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A novel Grouping Genetic Algorithm–Extreme Learning Machine approach for global solar radiation prediction from numerical weather models inputs

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Abstract

This paper presents a novel scheme for global solar radiation prediction, based on a hybrid neural-genetic algorithm. Specifically a grouping genetic algorithm (GGA) and an Extreme Learning Machine algorithm (ELM) have been merged in a single algorithm, in such a way that the GGA solves the optimal selection of features, and the ELM carries out the prediction. The proposed scheme is also novel because it uses as input of the system the output of a numerical weather meso-scale model (WRF), i.e., atmospherical variables predicted by the WRF at different nodes. We consider then different problems associated with this general algorithmic framework: first, we evaluate the capacity of the GGA–ELM for carrying out a statistical downscaling of the WRF to a given point of interest (where a measure of solar radiation is available), i.e., we only take into account predictive variables from the WRF and the objective variable at the same time tag. In a second evaluation approach, we try to predict the solar radiation at the point of interest at different time tags $t + x$, using predictive variables from the WRF. Finally, we tackle the complete prediction problem by including previous values of measured solar radiation in the prediction. The proposed algorithm and its efficiency for selecting the best set of features from the WRF are analyzed in this paper, and we also describe different operators and dynamics for the GGA. Finally, we evaluate the performance of the system with these different characteristics in a real problem of solar radiation prediction at Toledo's radiometric observatory (Spain), where the proposed system has shown an excellent performance in all the subproblems considered, in terms of different error metrics.

Keywords: Grouping genetic algorithm (GGA); Global solar radiation prediction; Solar energy; Extreme Learning Machines

1. Introduction

Solar energy is an important source of renewable and clean energy, currently under expansion in different countries of the world, and with a huge potential to contribute significantly to the energy mix and nations' economies of these countries. Solar energy development is specially important in mid-east and southern Europe countries, where the solar resource can be better exploited all year around (Kalogirou, 2014). Solar production is intrinsically stochastic (with reference to intra-hour solar forecasting) and significant variations in solar energy production occur due to the presence of clouds, atmospheric dust or

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particles. For longer time horizons (e.g. 6 h or more), physics-based models are usually employed (Diagne et al., 2014; Coimbra et al., 2013; Inman et al., 2013). Because of this, prediction of the energy production in solar energy plants is an important problem to integrate this renewable energy in the system. The problem of solar energy prediction usually involves the accurate prediction of the solar radiation at a given point (the solar plant facility), and this prediction depends completely on different atmospheric variables (Inman et al., 2013; Khatib et al., 2012; Sozen et al., 2004; Voyant et al., 2011).

In the last years, many different approaches have been proposed for global solar radiation prediction, a lot of them using Machine Learning or Computational Intelligence techniques. The majority of these approaches include different inputs based on geographical and atmospheric parameters such as latitude, longitude, temperature, wind speed and direction, sunshine duration, and precipitation (Mellit and Kalogirou, 2008; Mubiru, 2008). According to Bilgili and Ozoren (2011), sunshine duration, air temperature and relative humidity are the most widely used meteorological parameters to predict daily solar radiation and its components. All these parameters are well correlated with the daily solar global radiation as pointed out in Yacef et al. (2012). In López et al. (2005) a Bayesian framework for artificial neural networks, named as automatic relevance determination method, was developed to evaluate the more relevant input parameters in modelling solar radiation. In fact, neural computation paradigm has been massively applied to this prediction problem, like in Benghanem and Mellit (2010), where it is shown that Radial Basis Functions (RBF) neural networks obtain excellent performance in the estimation of solar radiation. In Dorvlo et al. (2002) a comparison between Multi-Layer Perceptrons (MLP) and RBF neural networks in a problem of solar radiation estimation is carried out. Experiments in eight stations in Oman show the good results obtained with the neural algorithms. A similar approach, also comparing MLPs and RBFs (with different predictive variables) has been recently proposed in Behrang et al. (2010), in this case the authors test the neural network with data obtained in Iran. In Paoli et al. (2010) the performance of a MLP in a problem of solar radiation prediction in time series is compared to that of ARIMA, Bayesian inference, Markov Chains and k-Nearest Neighbors models, for specific problems in Corsica and Southern France. Another work dealing with solar radiation time series prediction is Wu and Chan (2011), where a hybrid algorithm that involves an ARMA model and a time-delay neural network is proposed. In Hocaoglu et al. (2008) a neural network to predict hourly solar radiation in a region of Turkey is proposed. The paper also introduces a 2D model for solar radiation useful for visualization and data inspection. In Fu and Cheng (2013), the forecasting of solar irradiance proposed utilizes features extracted from all-sky images, such as the number of cloud pixels, frame difference, gradient magnitude, intensity level, accumulated intensity along the vertical line of sun or the number of corners in the image. Other works on solar radiation prediction involve ARMA models, as Ji and Chee (2011) a hybrid approach based on ARMA and time delay neural networks has been successfully tested in data from a solar station in Singapore. Another paper involving hybrid ARMA and neural networks is (Voyant et al., 2013), where this hybrid approach is successfully applied to solar radiation prediction in different cities of the French Mediterranean coast and Corsica. Alternative approaches that apply neural networks as prediction methodology also include novel predictive variables, such as satellite data (Senkal and Kuleli, 2009) or temperature and relative humidity (Rehman and Mohandes, 2008). Other machine learning algorithms, such as Support Vector Regression (SVR) algorithms have been also applied to solar radiation prediction problems from meteorological predictive variables (Chen et al., 2011; Zeng and Qiao, 2013). Specifically, a least-square SVM is proposed in that work, comparing the results obtained with that of auto-regressive and RBF neural networks. In Rahimikoob (2010) the potential of multi-layer perceptron neural networks with back-propagation training algorithm is shown in a problem of global solar radiation estimation in Iran. Results comparing the performance of the neural networks with that of an empirical equation for global solar radiation prediction (Hargreaves and Samani equation) show good performance of the neural approach. In Bhardwaj et al. (2013) a hybrid approach that includes hidden Markov models and generalized fuzzy models has been proposed and tested in real solar irradiation data in India. Finally, we discuss very recent hybrid approaches proposed to problems of solar energy prediction, such as Olatomiwa et al. (2015) where a SVR has been hybridized with a firefly algorithm to select the best parameters of the SVR, or Mohammadi et al. (2015), where a hybrid SVR-Wavelets approach is presented in a problem of horizontal global solar radiation prediction. The goodness of this novel approach has been tested in a real problem of solar radiation estimation in Bandar Abbas (Iran). Moreover, in Diagne et al. (2014), a post-processing technique (Kalman filtering) is used to improve the hour-ahead forecasted Global Horizontal Irradiance (GHI) from (1) the measured GHI at the ground, and (2) the Weather Research and Forecasting (WRF) meso-scale model, and results at Reunion Island are provided.

Different approaches discussing Extreme Learning Machine (ELM, a novel training method for artificial neural networks) applications in solar radiation prediction problems have been recently proposed, such as Sahin et al. (2014), where the ELM approach is applied to a solar radiation prediction problem from satellite measures. In Alharbi (2013) a case study of solar radiation prediction in Saudi Arabia is discussed comparing the performance of artificial neural networks with classical training and ELMs. In Dong et al. (2014) a hybrid wavelet-ELM approach is tested in a problem of solar radiation prediction for application in a photovoltaic power station.