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本科毕业设计

（本科毕业论文）

小初，黑体。

外文文献及译文

小三，Time New Roman

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外文文献也可直接插入原始文献并保留原始格式，不必再输入排版

Times New Roman，小三号，加粗,居中,正文文本,1.5倍行距,特殊格式:无

页眉：黑体，五号，居中

**Seasonal analysis and prediction of wind energy using random forests and ARX model structures**

Times New Roman，小四号，两端对齐，1.5倍行距，首行缩进2 字符

Times New Roman，小四号，居中,1.5倍行距,特殊格式:无

Yujie Lin, Uwe Kruger, Junping Zhang, Qi Wang, Lisa Lamont, and Lana El Chaar

**Abstract**—To effectively utilize wind energy, many learning-based autoregressive models have been proposed in the literature. Improving their short-term prediction accuracy, however, is difficult, which mainly result from the stochastic nature of wind. Moreover, the incorporation of seasonal effects to improve their accuracies has not been considered, as most reported studies only relied on relatively short data sets. This article examines meteorological data that was recorded over a 6 year period and contrasts various model structures and identification methods proposed in the literature. One focus of this paper is the prediction of wind speed and direction, which has not been extensively studied in the literature but is important for grid management. The reported results highlight that an increase in prediction accuracy can be obtained (i) by incorporating seasonal effects into the model, (ii) by including routinely measured variables such as radiation and pressure, and (iii) by separately predicting wind speed and direction.

**Index Terms**—Wind speed, wind direction, meteorological models, renewable energy, autoregressive data structure.

Times New Roman，小三号，加粗,居中，大纲级别：1级，特殊格式：无，1.5倍行距

**I. INTRODUCTION**

Being a sustainable and clean source of energy, wind power has gained considerable attention over the past few decades, for example driven by growing international pressure to reduce the carbon footprint [1], [2]. This has led to increasing efforts by the academic and industrial R&D communities to examine the feasibility of wind energy, as it does not possess a direct carbon footprint and has a low indirect carbon contribution to the environment [3].

Because of the stochastic nature of wind, the variability in wind conditions must be examined and forecasted for effectively and efficiently integrating wind energy into the power grid. Therefore, the volatility of wind conditions requires prediction models to reduce its impact on power generation. The research literature proposed two distinct approaches to directly address these issues. The first one refines the utilization of wind-related hardware [4], [5], [6]. For example, [4] showed the potential of advanced control methods to improve wind preview control and estimating rotor effective wind speed.

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**II. DATA DESCRIPTION**

The data was recorded in the Al Mirfa region, which is in the Emirate of Abu Dhabi, U.A.E. This region is located at a latitude of 24◦ and a longitude of 53◦, and is considered a strategic region for installing a power generation plant. The anemometer was placed at a tower hight of 10m. The variables, provided by the local weather station, included mean sea level pressure (P in hPa), global horizontal irradiation (r in W/m2), relative humidity (h in %), dew point temperature (dT in ◦C), ambient temperature (T in ◦C), vapor pressure (vP in hPa), wind speed (v in m/s) and wind direction (d in ◦). The data record spans from 2002 to 2007.

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Times New Roman，小四号，居左，大纲级别：正文，首行缩2字符，1.5倍行距，顺序编号，编号右对齐

The height of modern wind turbines typically range from 50 to 150m. Forecasting wind speed using models that predict speed at a different height is feasible, however. Wind speed increases logarithmically with height. Moreover, the shape of the wind speed profile depends on the aerodynamic roughness of the underlying surface. Empirically, the following relationship describes wind speeds at different heights [19]:

(1)

Here, v(z) and vδ are the wind speeds for heights z and δ, respectively, and α describes surface roughness.

**III. MODELING TECHNIQUES AND STRUCTURES**

This section briefly summarizes three modeling methods, which are traditional artificial neural networks, the support vector regression, and the more recently proposed random forests (RFs) [20] in Subsections III-A. As Table I highlights, existing work examined more conventional nonlinear methods. Furthermore, the section also introduces model structures for predicting wind speed and direction in Subsection III-B.

