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Wind speed prediction using the hybrid model of wavelet decomposition and artificial bee colony algorithm-based relevance vector machine

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ABSTRACT

In this paper, the hybrid model of wavelet decomposition and artificial bee colony algorithm-based relevance vector machine (WABCRVM) is presented for wind speed prediction. Here, wind speed can be regarded as a signal and decomposed into four decomposed signals with different frequency range, which can be obtained by 2-layer wavelet decomposition for wind speed data, and the prediction models of the four decomposed signals can be established by RVM with their each appropriate embedding dimension. Artificial bee colony algorithm (ABC) is used to select the appropriate kernel parameters of their RVM models. Thus, each decomposed signal's RVM model of wind speed has appropriate embedding dimension and kernel parameter. Finally, the experimental results show that it is feasible for the proposed combination scheme to improve the prediction ability of RVM for wind speed.

Introduction

It is well-known that wind power has been increasingly regarded as a significant source of renewable energy as its clean and pollution-free [1–3]. In the Inner Mongolia of China, abundant wind energy resources exist, especially in the Hohehot, which is one of the most wind energy reserve areas in China. Thus, the analysis and estimation of wind energy in this area is very significant. Accurate wind speed prediction is helpful for wind farm operation control, wind power prediction, and more [4,5]. As is known to all, one of the primary reasons for the low utilization rate of wind power is the volatility of wind speed, which makes it hard to predict. The time series-based method is a popular method to forecast wind speed as it uses only historical wind data and can obtain the suitable short-term prediction results for wind speed.

Recently, some time series-based intelligent prediction methods have been presented for wind speed, such as artificial neural networks and support vector machine. Li and Shi [6] presented the application of different artificial neural networks in 1-h ahead wind speed forecasting. Ren et al. [7] presented a wind speed method by combining the PSO-BP neural network with input parameters selection, and the experiment results indicate that the proposed method achieves much better forecast performance than the basic back propagation neural network and ARIMA model. However, application of artificial neural networks is limited due to the shortcomings of over-fitting and falling into local extremum easily [8,9]. Support vector machine is a kind of machine learning method based on the statistical learning theory. Compared with artificial neural networks, support vector machine (SVM) has the better generalization performance [10]. Sancho et al. [11] presented an evolutionary-SVM algorithm for short-term wind speed prediction, and applied the evolutionary-SVM algorithm to wind speed prediction in wind turbines of a Spanish wind farm.

Relevance vector machine (RVM) is an intelligent learning technique based on sparse Bayesian framework, the number of relevance vectors in RVM is much smaller than that of support vectors in SVM, which makes RVM have a sparser representation compared with SVM [12,13]. Moreover, there is no need to set the penalty parameter in RVM, which makes RVM more convenient to use than SVM. Thus, RVM has a better application prospect in wind speed prediction. As it is difficult to obtain an appropriate embedding dimension in creating directly the prediction model of wind speed by RVM, the hybrid model of wavelet decomposition and artificial bee colony algorithm-based RVM (WABCRVM) is presented for wind speed prediction in this paper. Here, wind speed can be regarded as a signal and decomposed into several sub-signals with different frequency range, we perform 2-layer wavelet decomposition for wind speed data, the four decomposed signals with different frequency range can be obtained, and the prediction models of the four decomposed signals can be established by RVM with their each appropriate embedding dimension. Artificial bee colony algorithm (ABC) is used to select the appropriate kernel parameters of their RVM models, artificial bee colony algorithm is a swarm-based meta-heuristic technique, which is inspired by the foraging behavior of honey bees. In the last few

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years, the ABC algorithm has been widely applied to various research fields including clustering analysis [14], image processing [15], optimal filter design [16], numerical optimization [17], and so on. Recently, artificial bee colony algorithm has been extended for parameters optimization of some popular intelligent learning algorithms, such as artificial neural networks [18] and support vector machine [19]. In some researches, artificial bee colony algorithm has been proved to be more effective than some other evolutionary algorithms, such as genetic algorithm (GA) and particle swarm optimization (PSO) [20–22]. Thus, each decomposed signal's RVM model of wind speed has appropriate embedding dimension and kernel parameter. In order to show the superiority of the proposed WABCRVM method, the RVM models with several different embedding dimensions and Gaussian RBF kernel parameters are used to compare with the proposed WABCRVM method. Finally, the experimental results show that it is feasible for the proposed combination scheme to improve the prediction ability of RVM for wind speed.

Wavelet decomposition of wind speed

Wavelet transform is an important mathematical tool for nonlinear and non-stationary signal analysis, which allows the decomposition of a signal into several sub-signals with different frequency range [23,24]. In this study, wind speed can be regarded as a signal and decomposed into several sub-signals with different frequency range, and we perform 2-layer wavelet decomposition for wind speed data, the four decomposed signals are signal 2-1, signal 2-2, signal 2-3 and signal 2-4, which are shown in Fig. 1. Signal 2-1 is a low frequency signal, which reflects the variation trend of wind speed. Other wavelet decomposed signals have higher frequency than wavelet decomposed signal 2-1, which includes the detailed information of wind speed. As the four decomposed signals have different characteristics, we must create four different prediction models to fit and predict them.

