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Damage prediction for wind turbines using wireless sensor and actuator networks

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ABSTRACT

The depletion of oil and gas reserves is bringing up economic, political and social issues which encourage the adoption of renewable, green energy sources. Wind energy is a major source of renewable energy because of the maturity and competitive costs of technological solutions to exploit this type of green energy. This kind of power generation is achieved through the use of wind turbines, which convert translational kinetic energy into rotational kinetic energy. The benefits already proven of this type of renewable energy source have motivated nations worldwide to adopt policies to improve the use of wind energy in order to minimize their dependence on oil and natural gas. However, the adoption of wind turbines poses several challenges. A key challenge is properly and timely identifying structural damages which affect the structural health of the wind turbine. In this context, we propose a damage prediction system for wind turbines based on wireless sensor and actuator network. The proposed system, called Delphos, is a decentralized system where all decision-making process is performed within the network, in a collaborative way by the nodes. The purpose of Delphos is to accurately predict when the turbine will reach a damage state, thus allowing timely actions on the turbine operation to prevent accidents, reducing maintenance costs and delays in the power generation. Delphos relies on a time series forecasting model, called ARIMA, and a fuzzy system to eliminate the influence of temperature in the process of damage prediction.

1. Introduction

The depletion of oil and gas reserves is bringing up economic, political and social issues that encourage the adoption of renewable energy sources. In this context, wind energy is one of the most promising renewable energy sources because of its technological maturity and competitive costs. This kind of power generation is achieved through the use of wind turbines, which convert translational kinetic energy into rotational kinetic energy. The benefits already proven of this type of renewable energy source have motivated nations worldwide to adopt policies to improve the use of wind energy in order to minimize their dependence on oil and natural gas (Ackermann, 2005). However, the adoption of wind turbines poses several challenges. One major challenge is properly and timely identifying structural damages that affect the structural health of the wind turbine, as illustrated in Fig. 1. According to Swartz et al. Swartz et al. (2010), a wind turbine is an expensive asset that suffers, in average, three incidents per year. Therefore, a damage prediction system, capable of identifying imminent incidents and performing control actions, is clearly applicable and useful in this context. Such system fits into the Structural Health Monitoring (SHM) application domain (Sohn et al., 2004). SHM systems are able to detect, locate and predict the evolution of structural damage, avoiding accidents as, for instance, a total breakdown of the structure. In the case of wind turbines, the use of damage prediction techniques allows (i) preparing, in advance, the required resources to perform the repair procedures; (ii) minimizing unnecessary component replacements; and (iii) avoiding the wind turbine inactivity, due to the equipment breakdowns.

The vibration analysis is a well-known method that allows assessing the structure condition. In such method, the natural frequencies of the structure are analyzed in order to identify the occurrence of damage. In other words, the natural frequencies are the primary information used to detect, predict or localize damage in a structure when using vibration analysis. These natural frequencies are influenced by environmental

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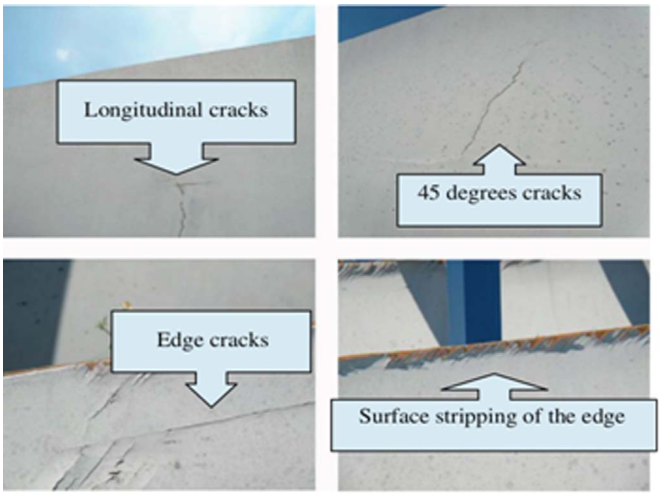

Fig. 1. Examples of structural damages in wind turbines (Chou et al., 2013).

parameters, such as temperature and humidity. Several works as (Xia et al., 2006; Moser and Moaveni, 2011) have reported that the values of natural frequencies can decrease or increase when these environmental parameters suffer variations. Therefore, the influences of such environmental parameters can be enough to mask any changes due to damages to a degree that it might not be detected (Sohn, 2006; Croxford et al., 2010). More specifically, the temperature not only modifies the material stiffness, but also alters the boundary conditions of a structure, thus hiding variations in the natural frequencies of the monitored structure (Sohn, 2006). Therefore, in order to achieve a high accuracy in the results of a vibration analysis, it is important to consider the influence of environmental parameters over the variation of the natural frequencies of vibration of the monitored structure.

