Towards Improving Solar Irradiance Forecasts with Methods from Computer Vision

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Importance of Renewable Energy

Development in recent years

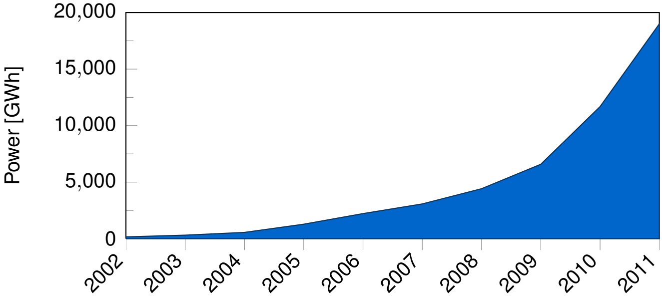

Figure : Power production by photovoltaics in Germany[1]

[1] Arbeitsgruppe Erneuerbare Energien-Statistik (BMU). *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland*. 2012.

Focus on Photovoltaics

Integration into power grid

Photovoltaics power production influenced by **local weather**

- Local: area of power plant
- Timespan: $< 10\ min$

Ensure stable supply by forecasting irradiance

Existing solutions:

Forecast method	Forecast time	Spatial resolution
Numerical weather models	$> 6h$	$3\ km \times 3\ km$
Analysis of satellite images	$30min - 6h$	$1\ km \times 1\ km$

Complementary Approach

Short-term predictions

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Problem

Existing methods lack spatial and temporal resolution.

Using ground-based cameras

1. Monitor the sky
2. Register & predict cloud motion
3. Predict irradiance

Sample Video

Main Challenges

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Motion Registration – Dynamics of Cloud Movement

- Formation, dissipation and merging of clouds
- Strong deformations

Motion Prediction

- Motion is governed by fluid mechanics
- High computational complexity for exact solution

Our Approach

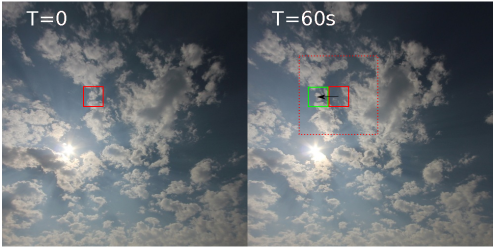
- Non-rigid registration for motion registration
- Comparison of three methods
- Forecasts for up to 5 minutes

Motion Registration

Block matching[2]

Divide image into squares

Search for similar square in next image using cross-correlation



Mean of all displacements used in further steps:

Assumes rigid motion!

[1] C. Chow et al. “Intra-hour Forecasting with a Total Sky Imager at the UC San Diego Solar Energy Testbed”. In: *Solar Energy* 85.11 (Nov. 2011), pp. 2881–2893.

Motion Registration

Non-rigid registration

Notation

T, R – Template and Reference image
$\mathbf{d}^{(n)}$ – Deformation field (after iteration n)

Thirion's Demons[3]

- Based on optical flow equation
- Deformation calculated iteratively

$$\mathbf{d}^n(\mathbf{x}) = \mathbf{d}^{n-1}(\mathbf{x}) - \frac{\left(T(\mathbf{x} + \mathbf{d}^{n-1}(\mathbf{x})) - R(\mathbf{x})\right)\nabla R(\mathbf{x})}{\|\nabla R\| + \left(T(\mathbf{x} + \mathbf{d}^{n-1}(\mathbf{x})) - R(\mathbf{x})\right)}$$

- Gaussian smoothing of $\mathbf{d}^n$ (i. e. diffusion regularisation)

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[3] J.-P. Thirion. "Image Matching as a Diffusion Process: An Analogy with Maxwell's Demons". In: *Medical Image Analysis* 2.3 (Sept. 1998), pp. 243–260.

Motion Registration

Non-rigid registration

Variational approach

- Energy functional minimisation

$$\mathcal{F}[\mathbf{d}] = \mathcal{E}[T, R, \mathbf{d}] + \alpha\mathcal{S}[\mathbf{d}]$$

- $\mathcal{E}$: Sum of squared differences
- $\mathcal{S}$: Curvature regularisation[4]

$$\mathcal{S}_{curv}[\mathbf{d}] = \int_{\Omega} |\Delta \mathbf{d}(\mathbf{x})|^2 d\mathbf{x}$$

- Affine transformations preferred $\left(\Delta(\mathbf{Rx} + \mathbf{a}) = 0\right)$

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[4] Bernd Fischer and Jan Modersitzki. "Curvature Based Image Registration". In: *Journal of Mathematical Imaging and Vision* 18 (2003), pp. 81–85.

Cloud Motion Prediction

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Prediction

1. Multiply current displacement field $\mathbf{d}$ with $f = \frac{t_{fc}}{20\,s}$

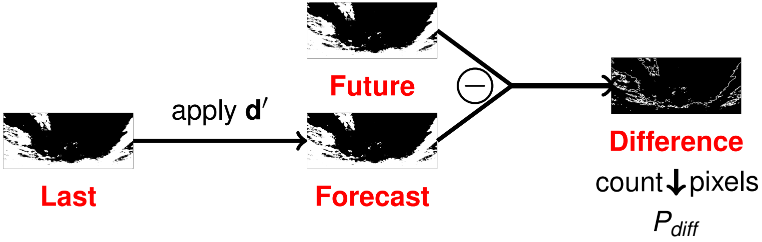
$$\mathbf{d}' = f \cdot \mathbf{d}$$

2. Warp sky image by $\mathbf{d}'$

Evaluation

No ground truth flow fields available!

Compare segmented sky images

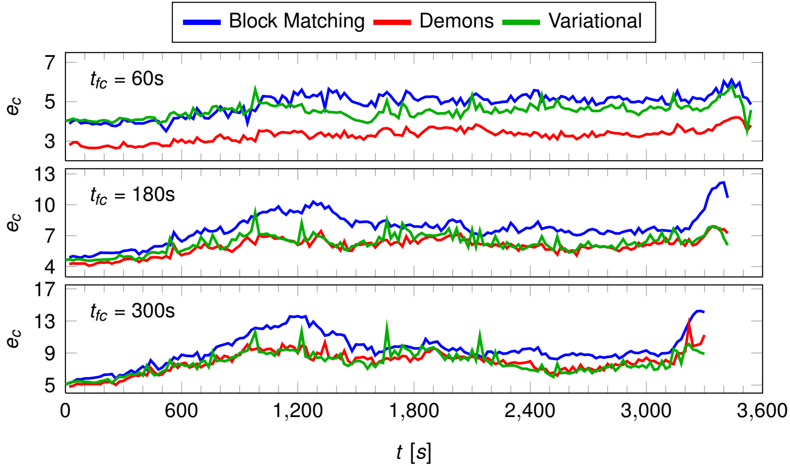


Count pixelwise differences

$$e_c = \frac{P_{diff}}{P_{contour}}$$

Results

Preliminary



Non-rigid approaches outperform baseline method!

Conclusion

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Challenges – Motion Registration & Prediction

- Large displacements
- Strong deformations
- Errors governed by forecast method

Current Achievements

- Two non-rigid registration methods applied for motion registration
- Non-rigid methods outperform state of the art method
- Forecasts possible for up to 5 minutes

Thank you for your attention!

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