Predicting the wavelet decomposed signals by ABCRVM

The regression model of relevance vector machine

The regression model of relevance vector machine can be used to solve the nonlinear regression problems [13]. The output target t_n of the regression model of RVM includes the additive noise, which can be formulated as follows:

$$t_n = y(\mathbf{x}_n, \mathbf{w}) + \varepsilon_n \tag{1}$$

where $\mathbf{x}_n$ is the input vector, and ε_n is assumed to be mean-zero Gaussian noise with variance σ^2.

The regression function of relevance vector machine consists of a linear combination of the weighted kernel functions, which can be described as follows:

$$y(\mathbf{x}, \mathbf{w}) = \sum_{i=1}^{N} w_i K(\mathbf{x}, \mathbf{x}_i) + w_0 \tag{2}$$

where $K(\mathbf{x}, \mathbf{x}_i)$ is kernel function, $\mathbf{w} = [w_1, w_2, \cdots, w_N]$ is the weight vector, and w_0 is the bias.

Gaussian RBF kernel has been used in this RVM, which can be expressed as follows:

$$K_{\mathrm{RBF}}(\mathbf{x}_i, \mathbf{x}_j) = \exp\left(-\frac{\|\mathbf{x}_i - \mathbf{x}_j\|^2}{\gamma^2}\right) \tag{3}$$

where γ denotes the kernel parameter of Gaussian RBF kernel.

Artificial bee colony algorithm

In this study, the kernel parameter of Gaussian RBF kernel is selected by artificial bee colony algorithm. Artificial bee colony algorithm is a swarm-based meta-heuristic technique, which is inspired by the foraging behavior of honey bees. The colony of artificial bees consists of three groups of bees: onlooker bees, employed bees and scout bees, among which onlooker bees and

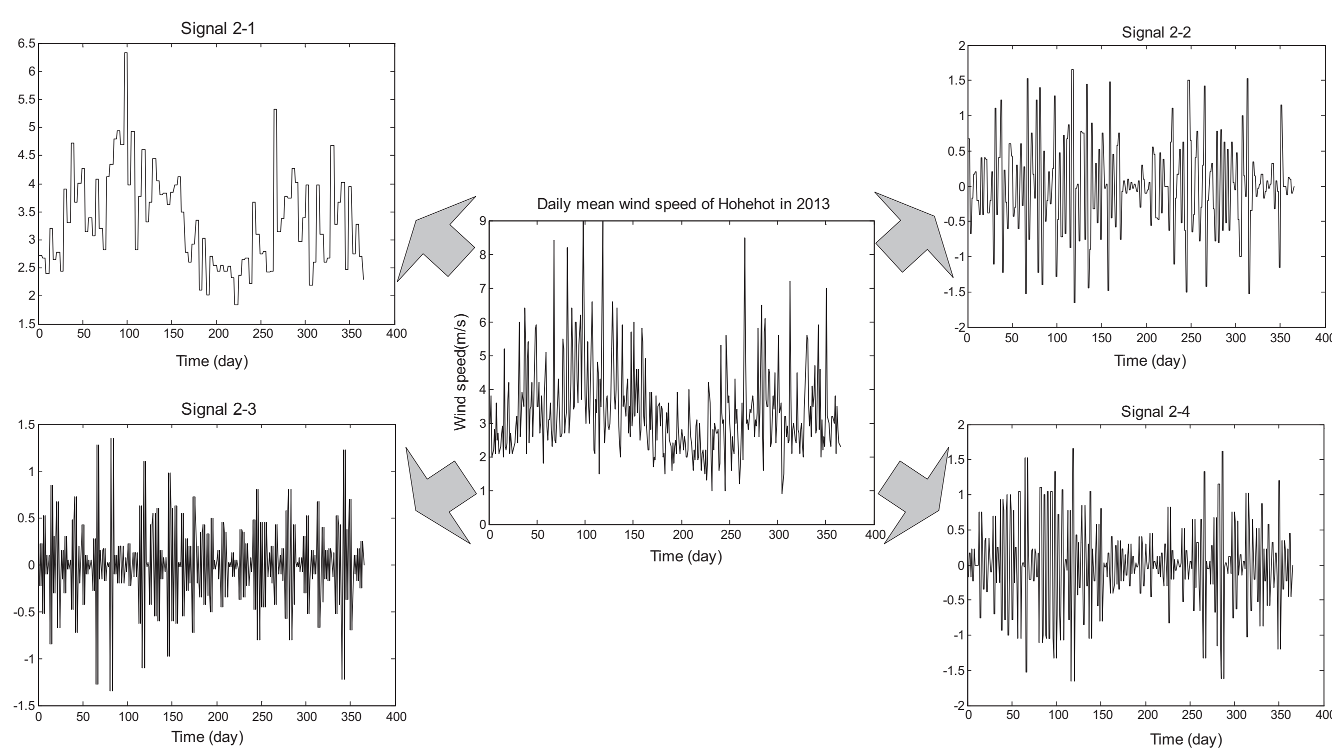

Fig. 1. Wavelet decomposition of wind speed data.