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"New Approaches on Maintenance Management for Wind Turbines Based on Acoustic Inspection"

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NEW APPROACHES ON MAINTENANCE MANAGEMENT FOR WIND TURBINES BASED ON ACOUSTIC INSPECTION

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Abstract

Nowadays, maintenance management is changing due to the new technologies in inspection and monitorization systems to reduce the production costs for the companies and risks for the operator. Maintenance management is a key factor in some industries as renewable energy, due to the high-cost consequences of a wrong failure detection in a wind turbine. Therefore, advances in condition monitoring systems are required for an early failure diagnosis. This paper contributes to the actual wind turbines diagnosis methods with a novel non-destructive inspection system based on acoustic analysis of the wind turbine condition. The paper presents a condition monitoring system based on an acoustic sensor embedded in an unmanned aerial vehicle to collect acoustic signals emitted by the wind turbine. The signals are sent to a ground remote-control centre, and then they are analysed. This data acquisition system needs of a qualitative and quantitative analysis to classify and identify the condition of the wind turbine. Wavelet transforms are employed for filtering the signals and pattern recognition. Several scenarios are considered and analysed considering the main mechanical parts and components of a wind turbine.

KEYWORDS: Fault Detection and Diagnosis, Non-Destructive Test, Wind Turbines Maintenance, Condition Monitoring System, Acoustic Inspection, Wavelet Transforms.

1.Introduction

In recent years, there is an important evolution in designs, materials, mechanical electronic, electrical, and control of wind turbines (WTs) [1]. The objective is to support the of energy production capacity and to improve the competitiveness of this industry [2,3]. Other key factor for the evolution of an industry is the cost reduction and the system efficiency by new strategies based on advance analytics [4,5], for example, the optimization of maintenance resources or the correct use of them [6,7]. Maintenance management is considered as transcendental to improve the benefit margin [8].

The wind farm maintenance management is complex due to the machine locations and meteorological conditions [9]. These preventive and corrective works are done over the time [10,11], but they are expensive and generate risk for the operators, working in high altitude, see Figure 1. The generation of false alarm or deceptive signals of the monitorization system is a fundamental issue in the management management [12-14].

Figure 1. Maintenance technician making a repair labor in a wind turbine [15].

The main interest in maintenance management is to employ a condition monitoring system (CMS) capable to predict failures [16]. A WT is composed of static parts, e.g. tower or support, blades and nacelle, and rotative or mechanical components, e.g. hubs, gearbox or generator [17]. Those components are exposed to physical efforts as stress or compression, and chemical or environmental conditions as erosion or surface degeneration [18]. During the performance of the installations appear mechanical or electrical failures due to the working conditions. For this reason, it is necessary the use of a maintenance plan and a correct CMS to study different failure scenarios [19]. There are some studies about WT maintenance and repair costs that conclude that between 12% and 23% of the total cost are belongs to operation and maintenance (O&M) costs [20,21]. The correct design of maintenance operations and a correct monitorization will reduce these costs, minimizing the downtimes [22,23].

Vibration analysis has been developed and applied previously with positive results; it is required the installation of different sensors joined in the components [24]. The methodology proposed in this paper is suggested to be employed together to this technique due to the similarities of the origin of physics perturbation. The novelty of the paper is based on the capacity of acoustic pattern recognition to detect a fault or wrong performance of some parts analysing the acoustic signals emitted by the machine [25]. The acoustic inspection does not require necessarily a physical contact between the surface and the sensors. Acoustic propagation ways present two characteristics, noise generated by mechanical rotative elements of the WT (hub, generator, gearbox, couplings) and the aerodynamics acoustic generated mainly by blade movement. The WT acoustic emissions depend on the dimensions of the machine, although the acoustic level range is 80 to 100 dB according to the rotation speed conditions [26]. The aerodynamic influence of turbulences area depends on the dimensions of blades and the rotation velocity will be an important factor for this operation [27].

Unmanned aerial vehicles (UAVs), or drones, are used to reduce the human risk or imprecisions in maintenance inspections [28], e.g. steel pipes leak detection inspection [29], power lines structures surveys [30] or solar panels supervision [31]. These vehicles allow the installation of different sensors and cameras as thermographic technology [32]. These tools enable the operator to develop the maintenance activities or tests remotely in safety conditions [33,34]. The use of UAVs must conform to the current legislation and aerial permissions of the operation. The CMS designed by Moraleda et al. [35] and used in this study, composed by an acoustic sensor embedded in the bottom of UAVs, see Figure 2.

