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ScienceDirect

Procedia Engineering 188 (2017) 25 – 32

Procedia Engineering

www.elsevier.com/locate/procedia

6th Asia Pacific Workshop on Structural Health Monitoring, 6th APWSHM

Mixture proposal particle filtering for guided wave based fatigue crack propagation prognosis

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Abstract

For on-line prognosis of fatigue crack propagation with guided wave based structural health morning, uncertainties always exist in the process of fatigue crack propagation and crack monitoring. The particle filtering is demonstrated as a powerful tool to deal with these uncertainties. However, most literatures adopt the standard sequential importance sampling resampling algorithm, which uses the transition probability density function as the importance density and neglects current measurement information. Satisfactory results may be unable to be achieved if particles are drawn from an inferior transition probability density. This paper proposes a kind of mixture proposal distribution as the importance density that linearly combines the measurement probability density with the transition probability density. In addition, the damage index of the on-line monitored guided wave signal is adopted for quantifying the crack length. Each time a new damage index is available, the mixture proposal particle filtering is adopted to evaluate the posterior probability density estimate of the crack length, as well as the crack propagation prognosis. Simulated crack propagation data is used for validation, and the result shows that the mixture proposal particle filtering outperforms the standard particle filtering algorithm.

Peer-review under responsibility of the organizing committee of the 6th APWSHM

Keywords: Mixture proposal; particle filtering; fatigue crack; prognosis; guided wave;

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Peer-review under responsibility of the organizing committee of the 6th APWSHM
doi:10.1016/j.proeng.2017.04.453

1. Introduction

In recent years, guided wave (GW) based structural health morning (SHM) has drawn a lot of attention due to its merits including the ability of traveling a long distance, the capacity to access hidden components, as well as the sensitivity to small damages [1]. As one of the principal failure modes of most structures, fatigue crack has been seriously considered, and GW based methods are adopted for fatigue crack propagation monitoring and prognosis[2]. However, uncertainties always exist during the fatigue crack propagation and GW based crack monitoring process, such as uncertainties which in the service load, environmental parameters and material properties. These uncertainties may have great effects on reliable crack propagation monitoring and prognosis.

To deal with these uncertainties, methods using Bayes theory to combine actual monitoring data and the physical crack propagation model are receiving more and more attention. Among them, the particle filtering (PF)[3] is demonstrated as a powerful tool to handle crack propagation problems without restrictive assumptions. The underlying principle of the PF is to approximate the conditional probability density function (pdf) by a swarm of samples called 'particles' and corresponding weights. Some literatures have applied the PF to the fatigue crack propagation problem. For example, Zio et al. [4] developed a PF based method for fatigue crack propagation estimation and remaining useful life prediction. Corbetta et al.[5] proposed a self-updating stochastic dynamic state space model for the PF based fatigue crack propagation method. Leem et al. [6]adopted the PF for the fatigue crack propagation problem under variable amplitude load. Moreover, Neerukatti *et al.* [7] combined the GW based damage localization algorithm with the PF to prognose the crack length of a lug joint. Chen *et al.* [8] proposed a Lamb wave and particle filter based method for on-line fatigue crack propagation prognosis. However, most literatures adopted the PF algorithm as the standard sequential importance sampling resampling (SIR) algorithm. The SIR algorithm takes the transition probability density as the importance density, which neglects current measurement information. If the transition probability density defined by the prior crack propagation model is inferior, particles would be sampled far away from the measurement region and satisfactory results may be unable to be achieved with the SIR algorithm.

To introduce current measurement information into the importance density, this paper proposes a kind of mixture proposal distribution as the importance density, which is the linear combination of the transition probability density and the measurement probability density. Each time a new GW damage index is available, this mixture proposal PF utilizes the damage index to estimate the posterior pdf of the crack length. Based on this posterior pdf, fatigue crack propagation prognosis is performed. The proposed method is validated with the simulation data of the fatigue crack propagation using the NASGRO model.

2. Mixture proposal PF based fatigue crack prognosis method

The framework of the GW and PF based method is shown in Fig. 1. The GW based structural health monitoring method is adopted to monitor the fatigue crack. Guided waves are elastic waves that propagate in waveguide structures, which are usually excited and acquired using piezoelectric transducers (PZTs) attached on structure surfaces. An integrated instrument is employed for signal acquiring and processing. After the guided wave is excited in the structure, changed features of the received GW signal can be extracted to represent the existence and propagation of the crack.

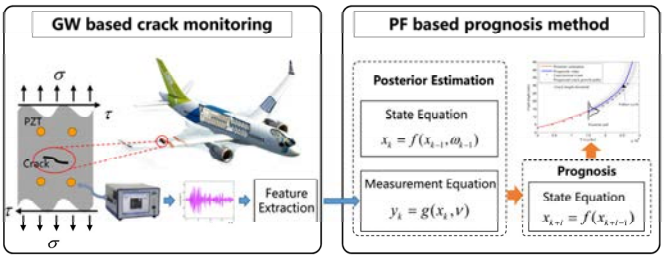

Fig. 1. The framework of the GW and PF based method.