cloud
- Calculation of *modeled shadow*
Validation: creation of ortho images

based on:
• position
• orientation
• camera model

1 Pixel $\equiv 1$ m
Validation: segmentation of ground shadow
Validation of modelled shadow

\[ \text{ACC} = \frac{\text{TP} + \text{TN}}{\text{surface}} \]

- Tested with \(~100\) cases
- \(\text{Mean(ACC)} = 0.72\)
- Prototype of system (hardware + processing) running live at PSA
Sensitivity analysis: methodology

- Define artificial spherical clouds (initial position, radius, motion vector)
- Create artificial WSI Images from known camera setup
- Model shape and position of cloud and its shadow from artificial WSI images
- Compare shadow from artificial cloud and the voxel carving model
Sensitivity analysis: Comparison of Set ups

Max camera distance ~ 0.8 km (infrastructural reasons)
Current set up @ PSA

Max camera distance ~ 1.9 km
Edges of 50 MW CSP trough power plant

Stretched clouds when far away from cameras
Good agreement when clouds are close to the cameras
Better spatial coverage with camera geometry for plant
<table>
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<tr>
<th>CH [m]</th>
<th>PSA set up</th>
<th>Quality</th>
<th>50 MW set up</th>
<th>Quality</th>
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<td>1000</td>
<td><img src="1000.png" alt="Image" /></td>
<td>0.22</td>
<td>- pixel coordinates of figures are x and y coordinates at PSA</td>
<td>- green markers position of shadow’s center for one simulation</td>
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<tr>
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<td><img src="3000.png" alt="Image" /></td>
<td>0.26</td>
<td>- color: quality for this point</td>
<td>- spatial interpolation of color only for visualization (average quality only from results for each simulation)</td>
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<td><img src="5000.png" alt="Image" /></td>
<td>0.30</td>
<td>- pixel coordinates of figures are x and y coordinates at PSA</td>
<td>- green markers position of shadow’s center for one simulation</td>
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Average of \( \frac{TP}{TP + FN + FP} \) for all simulated cases (”small shadow skill”)
Sensitivity analysis: comparison of set ups

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TP/(TP + FN + FP) changed by factor ~2

-best quality within the polygon formed by the cameras
Summary

• Modelling of cloud shape and position from WSI images by voxel carving is possible
• Validation with shadow cameras shows good agreement for selected events
• Sensitivity analysis reveals potential of long base line system (CSP plant size)
• Large data sets for solar radiation forecasting available

Outlook

• Implement additional measures/assumptions to trim implausible voxel carving results (typical cloud height and shapes from classification)
• Adjust experimental setup to plant geometry and create data for validation at several sites.
• Validation of method with time series > 1 year, for several sites
  • With irradiance maps instead of shadow maps (live and nowcasted)
• Implementation of adequate cloud evolution prediction
  • Investigate possible benefits for cloud tracking with voxel carving
Thank you for your attention.

For questions or further details please contact

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