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A spatio-temporal model to estimate hourly solar radiation using Extreme Learning Machines

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Generating solar photovoltaic (PV) power in urban areas is a promising approach to cover our energy demand and reduce greenhouse gas emissions. However, the high variability of solar energy in both time and space must be taken into account when assessing the suitability of solar PV panels in urban areas. To model the spatio-temporal variation of solar irradiance (i.e. solar power at the earth's surface per unit area), several statistical and machine learning approaches have been applied. The existing models mostly focus on either spatial or temporal estimation and forecasting, and hence are not optimal for very large spatio-temporal data. We propose a high-performance implementation of an Extreme Learning Machine (ELM) ensemble algorithm to estimate the solar irradiance (i) at an hourly temporal resolution (ii) on a national scale (iii) from a large historical data set.

ELM ensembles are well-suited for large-scale estimation, as they exhibit the following characteristics (Huang et al, 2014): (i) they are fast and scalable algorithms, (ii) the number of parameters to tune is low, (iii) they allow an indication of confidence intervals. An ensemble combines a set of Extreme Learning Machines (Huang et al, 2006), which are Single-Layer Neural Networks (SLNs) with randomly assigned input weights that can be trained extremely quickly. The input to each ELM is a subsampled version of the training data based on a bootstrapping approach. The outputs of the individual ELMs are aggregated and give the estimated value as well as the probability distribution from which the confidence intervals are constructed. To reduce the computational complexity of training many ELMs on a large multi-dimensional dataset, the Bag of Little Bootstraps approach can be used (Kleiner et al., 2012).

In the present study, we use an Extreme Learning Machine ensemble algorithm to estimate the monthly-mean-hourly global and direct solar irradiance at the national scale of Switzerland. The model is trained on hourly satellite-based irradiance data of Switzerland ($\sim$10,000 locations) from 2004 to 2015. A Digital Elevation Model (DEM) is used to define the coordinates of the training data points. The modelling is performed in three stages: (i) data pre-processing to identify missing values and outliers, (ii) ensemble training using a high-performance ELM implementation, (iii) estimation of hourly solar irradiance for a dense grid (200m $\times$ 200m) over Switzerland. This approach could be easily expanded to include auxiliary environmental parameters such as temperature, precipitation, or sky clearness index. It may further be applied to other environmental problems for computationally efficient large-scale spatio-temporal estimation, forecasting and quantification of uncertainties.

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