Structural health monitoring of wind turbines observed by autonomous software components – 2nd level monitoring

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Wind energy, with an annual growth of about 30%, represents one of the fastest growing renewable energy resources (Bloomberg, 2011). According to the World Wind Energy Association, wind energy systems are currently used for power generation in 83 countries, 52 of which having increased their totally installed wind energy generation capacity in 2010 (WWEA, 2011). The worldwide capacity has reached the potential of 196,630 MW in 2010, and is estimated to exceed 600,000 MW in 2015, and 1,500,000 MW in 2020. When installing wind turbines, key considerations are their availability, reliability, and profitability. In this context, the necessity of deploying structural health monitoring (SHM) systems on wind turbines has been recognized (BMJ, 2009; MIWF, 2009). Continuous long-term monitoring of wind turbines can greatly reduce maintenance and repair costs, ensure structural safety, extend operational life, and, ultimately, improve the profitability of wind turbines.

In an ongoing research project funded by the German Research Foundation (DFG) at the Ruhr-University Bochum (Hartmann and Höffer, 2010), a decentralized real-time SHM system has been designed, implemented, and installed on a 500 kW wind turbine in Germany. The SHM system couples different information and communication technologies and provides automated data acquisition, data storage, and data interrogation functionalities (Smarsly et al., 2010). In addition, it enables remote access to the monitoring data taken from the wind turbine including flexible data visualization, data analysis and data export mechanisms.

During the operation of the SHM system, it has been observed that temporary malfunctions occurred, affecting the performance and the reliability of the system. Malfunctions of a SHM system or breakdowns of sensor components can lead to undesirable interruptions of data acquisition, degrading the data quality and system reliability considerably (Besnard, 2009; Hameed, et al., 2009; Nilsson and Bertling, 2007). The causes for such malfunctions are manifold, e.g. communication problems when using long-distance lines, temporary power outages that affect the computer systems or simply hardware problems of the data acquisition units due to extreme weather conditions. Evidently, if not detected timely the malfunctions might cause the loss of valuable monitoring data.

To overcome such drawbacks, autonomous software is implemented and integrated into the existing SHM system. Based on multi-agent technology, the autonomous software is designed to automatically detect malfunctions of the entire SHM system and its components and to immediately send out alerts for remediation (“2nd level monitoring” or “monitoring the monitoring”). Multi-agent technology, which is characterized by the cooperation and communication capabilities among the software entities (“software agents”), allows creating modular and extensible software systems. Software agents are self-contained software entities that are capable of autonomously carrying out monitoring tasks, e.g. detecting malfunctions, generating alert messages, and sending notifications.
With a certain degree of flexibility and autonomy, a software agent can decide on its own which actions are appropriate to solve given tasks, and which of the other agents need to be requested for assistance to achieve a specific goal.

As demonstrated in this paper, the agent-based autonomous software, which is in continuous operation since 2009, has reliably detected all malfunctions occurred. Once having detected a malfunction, the autonomous software has immediately notified the responsible engineers by email, whereupon the affected, i.e. malfunctioning, sensing units were remotely restarted in a timely manner. The ability to automate the (2nd level) monitoring of the SHM system and its components is important to ensure the reliability and integrity of the overall system.

This work has demonstrated that multi-agent technology can be flexibly deployed for long-term monitoring practice. Software agents, because of their modularity and extensibility, can be installed on any computer external to the SHM system. Representing another distinct advantage, various algorithms for malfunction detection and for further monitoring functions (e.g. damage detection of the wind turbine) can easily be embedded into the software agents and added into the SHM system. In short, the multi-agent approach has proven to be a promising paradigm for the implementation of autonomous software in structural health monitoring.

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References


HARTMANN, D. and HÖFFER, R. (2010). Lifespan assessment of wind energy converters through system identification (Lebensdauerabschätzung von Windenergieanlagen mit fortfalend durch Systemidentifikation aktualisierten numerischen Modellen). Research project funded by the German Research Foundation (DFG) through the research grant HA 1463/20-1. Ruhr-University Bochum, Bochum, Germany.