**3.1 Three modeling methods**

Times New Roman，四号，加粗,居左，大纲级别：2级，1.5倍行距

Times New Roman，五号，居中，1.5倍行距

An Artificial Neural Network is a non-linear modeling and classification technique employed to model complex relationships between cause and effect variable sets or to identify patterns within data. They have broad applications in a variety of fields including transient detection, pattern recognition, approximation, and time-series prediction [21], [22]. The network topology includes an input layer, one or several hidden layers and an output layer. The neurons, which form part of the individual layers, are connected by unknown parameters. These parameters can be adjusted using a variety of algorithms, e.g. the Levenberg-Marquardt algorithm [23]. The training procedure of ANNs in this work was carried out using the Neural Network Toolbox in Matlab®.

TABLE I．DESCRIPTION OF RECORDED DATA SETS ANALYZED THE LITERATURE

(ABBREVIATIONS FOR MODEL STRUCTURES ARMA, AR AND ARX, AND MODELING METHODS ANN, SVR AND RF ARE EXPLAINED IN SECTION III, L AND NL ABBREVIATE LINEAR AND NONLINEAR).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Analyzed data set | Period | Frequency | Variable(s) | Structure |
| Erdem and Shi [10] | 6 months (May to October 2002) | hourly | speed,direction | ARMA(l) |
| Barbounis *et al.* [11] | 8 months (April to December 2000) | hourly | speed | AR(nl)/ANN |
| Li and Shi [14] | 1 year (2002) | hourly | speed | AR(nl)/ANN |
| Guo *et al.* [15] | 5 years (2001-2006) | daily | speed | AR(nl)/ANN |
| Mohandes *et al.* [17] | 12 years (1970-1982) | daily | speed | AR(nl)/SVR |
| Abo-Khalil and Lee [16] | - | - | speed | AR(nl)/SVR |
| Mabel and Fernandez [18] | 3 years (2002-2005) | - | speed,humidity | AR(nl)/ANN |
| El-Fouly *et al.* [9] | 3 years (2003-2005) | hourly | speed,direction | AR(l) |
| Presented work in this article | 6 years (2002-2007) | hourly | 8 variables | ARX(nl)/RF |

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三线表，Times New Roman，五号，文字居左，数字居右，1倍行距

Times New Roman，五号，居中，1.5倍行距

0.2

0.25

0.3

0.35

MSE

ARX−nonlinear

AR−nonlinear

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

n, M

Fig.1 Selection of the number of lagged terms, n for the AR and M for the ARX model structure.

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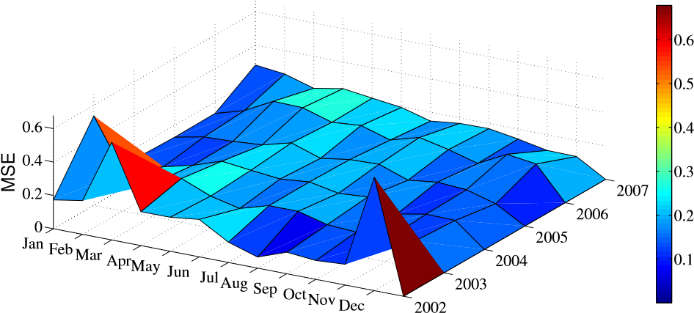


Fig.6 Accuracy of predicting wind speed using nonlinear ARX model structures by month and year.

