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Short-term wind speed prediction using an unscented Kalman filter based state-space support vector regression approach

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HIGHLIGHTS

- A novel hybrid modeling method is proposed for short-term wind speed forecasting.
- Support vector regression model is constructed to formulate nonlinear state-space framework.
- Unscented Kalman filter is adopted to recursively update states under random uncertainty.
- The new SVR–UKF approach is compared to several conventional methods for short-term wind speed prediction.
- The proposed method demonstrates higher prediction accuracy and reliability.

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ABSTRACT

Accurate wind speed forecasting is becoming increasingly important to improve and optimize renewable wind power generation. Particularly, reliable short-term wind speed prediction can enable model predictive control of wind turbines and real-time optimization of wind farm operation. However, this task remains challenging due to the strong stochastic nature and dynamic uncertainty of wind speed. In this study, unscented Kalman filter (UKF) is integrated with support vector regression (SVR) based state-space model in order to precisely update the short-term estimation of wind speed sequence. In the proposed SVR–UKF approach, support vector regression is first employed to formulate a nonlinear state-space model and then unscented Kalman filter is adopted to perform dynamic state estimation recursively on wind sequence with stochastic uncertainty. The novel SVR–UKF method is compared with artificial neural networks (ANNs), SVR, autoregressive (AR) and autoregressive integrated with Kalman filter (AR-Kalman) approaches for predicting short-term wind speed sequences collected from three sites in Massachusetts, USA. The forecasting results indicate that the proposed method has much better performance in both one-step-ahead and multi-step-ahead wind speed predictions than the other approaches across all the locations.

1. Introduction

Green wind power is one of the promising renewable energy sources to substitute traditional coal and fossil fuel based power generation with mitigated carbon footprint and environmental impact. Due to its renewable nature and environmental friendliness, wind energy has received fast growing attention throughout the world and the utilization of wind power has increased dramatically over the past decade. For instance, the construction of new wind power generation capacity in the first three quarters of 2012 was 4728 MW in total and the cumulative wind power capacity in the United States was increased to 51,630 MW [1]. However, significant intermittency and stochastic fluctuation of wind speed pose great challenges to controlling wind turbines and optimizing wind farm operation towards reliable wind power generation [2]. Therefore, it is crucially important to accurately forecast wind speed so that the model based optimal control of wind turbines can be achieved with stabilized wind power output. Specifically, long-term wind speed forecasting is important for optimizing the site selection and production planning of wind farms, while short-term prediction is vital for controlling wind turbines and improving their power generation efficiency and life span [3–6].

In literature study, the methods developed for wind speed prediction can be divided into two main categories: physical model based approaches and statistical modeling methods. As one type of physical model based approaches, numerical weather prediction (NWP) techniques rely on a class of physical models with numerical parameters characterizing local meteorological and geographical properties such as temperature, atmospheric pressure, surface roughness and obstacles [7–9]. Nevertheless, the prediction

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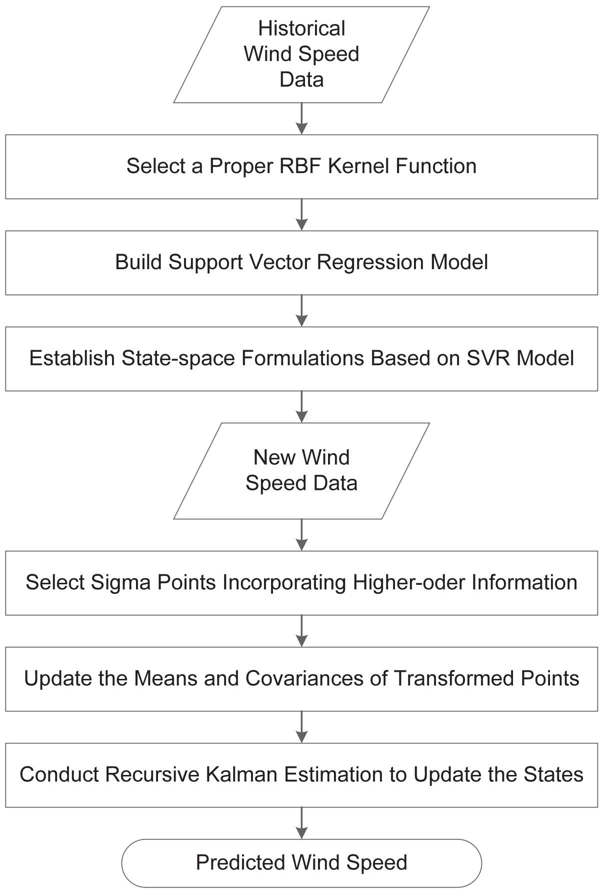

Fig. 1. Schematic diagram of the proposed SVR–UKF approach for wind speed prediction.

