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A new hybrid support vector machine–wavelet transform approach for estimation of horizontal global solar radiation

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ABSTRACT

In this paper, a new hybrid approach by combining the Support Vector Machine (SVM) with Wavelet Transform (WT) algorithm is developed to predict horizontal global solar radiation. The predictions are conducted on both daily and monthly mean scales for an Iranian coastal city. The proposed SVM–WT method is compared against other existing techniques to demonstrate its efficiency and viability. Three different sets of parameters are served as inputs to establish three models. The results indicate that the model using relative sunshine duration, difference between air temperatures, relative humidity, average temperature and extraterrestrial solar radiation as inputs shows higher performance than other models. The statistical analysis demonstrates that SVM–WT approach enjoys very good performance and outperforms other approaches. For the best SVM–WT model, the obtained statistical indicators of mean absolute percentage error, mean absolute bias error, root mean square error, relative root mean square error and coefficient of determination for daily estimation are 6.9996%, 0.8405 MJ/m^2, 1.4245 MJ/m^2, 7.9467% and 0.9086, respectively. Also, for monthly mean estimation the values are 3.2601%, 0.5104 MJ/m^2, 0.6618 MJ/m^2, 3.6935% and 0.9742, respectively. Based upon relative percentage error, for the best SVM–WT model, 88.70% of daily predictions fall within the acceptable range of −10% to +10%.

1. Introduction

Developing solar energy technologies are being substantially increasing to supply the energy demand and provide sustainability in many locations across the globe. Solar energy systems can be employed for variety of purposes such as heating, cooling and providing electricity. One of the greatest applications of solar energy technologies is in the isolated regions where there is no accessibility to accurate and reliable measured solar radiation information. The scarcity of real solar data is chiefly contingent upon several factors such as paucity of solar radiation measurement equipment as well as fiscal issues [1–3]. Nevertheless, despite such unavailability, other meteorological elements including sunshine hours, ambient temperature, relative humidity, pressure, etc. are widely measured in most of sites owing to their significant applications in various fields. Therefore, several models have been developed to estimate horizontal global solar radiation based upon a series of commonly available meteorological and geographical parameters including sunshine duration, ambient temperatures, relative humidity, water vapor and sea level pressures, cloud cover, altitude, latitude and longitude and extraterrestrial radiation [4–20]. In fact, finding an appropriate relationship between horizontal global solar radiation and one or more input variables has been a serious challenge in the realm of solar radiation simulation.

Although a vast number of models have been proposed to estimate the global solar radiation, developing proper algorithms and approaches to achieve further reliability, accuracy and convenience in computational process is still highly demanding. Over the past years, various artificial intelligence and computational intelligence techniques have been applied by researchers as especially efficient approaches for the problem of global solar radiation prediction in many locations across the globe.

Bosch et al. [21] carried out an investigation to estimate daily global solar radiation using artificial neural networks (ANN) over