Wireless sensor networks (WSN) (Akyildiz and Vuran, 2010) are a promising choice for performing structural health monitoring. Such networks are composed of smart sensors; one or more sink nodes and can also include actuators (in this case being called wireless sensor and actuator networks – WSAN). Smart sensors are small devices with (constrained) computational power, wireless communication and sensing capabilities (e.g. humidity, temperature and acceleration) (Lim, 2011). Unlike traditional sensors, these smart sensors can perform computational tasks as well as making intelligent decisions upon the collected data. A sink node is typically a more powerful device in terms of processing, storage and energy capacities, and is responsible for connecting the WSAN with external applications and/or networks (as the Internet, for instance). Actuators are devices able to act on the environment and perform control actions in response to decisions taken by the smart sensors. In the context of SHM applications, various sensors are attached to buildings/machinery/structures to acquire data containing physical or environmental states of these mechanical structures. Typical sensing units used for this type of application are accelerometers and strain sensors.

The adoption of WSAN for monitoring wind turbines brings several advantages when compared to other approaches (e.g., in situ inspections and wired sensor networks). One advantage is to achieve different viewpoints about the state of the structure with minimal physical impact, since wireless sensors are typically light devices of reduced size and they do not require power and transmission cables. Another advantage is that each device is able to measure different physical quantities (e.g., acceleration, temperature, humidity and wind speed), and such measurements can be used together to ascertain the state of the turbine with potentially higher accuracy. Moreover, WSAN nodes are able of locally processing the data collected to make decisions about the state of the structure and to implement actions to locally control the

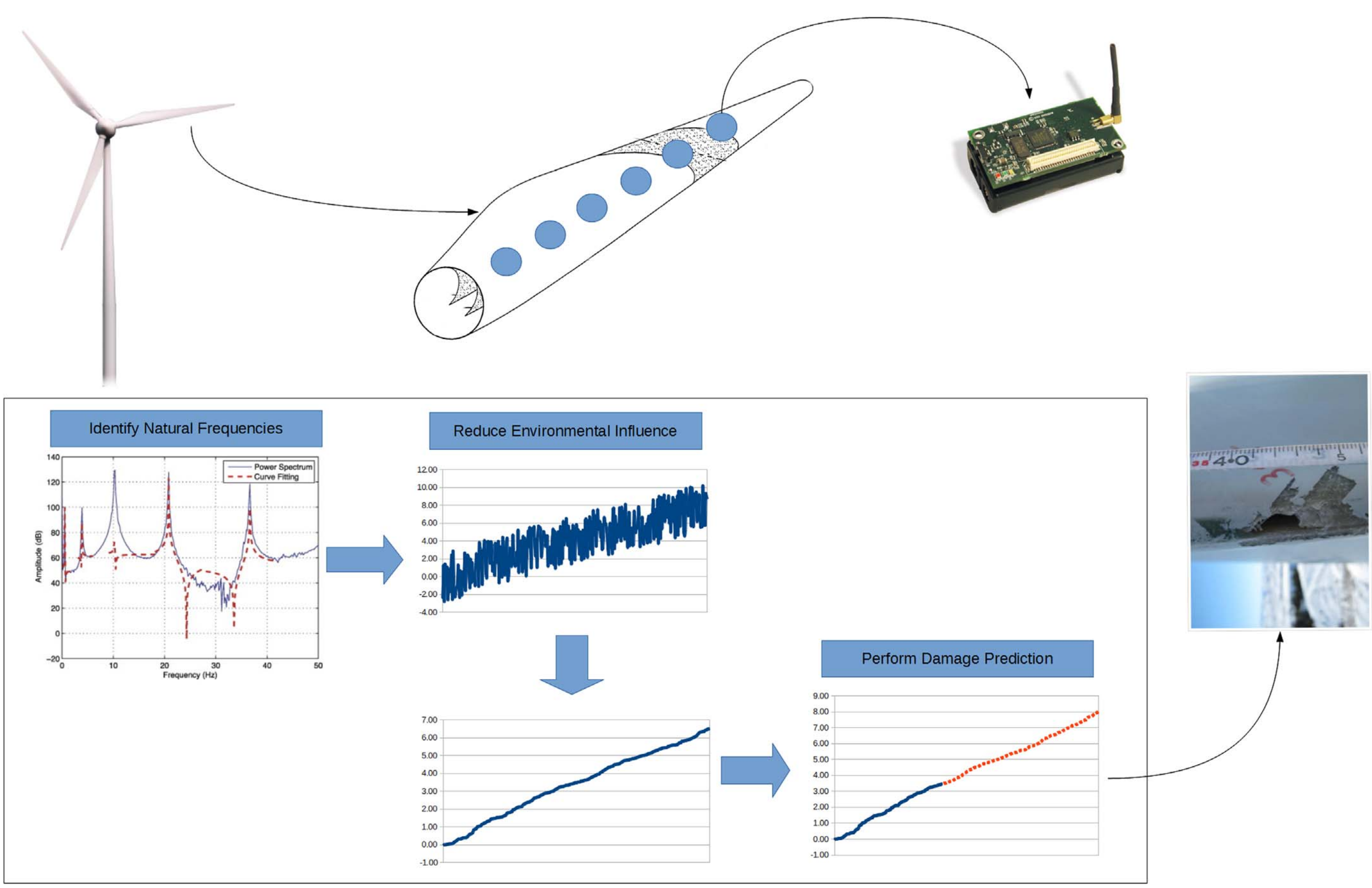

Fig. 2. Overview of Delphos Operation.