Towards Improving Solar Irradiance Forecasts with Methods from Computer Vision

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Abstract. Modern economies turn towards renewable energy to lower the dependency on fossil fuels and nuclear power. The integration of these power sources into the power grid poses new challenges. To enable the economic exploitation of solar power, short-term forecasts of solar irradiance are required. We try to establish such forecasts using a ground-based camera. We aim to predict the movement of clouds with an image registration approach. First results are encouraging, yielding an improvement over prior work of 19%.

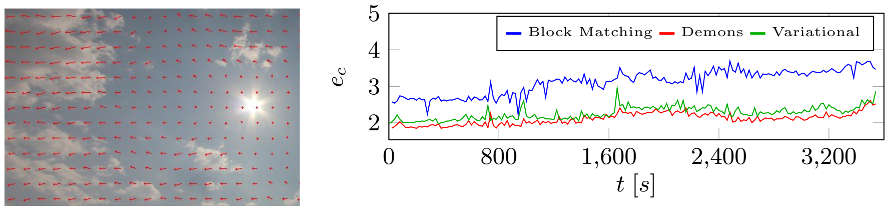
The output of solar and wind power plants is dependent on the local weather and can fluctuate at short notice. The power grid, however, requires a stable supply. Therefore, production peaks have to be stored, and periods of low production have to be bridged. The switching between producers requires precise forecasts. Prediction errors can lead to a waste of power, instabilities, or even a collapse of the grid.

We focus on the prediction of power output for solar power plants. Occlusions of the sun by single clouds are the main cause of drop-offs in power production. Traditional prediction methods for weather and cloud coverage, e. g. satellite imagery or numerical models [1], lack the necessary spatial and temporal resolution to predict these occlusions.

To extend the existing prediction methods, we use a ground-based camera to monitor the sky. The feasibility of this approach for irradiance prediction has been shown by Chow *et al.* [2]. We refine their work to better address the difficult dynamics of cloud movement. Not only can clouds deform over time, but also clouds at different heights can move at different speeds and directions. Clouds can merge, existing clouds can dissipate and new clouds can form. Thus, the choice of the motion model is an important decision. Chow *et al.* proposed to use a rigid motion model by employing a block matching strategy to detect the cloud movement. This approach does not incorporate all of the mentioned aspects of cloud movement. Therefore, it has drawbacks when parts of clouds change their appearance over time, or when regions with different wind speeds are present.

We address these limitations by using non-rigid registration to model complex dynamics of the cloud motion. In detail, we investigate two different approaches to non-rigid registration that employ different regularisation and matching strategies.

- Thirions *Demons* [3] algorithm is based on optical flow. It iteratively calculates forces that deform the template image to match it to a reference image. Spatial



(a) (b)

Fig. 1. (a) Example sky image with overlaid motion vectors. (b) Average error of the motion estimation in pixels for one hour of data for a 20s forecast horizon.

regularisation is achieved by applying Gaussian smoothing to the deformation field between iterations.

– The variational approach by Fischer *et al.* [4]. The principle of variational approaches is to minimize an energy functional. The functional consists of a sum-of-squared-differences similarity measure and a curvature regularization. The latter penalises affine transformations less than other types of motion.

We compared these two approaches to the block matching method of Chow *et al.* Forecasts for up to 5 minutes are performed by multiplying the registered movement with a factor $f = t_{fc}/20\,s$, where t_{fc} is the forecast time and $20\,s$ is the time step between the acquisition of images. In a second step we segment the clouds applying a threshold on the ratio of the red and blue channel. The resulting deformation field is then used to advance the segmented image in time.

In our experiments an improvement in motion registration could be seen. Figure 1(b) shows example results for a 20s forecast horizon, using the evaluation protocol by [2]. The proposed method improves the block matching strategy by 19%. Our next step will be to extend our method to power forecasts by incorporating measurements of the produced energy.

References

[1] Heinemann, D., Lorenz, E., Girodo, M.: Forecasting of Solar Radiation. In: Solar Resource Management for Electricity Generation from Local Level to Global Scale. Nova Science Publishers, New York (2006) 83–94

[2] Chow, C., Urquhart, B., Lave, M., Dominguez, A., Kleissl, J., Shields, J., Washom, B.: Intra-hour Forecasting with a Total Sky Imager at the UC San Diego Solar Energy Testbed. Solar Energy **85**(11) (November 2011) 2881–2893

[3] Thirion, J.P.: Image Matching as a Diffusion Process: An Analogy with Maxwell's Demons. Medical Image Analysis **2**(3) (September 1998) 243–260

[4] Fischer, B., Modersitzki, J.: Curvature Based Image Registration. Journal of Mathematical Imaging and Vision **18** (2003) 81–85