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a mountainous region situated in South East of Spain. Their results demonstrated that ANN can be considered as an effective technique with easy usage for estimation of solar radiation in complex mountain terrains. Rehman and Mohandes [22] used ambient temperature and relative humidity as inputs to predict global solar radiation for Abha city in Saudi Arabia using artificial neural network (ANN) technique. The obtained results illustrated that ANN is favourably capable to estimate global solar radiation based upon these two parameters. Benghanem et al. [23] developed six ANN-based models to estimate horizontal global solar radiation at Al-Madinah in Saudi Arabia. They utilized different combinations of input parameters consisting sunshine hours, ambient temperature, relative humidity and the day of year. Their results showed that a higher accurate model is dependent upon sunshine duration and air temperature. Rahimikhoob [24] applied ANN technique to estimate global solar radiation based on ambient temperature in a semi-arid environment. The ANNs were trained based upon maximum and minimum air temperatures and extraterrestrial radiation. Then the ANNs were compared with a traditional temperature-based empirical model. It was found that estimation of global solar radiation using ANN technique offers higher accuracy. Solmaz and Ozgoren [25] utilized ANN approach for prediction of hourly global solar radiation in six different provinces of Turkey. For this purpose, they developed two ANN-based models using six input parameters. Behrang et al. [26] utilized particle swarm optimization (PSO) technique to develop some new sunshine-based models for estimation of monthly mean global solar radiation in 17 Iranian cities. Their results illustrated that for most of the cities the new models developed based on PSO have higher performance than the existing models. Chen et al. [27] examined the possibility of employing the Support Vector Machines (SVMs) for estimating the monthly mean global solar radiation utilizing maximum and minimum air temperatures at Chongqing station, China. They applied three different functions of SVM and found that the developed SVM model using polynomial kernel function shows superiority over other SVM models. Ozgoren et al. [28] developed an artificial neural network (ANN) model on the basis of multi-nonlinear regression (MNLR) method for estimation of the monthly global solar radiation over Turkey. They used various variables and then employed the Stepwise MNLR method to determine the most proper input values. Their results showed that the ANN model can predict the values with acceptable errors compared with the actual data. Yacef et al. [29], in a comparative study, assessed the performance of Bayesian Neural Network (BNN) in comparison with classical Neural Network (NN) and empirical models to estimate daily global solar irradiation at Madinah, Saudi Arabia. They used four different input elements and found that BNN enjoys higher capability for estimation of solar radiation. Rodriguez et al. [30] developed an optimized artificial neural network model to calculate daily global solar radiation over Andalusia, Spain. In the developed model, they utilized both clear-sky estimates and satellite images as input elements and also applied genetic algorithm to optimize the selection of inputs. They found that the predicted values by the model are relatively precise. Ramedani et al. [31] employed support vector regression (SVR) technique to develop a model for prediction of global solar radiation in Tehran, Iran. They used two SVRs models of radial basis function (SVR-rbf) and polynomial function (SVR-poly). Their results showed the superiority of SVR-rbf technique. Chen et al. [32] evaluated the possibility of applying Support Vector Machine (SVM) for prediction of daily global solar radiation in Liaoning province in China. They developed seven sunshine duration-based SVM models and compared their performance with five empirical models. Their results indicated that all SVM models outperform the empirical models remarkably. Ramedani et al. [33] performed a comparative investigation between fuzzy linear regression (FLR) and support vector regression (SVR) techniques to predict global solar radiation in Tehran, Iran. They found that, owing to substantially lower errors, SVR-rbf approach enjoys superior performance compared to FLR. Chen et al. [34] appraised the transferability of Support Vector Machines (SVM) to estimate global solar radiation using ambient temperature in subtropical zone in China. They found that global solar radiation at one site can be estimated acceptably by SVM model established for another site. Also, the estimation precision is influenced by the distance and temperature difference between two locations and altitude.

Additionally, many authors have aimed at achieving further accuracy in estimating the solar radiation by hybridizing different approaches. Basically, the fundamental objective of combing different approaches is the utilization of specific nature of each technique to obtain further accuracy for estimation of solar radiation.

Wu and Chan [35] combined the Autoregressive and Moving Average (ARMA) model with the controversial Time Delay Neural Network (TDNN) for prediction of hourly solar radiation. The achieved results revealed that the hybrid model has higher capability compared to both ARMA and TDNN. Bhardwaj et al. [36] proposed a hybrid approach which includes hidden Markov models and generalized fuzzy models to estimate solar irradiation in India. They assessed the influence of different meteorological parameters for estimation of solar radiation using the developed model. Their results showed that the predicted values by the proposed model are in a favorable agreement with measured data. Mostafavi et al. [37] developed a hybrid approach by combining Genetic Programming (GP) with simulated annealing (SA) for estimating the global solar radiation. They also performed a sensitivity analysis to assess the influence of the different meteorological parameters on solar radiation estimation. Their results showed that the suggested model provide precise predictions. Hung et al. [38] developed a hybrid Auto Regressive and Dynamical System (CARDS) model to forecast hourly global solar radiation in Mildura, Australia. Their results indicated that the CARDS model can forecast hourly solar radiation favourably. Salcedo-Sanz et al. [39] assessed the capability of a novel Coral Reefs Optimization–Extreme Learning Machine (CRO–ELM) algorithm to predict the global solar radiation at Murcia (southern Spain) using different meteorological data. They concluded that the CRO–ELM approach can predict the daily global radiation accurately with further preciseness than the classical ELM and the Support Vector Regression algorithm. Wu et al. [40] developed a genetic algorithm combing multi-model framework to predict solar radiation. By comparing the prediction performance of the proposed technique with some other algorithms they found higher accuracy and consistency for their approach.

In this paper, the Support Vector Machines (SVMs) and Wavelet Transform (WT) algorithm are combined to propose a new hybrid approach to predict horizontal global solar radiation. The primary aim is achieving further accuracy and reliability in estimations by taking the advantages of both approaches. For this purpose, long-term measured databases consisting horizontal global solar radiation and different meteorological elements for a city situated in south costal part of Iran have been used. The motivation behind this research work is mainly twofold. First, there is a special need to reliable and accurate solar information in various applications such as the design and simulation of solar energy technologies, agricultural production, irrigation management and water resources allocation. Furthermore, despite the substantial solar energy potential, precise long-term measured solar data is unavailable in the vast neighboring region around the considered case study. The merit of proposed hybrid SVM–WT model is assessed thoroughly in terms of both daily and monthly mean daily estimation using various reliable and widely-known statistical indicators to draw more conclusive conclusions. Owing to significance of