Figure 2. UAV with an acoustic sensor embedded.

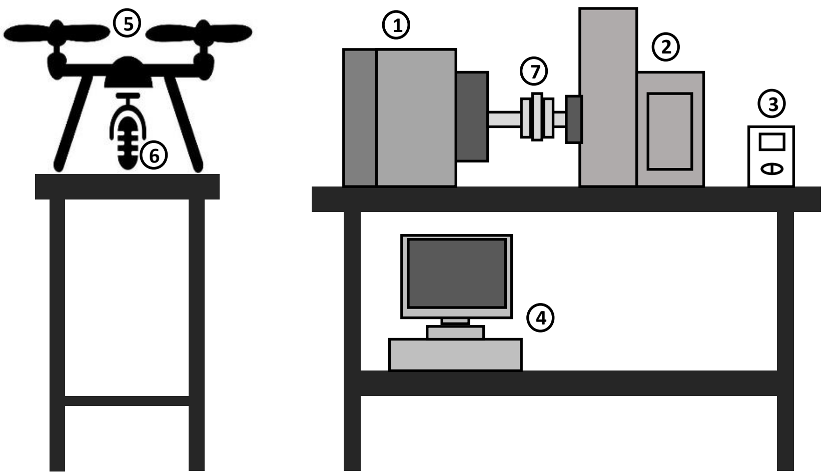
This sensor will transmit a wireless signal to a remote centre receiver, where the signal will be analysed in a ground station by a filtering algorithm. The filtering signal is required in order to ensure the elimination of noise or undesirable data [36].

The contribution of this work is resumed in:

- The development of a novel CMS and fault diagnosis based on acoustic computation. The WT acoustic emissions machinery is captured using a UAV and an acoustic sensor.
- Different mathematical and computational tools are applied for filtering and posterior acoustics characterization of the signals.
- It is used a test bench simulating a real scenario to validate this fault detection method.

2. Methodology and fundaments.

The WT is simulated in laboratory according to Figure 3.



1	Engine	5	Drone
2	Generator	6	Microphone
3	Frequency Converter	7	Coupling
4	Computer		

Figure 3. Test bench designed by the development of the system.

A structural alteration of a solid material under thermic or mechanical stress spreads a transielastic event generating an Acoustic Emission (AE) [37]. These emissions are related with cracks, defects or imperfections both internal and superficial of the material [38]. AE penetrates inside to find the origin and predicts the fail propagation [39]. The acoustic data acquired in the tests are analysed in this paper. A preliminary computational analysis is about a graphical representation of the signals in time domain, see Figure 4

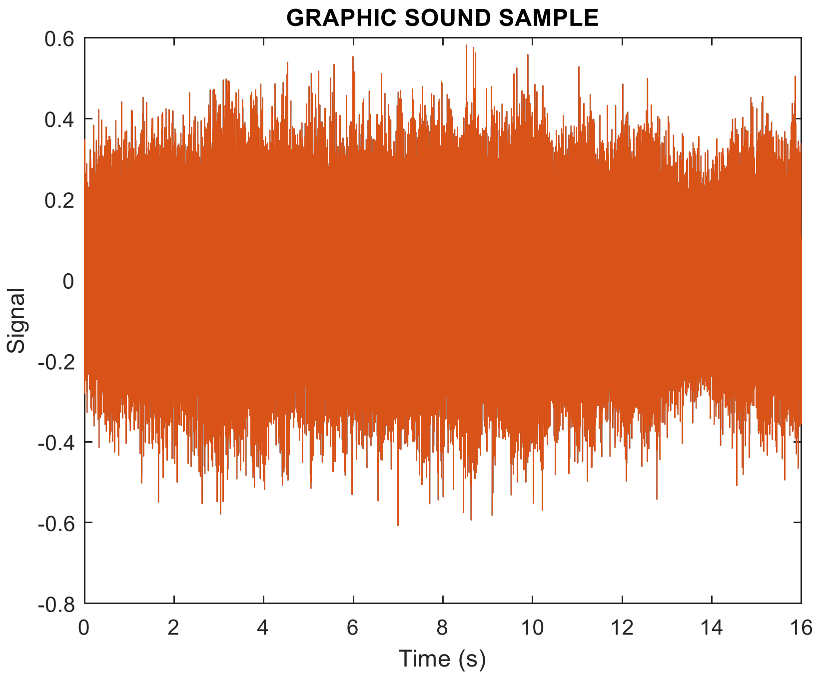


Figure 4. Acoustic signal in time domain

The graphic representation is not useful for a deep study of an acoustic characterization. For this reason, it is necessary to support this work with a mathematical treatment. The acoustic is a non-periodic deterministic signal, characterized with a sinusoidal pulse and defined by wavelength, amplitude, frequency… The acoustic signal can be analysed mathematically in time- frequency [40], therefore, the signal analysis can be studied by mathematical tools as Fourier Transform (FT) [41]. The advantages of the Wavelet Transform (WT) prove that this technique is efficient for acoustic signals [42]. WT is defined by equation (1).

