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Wind turbine fault detection and classification by means of image texture analysis

Magda Ruiz *, Luis E. Mujica, Santiago Alférez, Leonardo Acho, Christian Tutivén, Yolanda Vidal, José Rodellar, Francesc Pozo

Control Dynamics and Applications (CoDAlab), Departament de Matemàtiques, Escola d'Enginyeria de Barcelona Est (EEBE), Universitat Politécnica de Catalunya (UPC), Campus Diagonal-Besòs (CDB), Eduard Maristany, 6-12, Sant Adrià de Besòs, Barcelona 08930, Spain

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ABSTRACT

The future of the wind energy industry passes through the use of larger and more flexible wind turbines in remote locations, which are increasingly offshore to benefit stronger and more uniform wind conditions. The cost of operation and maintenance of offshore wind turbines is approximately 15–35% of the total cost. Of this, 80% goes towards unplanned maintenance issues due to different faults in the wind turbine components. Thus, an auspicious way to contribute to the increasing demands and challenges is by applying low-cost advanced fault detection schemes. This work proposes a new method for detection and classification of wind turbine actuators and sensors faults in variable-speed wind turbines. For this purpose, time domain signals acquired from the operating wind turbine are represented as two-dimensional matrices to obtain grayscale digital images. Then, the image pattern recognition is processed getting texture features under a multichannel representation. In this work, four types of texture characteristics are used: statistical, wavelet, granulometric and Gabor features. Next, the most significant ones are selected using the conditional mutual criterion. Finally, the faults are detected and distinguished between them (classified) using an automatic classification tool. In particular, a 10-fold cross-validation is used to obtain a more generalized model and evaluates the classification performance. Coupled non-linear aero-hydro-servo-elastic simulations of a 5 MW offshore type wind turbine are carried out in several fault scenarios. The results show a promising methodology able to detect and classify the most common wind turbine faults.

1. Introduction

Offshore wind farms promise to become an important source of energy in the near future. However, their operation and maintenance is more difficult and expensive than equivalent onshore wind farms. The current reliability and failure modes of commercial offshore wind turbines are such that a no-maintenance strategy is not a viable option. Improved preventive and corrective maintenance schemes will become crucial for economic exploitation of offshore wind power. Thus, a promising way to contribute is by applying low-cost advanced fault detection schemes. In this regard, this work proposes a new fault

* Corresponding author.
E-mail address: magda.ruiz@upc.edu (M. Ruiz).
URL: https://codalab.upc.edu/en (M. Ruiz).

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detection and classification method that uses on-line SCADA (supervisory control and data acquisition) data already available at a megawatt-sized industrial wind turbine.

On one hand, several methods for fault detection have been proposed for wind turbines. These methods can be mainly classified according to their procedure. Namely, model based and data based. This work uses the data based approach, as in recent years these techniques seem to have received more attention in academia and industry. For example, Bessa et al. [1] propose a new data-driven fault detection and isolation scheme based on time series and data analysis without using any kind of physical modeling; Gong et al. [2] propose a mechanical fault detection algorithm by using only nonstationary generator stator current measurements; Teng et al. [3] propose a multi-fault detection method using vibration signals originated from a real multi-fault wind turbine gearbox with catastrophic failure. In all the aforementioned papers, the fundamental part is the signal processing method. Wherein, the goal in signal processing is to highlight the signal behavior. Refs. [4,5] give a detailed survey on wind turbine condition monitoring and fault diagnosis. Also, an excellent review on wind turbine condition monitoring methods is given in [6] subdividing them into subsystem techniques and overall system techniques as well as destructive and non-destructive techniques.

On the other hand, recent engineering applications have begun to use digital images for fault detection. For instance, Shahriar et al. [7] propose fault diagnosis of induction motors using digital grayscale images. In this sense, we have been working in fault detection of wind turbines based on data [8] and in the classification of abnormal cells images using texture features [9]. Thus, merging these two areas of knowledge; in this work, a methodology for wind turbine fault detection and classification, based on digital image processing, is proposed. The most common fault detection techniques based on signals focus on the frequencies and magnitude of the signal, which are dealing with a one dimensional domain. In this paper, however, by translating the signal into an image (two dimensions), other local features are explored. Another reason to use image texture analysis is that wind turbines are noisy environments, and, thus, noise is added in the recorded signals. However, when the data is translated into images, the added noise is considered as the illumination of the light to the image [10]. Hence, the effect of noise to the signal is removed. The results achieved by the proposed approach, with high classification accuracies, clearly demonstrate the potential of exploiting the feature design from texture analysis.

It is well known that a learning model tends to overfit when using a large number of features. To address this problem, feature extraction and feature selection techniques are widely employed for dimensionality reduction in classification problems [11–13]. On one hand, feature extraction maps the original feature space to a new one with lower dimensions by combining the original feature space. On the other hand, feature selection selects a subset of features from the original set without any transformation. For the classification problem proposed in this work, both, feature extraction and selection are used with the aim to select a subset of highly discriminant features.

In this paper, the benchmark model for large-scale wind turbine fault detection and accommodation proposed in [14] is used. The aim of the benchmark model is to provide a common ground to test and compare different methods considering the most common faults in megawatt-sized wind turbines. Once the time domain signals are stored, they are represented by grayscale images. Next, a set of texture features is extracted from each image. In this process, it is computed the visual patterns that composes an image, which can be regarded as a similarity grouping in an image. Because of the high computational cost associated with the use of all the texture features, the number of features must be reduced. This is achieved by giving priority to the most relevant and less redundant texture features. Finally, a process of training and validation of the classification technique is developed by using a 10-fold cross-validation. Thus, the methodology for fault diagnosis is completed and calibrated. Regarding novelty and contribution, three crucial issues are highlighted:

1. the use of texture features for fault diagnosis in large-scale wind turbines;
2. the integration of different techniques used in other engineering fields to solve a latent problem;
3. the acquisition of new features based on Gabor Filters.

The rest of the paper is organized as follows. The benchmark model for wind turbines is explained in Section 2. Then, the overall design of the methodology, including the stages that comprise it, are reported in Section 3. Likewise, since the features based on Gabor filters are a contribution of this paper, and it is the first time they are applied to fault detection in mechanical systems, a detailed explanation of its realization is included in the same section. Next, results are presented and discussed in Section 4. Finally, conclusions are drawn in Section 5.

2. Benchmark model

2.1. Reference 5 MW wind turbine

The benchmark model for fault detection and fault tolerant control of wind turbines proposed in [14] is used in this work. The benchmark is based on the model of a generic three blade horizontal variable speed wind turbine with a full converter coupling and a rated power of 5 MW. The aim is to provide a common ground to test and compare different methods for fault detection and fault tolerant control of wind turbines. This benchmark is based on FAST and thus proposes a higher-fidelity model of the WT, see [15]. FAST is the National Renewable Energy Laboratory's (NREL) primary computed aided engineering tool for simulating the coupled dynamic response of wind turbines. FAST joins aerodynamics models, hydrodynamics models