An asset management framework for wind turbine blades considering reliability of monitoring system

Wen Wu

Institute for Aerospace Technology & Resilience Engineering Research Group, University of Nottingham, UK.
E-mail: wen.wu@nottingham.ac.uk

Darren Prescott, Rasa Remenyte-Prescott

Resilience Engineering Research Group, University of Nottingham, UK.
E-mail: darren.prescott@nottingham.ac.uk, r.remenyte-prescott@nottingham.ac.uk

Ali Saleh, Manuel Chiachio Ruano

Department of Structural Mechanics and Hydraulic Engineering, Andalusian Research Institute in Data Science and Computational Intelligence (DaSCI), University of Granada (UGR), Granada 18001, Spain.
E-mail: alisaleh@ugr.es, mchiachio@go.ugr.es

In this study, a wind turbine (WT) blade asset management (AM) Petri net (PN) model is presented, which incorporates risk-based maintenance and structural health monitoring (SHM). Firstly, PN modules cover the entirety of the blade AM process, describing degradation, inspection, condition monitoring, and maintenance processes. The PN model is used to predict the future blade condition for a given AM strategy and provide information to support AM decision-making for blades during WT operation. Secondly, the monitoring system reliability is considered by calculating expected sensor network information gain/loss using a Bayesian inverse approach. The effect of the monitoring system's accuracy on maintenance cost can be obtained.

Keywords: Asset management, Wind turbine blades, Petri nets, Bayesian inference, Value of Information, Reliability of monitoring system.

1. Introduction

In the context of rapid development of wind energy, developing robust asset management modelling tools to minimise wind turbine operation and maintenance costs, and assure their reliability and sustainability is of paramount importance. Due to their flexibility and applicability to dynamic process simulation, Petri net models are used to build an asset management model for wind turbine blades, providing decision makers with a realistic representation of degradation processes and complicated maintenance actions Murata (1989). In the framework proposed in this paper, the monitoring system has some variability of monitoring accuracy. As a result, the influence of the reliability of the monitoring system on the adopted asset management strategy can be analysed.

2. Proposed model

2.1. *PNs modules*

The AM framework consists of degradation, inspection, condition monitoring and maintenance modules. The different components that make up a WT may be monitored in different ways. Here, we are limited to drone inspection and ultrasonic monitoring technologies. Descriptions of the different modules are shown below:

- Blade degradation: stochastic distributions are used to simulate the degradation process of different types of damage. Distribution parameters are obtained from inspected failure history data using maximum likelihood estimation. Different damage types have their own degradation parameters.
- Drone inspection: drone inspection is one of the popular inspection techniques for WT blades. It is performed annually and is used to inspect

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defects on blade surfaces. The drone inspection processes for two types of damage are presented in the PN.

- Condition monitoring (CM): CM can provide a continuous indication of blade condition. Ultrasonic monitoring can be used to detect damage on the inner surface of blades. Sensors installed in these monitoring systems may degrade over time, affecting monitoring accuracy; this module includes this degradation process.
- Maintenance and cost: engineers grade the damage by size and then decide on a repair strategy. Five damage ratings and f corresponding repair actions are considered. Rating 1 is ”no need for immediate action”. Rating 2 is ”repair if nearby damage is to be repaired (Type I)”. Rating 3 is ”repair within 6 months (Type II)”. Rating 4 is ”repair within 3 months with monitoring ((Type III))”. Rating 5 is ”stop turbine and repair/replace (IV)”. The repair cost ratio of different repair actions is calculated based on the cost provided by Mishnaevsky Jr and Thomsen (2020). Type I is not considered for current research. The repair cost ratio of Type II, Type III and Type IV is 1:2.95:206.32.

2.2. *Considering of SHM system reliability*

The most intuitive manifestation of the reliability of the monitoring system is monitoring accuracy. However, the monitoring accuracy of a complex monitoring system is difficult to directly measure or characterise. In this study, firstly, Kullback-Liebler divergence (KL div) with Bayesian inverse Thomas and Joy (2006) is used to calculate the expected information loss due to sensor failure. Secondly, the relationship between information loss and monitoring accuracy is established. Thirdly, the monitoring accuracy is linked to the number of tokens to reflect the reliability of the monitoring system in the PNs module.

3. Results

Monte Carlo simulation is used to analyse the PNs, with the changing PN marking used to analyse the changing system state, which could be used to investigate the system lifecycle by analysing the system condition or cost for example. The convergence criterion is set according to whether the number of different repair actions reach a stable value. The monitoring accuracy decreases over time. An example set of results is shown in Fig. 1, which shows the cost of different repair actions for varying rates of degradation of the monitoring system. Level 1 indicates a perfect monitoring system. The monitoring system's failure rate increases from Level 2 to Level 4. Although the repair cost of Type II falls as the failure rate increases, the repair costs of Types III and IV, as well as the total cost, increase significantly. This shows that monitoring system degradation will bring additional cost, which can be quantified using the proposed PN model. This result emphasises the importance of the CM system reliability on system performance and lifecycle cost.

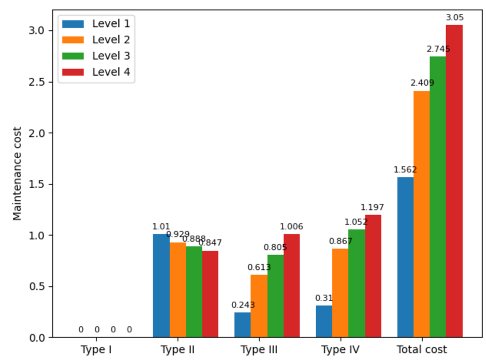

Fig. 1. The observed change in maintenance cost for decreasing levels of CM system reliability

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