Table 1
Comparison of RMSE values in wind speed prediction using ANN, AR, AR-Kalman, SVR and SVR–UKF methods.

RMSE (m/s)	Blandford		Chester		Falmouth	
	1-Step	5-Step	1-Step	5-Step	1-Step	5-Step
ANN	0.7534	0.8622	0.9359	1.1295	0.7440	0.9991
AR	0.7341	1.1846	0.9114	1.4992	0.5839	1.0788
AR-Kalman	0.2849	0.5291	0.3427	0.6918	0.2290	0.5211
SVR	0.3336	0.4808	0.2492	0.5180	0.2834	0.5827
SVR–UKF	0.2123	0.3337	0.1502	0.4266	0.1843	0.4055

Table 2
Comparison of MAPE values in wind speed prediction using ANN, AR, AR-Kalman, SVR and SVR–UKF methods.

MAPE (%)	Blandford		Chester		Falmouth	
	1-Step	5-Step	1-Step	5-Step	1-Step	5-Step
ANN	13.14	15.61	14.10	17.77	16.69	23.03
AR	12.86	21.79	12.36	21.73	10.58	21.05
AR-Kalman	4.98	9.41	4.84	9.54	4.28	9.72
SVR	5.75	9.72	3.42	10.19	4.10	10.36
SVR–UKF	3.57	6.72	2.07	5.68	2.88	7.51

capability of NWP methods degrade significantly when the random uncertainty of weather conditions is strong. In practice, physical models are often utilized through integration with statistical modeling methods in order to combine the advantages of two different types of techniques while mitigate the restrictions of NWP methods [10–12].

Since physical models alone may not well capture the stochastic nature of wind speed, statistical modeling methods are developed for wind speed prediction with some success. Different from physical models, statistical methods depend on historical wind speed

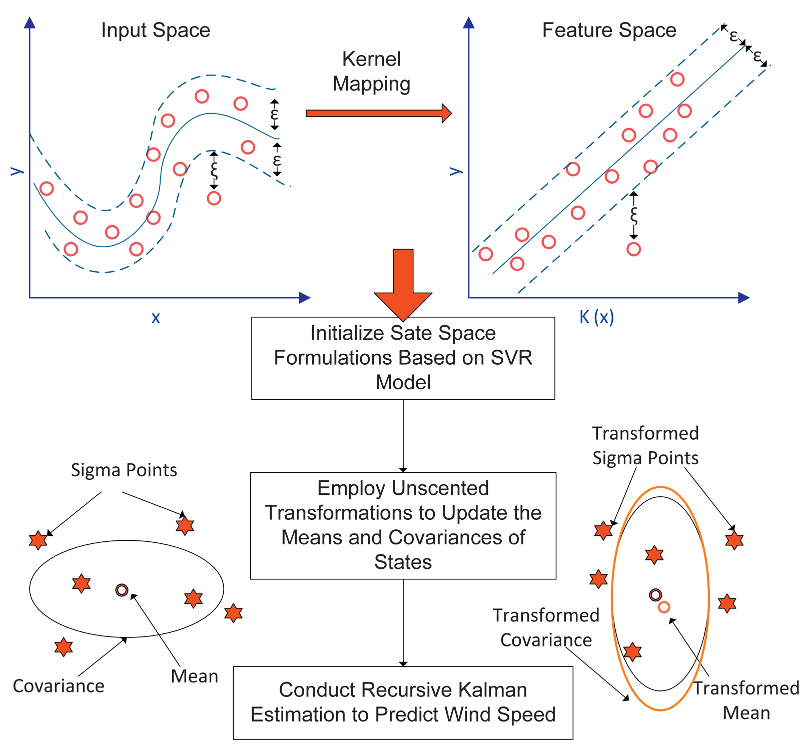

Fig. 2. Graphic illustration of the proposed SVR–UKF approach for wind speed prediction.