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**中文译文：**

宋体，小四号，1.5倍行距

黑体，小3号， 1.5倍行距

黑体，小三号，居中，大纲级别：1级，1.5倍行距

**基于随机森林和ARX模型的风能季节分析与预测**

Yujie Lin, Uwe Kruger, Junping Zhang, Qi Wang, Lisa Lamont, and Lana El Chaar

**摘要**：为有效地利用风能，文献中提出了许多基于学习的自回归模型。然而，由于风的随机性，提高其短期预测的精度是困难的。此外，由于大多数报告的研究仅依赖相对较短的数据集，故还没有考虑将季节性效应纳入到提高精度中。本文探讨了6年期间记录的气象数据，并对比了文献中提出的各种模型结构和识别方法。本文的重点是风速和风向的预测，这在文献中尚未得到广泛研究，但对于电网管理具有重要意义。报告的结果强调，要获得预测精度的提高，可以（i）通过将季节性效应结合到模型中，（ii）通过包含进像辐射和压力的常规测量变量，以及（iii）通过单独预测风速和方向。

**关键词**：风速, 风向, 气象模型, 可再生能源, 自回归数据结构.

正文：中文 宋体，英文 Times New Roman，小四号；首行缩进2字符1.5倍行距

黑体，小三号，居中，大纲级别：1级，1.5倍行距

1 引言

作为一种可持续和清洁的能源，风力发电在过去几十年在如不断增加减少碳足迹的国际压力等的推动下得到了相当大的关注[1,2]。这导致学术界和工业界越来越多地努力研究不具有直接的碳足迹且对环境的间接碳贡献也很低的风能的可用性[3]。

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现代风力涡轮机的高度通常在50到150米之间。然而，使用预测不同高度风速的模型来预测风速是可行的。风速随高度成对数增长。此外，风速剖面的形状取决于下垫面的空气动力学粗糙度。根据经验，以下关系描述了不同高度的风速[19]：

(1)

*v*(*z*) 和*vδ*分别是高度*z*和*δ*的风速，*α*表示表面粗糙度。

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3 建模与系统结构

本节简要总结了三种建模方法，即传统的人工神经网络，支持向量回归，以及在第3-A小节中的最近提出的随机森林（RFs）[20]。如表1所示，现有工作研究了更传统的非线性方法。此外，本节还介绍了用于预测第3-B小节中风速和风向的模型结构。

3.1三种建模方法

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**人工神经网络**是一种非线性建模和分类技术，用于模拟因果变量集之间的复杂关系或识别数据中的模式。它们在瞬态检测、模式识别、近似和时间序列预测等领域有着广泛的应用[21,22]。网络拓扑包括输入层，一个或多个隐藏层和输出层。神经元是各个层次的一部分，由未知参数连接。可以使用各种算法来调整这些参数，例如，Levenberg-Marquardt 算法[23]。人工神经网络在这项工作中的训练程序是使用Matlab®中的神经网络工具箱进行的。

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表 1.已分析的文献记录数据集描述

（模型结构的缩写为ARMA、AR和ARX，以及第3节中介绍的建模方法ANN、SVR和RF，L和NL为线性和非线性的缩写）

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Analyzed data set | Period | Frequency | Variable(s) | Structure |
| Erdem and Shi [10] | 6 months (May to October 2002) | hourly | speed,direction | ARMA(l) |
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| El-Fouly *et al.* [9] | 3 years (2003-2005) | hourly | speed,direction | AR(l) |
| Presented work in this article | 6 years (2002-2007) | hourly | 8 variables | ARX(nl)/RF |

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三线表，Times New Roman，五号，文字居左，数字居右，1倍行距，表格内容不翻译

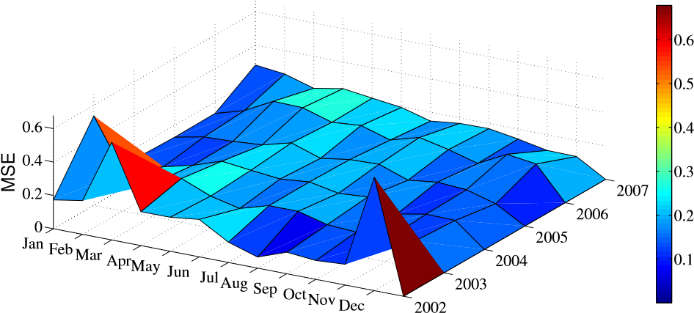


图6. 使用非线性ARX模型结构按月和年对风速的预测精度

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