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Testing of wind turbine towers using wireless sensor network and accelerometer

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A B S T R A C T

Structural Health Monitoring (SHM) is commonly used in the health assessment of wind turbines. The system is installed during construction of the structure and consists of wired sensors connected to a central data acquisition unit via cables. In most cases, the data acquisition unit is located on the wind turbine itself. SHM is verified by comparison of results over time from wireless sensor systems. This study presents the Supervised Event Server Health Monitoring System (SESHMS) as a relatively simple, economical wireless system for use within the arena of structural health assessment.

1. Introduction

Wind turbines provide 2.3% of the world's electric power supply [1].The maintenance of a structure such as a wind turbine involves the consideration of a range of dynamic and environmental loads, including weather conditions. These loading conditions are important factors in the design stage where they occur, wind turbine collapses are not commonly attributed to design stage miscalculations, since the inconsequential errors at these initial stages are compensated for by the implementation of various safety features and the strength of the construction materials. The information gained from the analyses of wind turbine structures continues to add to the knowledge base regarding methods of structural assessment, which plays an important role in refining the technologies available [2,3].

There are various methods of structural assessment available to wind turbine engineers, and the particular method of assessment to be used in each case depends on the production methods and materials used and, which particular constituent of the structure is to be assessed. A widely used method of assessing the condition of structures is known as non-destructive testing (NDT) [4,5], although in fact some NDT techniques necessitate a minute amount of damage to a small surface area of the structure (i.e., they are partially destructive). Wireless sensors can detect the entire spectrum of vibrational frequencies that are likely to be generated in the operation of a wind turbine [1,6]. Its capacity to ascertain the existence of faults and flaws within a structure, as well as to ascertain the actual arrangement of the structure, makes NDT a popular choice for wind turbine engineers. With recent technological advances in NDT, it is now possible to remotely and accurately assess the condition of wind turbines by implementing a recording apparatus to detect real-time vibration. This remote and automatic genus of assessment and monitoring reduce the dependence on turbine engineers, which in turn translates into improved safety and enhanced data collection [7–9].

One method of NDT is the Interferometry Based Information System – Static (IBIS S) radar technique, which utilises the principle of electromagnetic interference between coherent waves to conduct and receive electromagnetic waves. IBIS S provides accurate (to one hundredth of a millimetre) data on the dynamic and static movement and vibration of structures and is commonly employed by engineers working with bridges, towers and dams. Research conducted by Ref. [10] stresses the ability of IBIS-S to monitor structural displacement in cases where vertical bending movements dominate torsional movements. It is important to increase the understanding of the dynamic behaviour of wind turbines, in particular, to the practical problems encountered in monitoring the dynamics of the wind turbine concurrent to monitoring wind forces [3].

Accelerometer sensors are low-cost and straight-forward to install. They are used within SHM and function by capturing three-way measurements of the acceleration of the structure under

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inspection, which measurements are then used to compute deflection. The types of accelerometer sensor include those with various measurement ranges and resolutions, and from which selection will be made according to the use to which they will be put [11]. This system is commonly used to assess rotating machinery, moving vehicles, aircraft and structures [12]. By assimilating the collected acceleration data, accelerometers can produce information both on the integrated response of a structure and on a structure's deflection and rotation.

This method of assessment however, has a number of drawbacks, and Ref. [13] notes that one such disadvantage relates to the large amount of power required to transmit the collected information from the main station via cellular modem. A further disadvantage relates to the limited resolution capacity of the system.

The wireless sensor network (WSN) is another non-destructive structural testing method, whose growing in popularity may mean that wired inspection mechanism become absolute. The wireless capability of the system is quick to install, low maintenance, low cost, reliable and is easy to reconfigure. Several structures have the WSN in place, as reported by Ref. [11]. As with the accelerometer sensor method of assessment, the WSN system has disadvantages, which in this case relate to its restricted range in terms of data transfer, computer compatibility and limitations of reliability for damage detection.

Significant cost reductions and enhanced functionality and flexibility of use can be gained by incorporating advanced embedded systems into existing systems. Another benefit is the wireless nature of the system and the lack of cabling. Therefore, WSN is well designed to meet the monitoring and assessment needs of wind turbine engineers, as already demonstrated by previous research [14]. A further advantage is the flexibility of the system, with its between-node communication capabilities [15].

With the latest enhancements to the WSN system, communication between nodes, as well as between nodes and the data acquisition centre, further enhances its capabilities to assess the health of structures. The greatest advantage is the absence of long-cabling, which reduces the cost of installation of the system compared to that of wired sensor technology. The next section presents the wireless sensor called Sun Spot that is utilised in the health monitoring system.