$$S(\tau,a)=\int_{-\infty}^{+\infty} s(t)\frac{1}{\sqrt{a}}\Psi^{*}\left(\frac{t-\tau}{a}\right)dt \qquad (1)$$

Obtaining the conjugate of the mother wavelet Ψ^*, moved and scaled point to point to detect the levels of contrast of the signal $s(t)$, being $f(t)$ the digitized signal in the time domain, $a=f/f_0$ $(a\neq 0)$ the magnitude factor or delay of the wavelet, with f_0 as central frequency and τ the translation in time [43]. Other common expression in acoustic representation is a frequency domain spectrum, shown in Figure 5, to study the frequency distribution range of the signal [44].

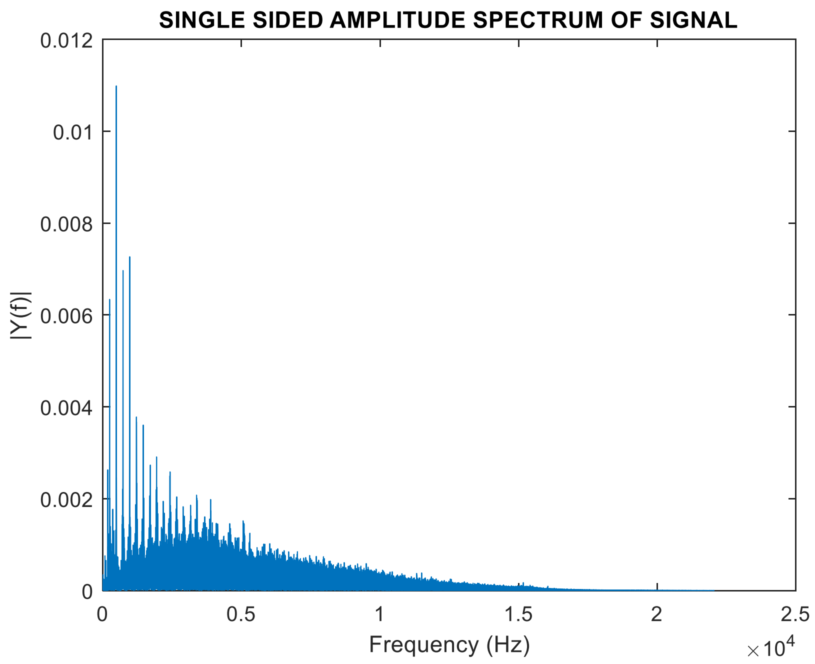


Figure 5. Acoustic signal amplitude spectrum in frequency domain representation

The wavelet transform is employed to obtain the signal energy decomposition divided in levels with the pyramidal algorithm and the decomposition tree showed in Figure 6. This method is very for a acoustics characterization and filtering [45,46]. There are various wavelet transform modes, e.g. discrete or continue [47,48]. WT has been different offspring families depending of the case of application, being Dauchebies family the commonly used in acoustic signal treatment [49,50].

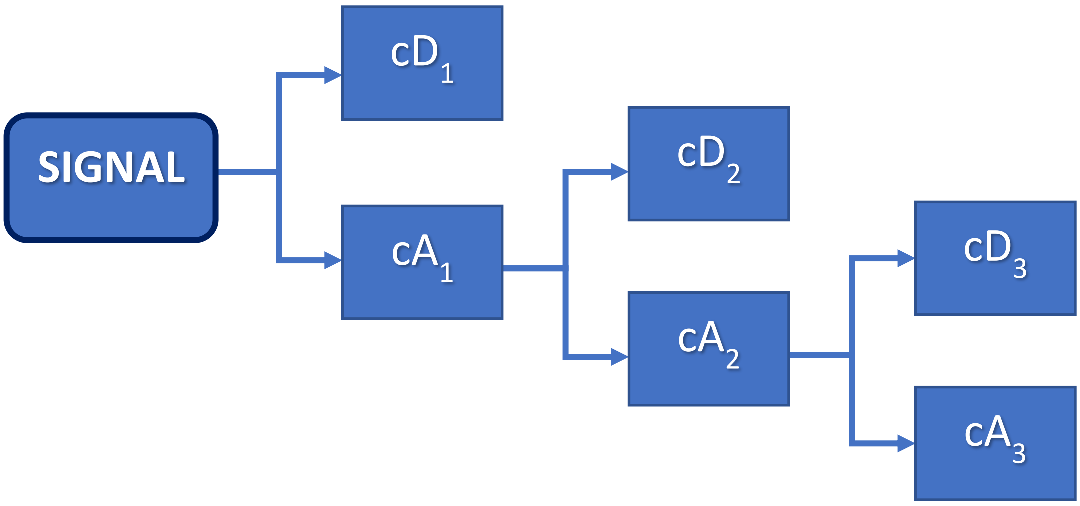


Figure 6. Wavelet decomposition tree with 3 levels.

3. Results

The experiments are employed to validate the reliability of the approach. The mechanical WT components analysed are gearbox, generator and hubs, that are usually subjected to high stress, speed, abrasion and corrosion [51,52]. These scenarios can be classified by function of the acoustic response due to the variation of the generated AE. It has been proved that the gearbox presents more faults in the WT machinery, close to 60 % of the total faults [53]. The studies about electrical machinery failures have concluded that bearings failures are about 40%, the stator system 38%, the rotor round 10% and 12% to other components of the machine [54].

For this reason, this papers analyses acoustics due to the rotational components to fault detection, reducing the high costs of the operational maintenance [55-57]. It is required a deep analysis of the samples by the signal energies to obtain the acoustics characterization. It has been employed WT Dauchebies family analysis [58]. Considering the acoustic samples signals acquired by the CMS embedded in the UAV in off, and the signals come from the engine and considering the UAV on. Figure 7 shows the patterns of the signals and the recognition between both cases.

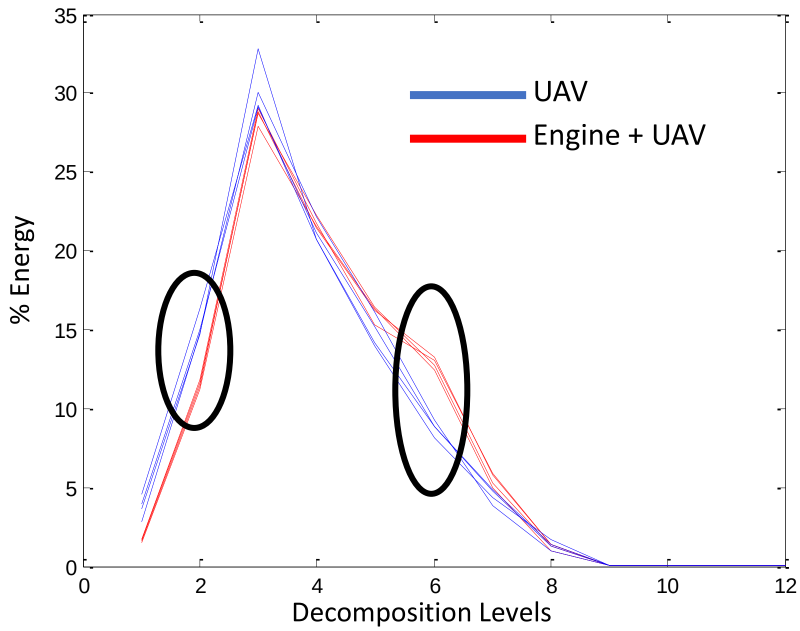


Figure 7. Comparative pattern with energy levels analisys.

It was found the different responses in some levels at the frequencies range determined by Wavelet transform, exactly in levels 2 and 6. They have a frequency range that will need a posterior analysis to compare the energy magnitude in each level [59]. This analysis allows the analysis of different scenarios to classify and identify a relation between components and the energy level pattern [60,61]. The treatment and filtering approach allows the diagnosis between the characteristic acoustic signal of UAV, engine and structure AE, being it a novelty regarding to the state of the art.

4. Conclusions

This work presents a new fault diagnosis technique for wind turbines based on acoustics analysis acquired by an acoustic monitoring system. This system is composed by an acoustic sensor embedded in an aerial vehicle manned, and a ground station receiving acoustic signal in real time that save it for a post-processing filtering. The signal processing leads to develop the acoustic characterization about possible mechanical or structural faults. A test bench has been designed to simulate a wind turbine. The energy filtering is obtained by Wavelet transforms. It is employed to identify the main wind turbine failures for a suitable maintenance management.

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