2. Monitoring strategy of wind turbine

There exist some difficulties caused by resource limitations [16] due to the large quantity of data produced during inspections of civil engineering infrastructure, including those in relation to calculating a structure's load bearing capacity. In the case of wind turbines inspections must also evaluate the quasi-static response of the structure, in terms of a structure's neutral axis locations and load shedding paths, by gauging structural performance. The recording of data of applied loads requires the interpretation of operation, and thus, must be carried out at intervals rather than continuously [17]. Fig. 1 shows the locations of wireless sensor nodes (W), and accelerometer sensors (A).

Another WSN system, known as the Oracle Sun Spot (Sun Small Programmable Object Technology), is also used within the context of assessing the health of civil engineering structures. The Sun Small Programmable Object Technology (Sun SPOT) shown in Fig. 2 is utilised as the sensor for the purpose of health monitoring of wind turbines. It is a small wireless device with battery which runs on Java embedded software without any operating system. The accelerometer is also embedded inside the Sun SPOT. To get the highest sampling rate for the data readings, the SPOT application was only used to read the accelerometer. There were no other

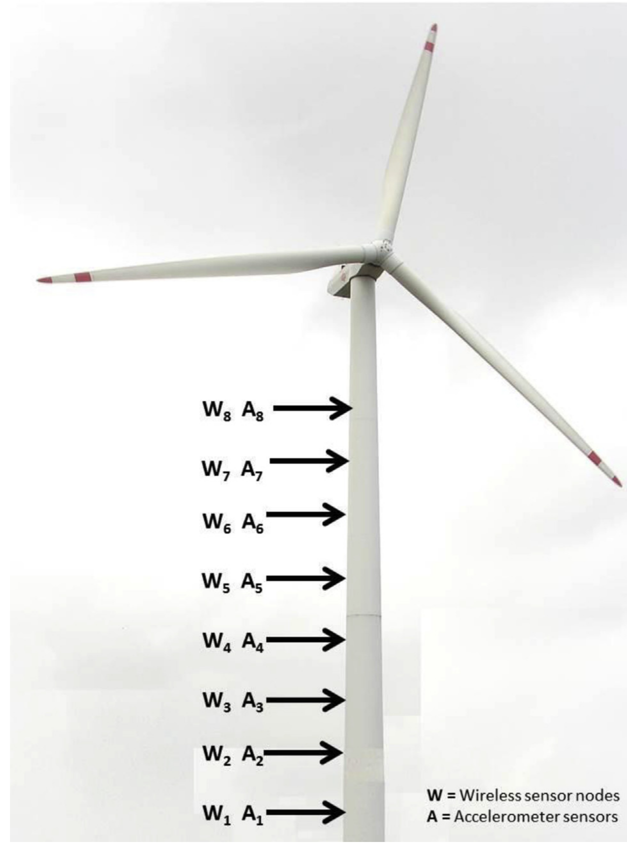

Fig. 1. Picture of the wind turbine and position of WS nodes and accelerometers.

applications ran on the SPOT. The main processor is an Atmel AT91RM9200 system on a chip, founded on an ARM (Acorn Reduced instruction set computer Machine) processor. Some 512 K of RAM and 4 MB of flash memory is available. The design of the sensor communication board is found on the IEEE 802.15.4 radio over the 2.4 GHz frequency band (Oracle Corporation, 2012). For the purposes of this work, Oracle Sun Spot wireless sensor nodes were installed onto a wind turbine.

Each SPOT has several listeners and a data monitor. Each listener receives the data readings from the neighbouring SPOTS and delivers it to the other SPOTS. Data monitor is the one which collects the data readings from the accelerometer and sends them to the neighbouring listeners. The data finally reaches the base station in a peer-to-peer communication style. Fig. 3 depicts the setup of this

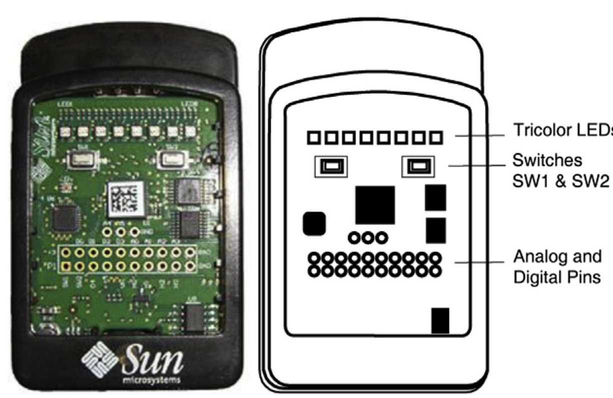

Fig. 2. Oracle Sun Spot wireless sensor.