ENHANCED REAL TIME FATIGUE CRACK MONITORING AND UPDATING IN WELDED STRUCTURAL COMPONENTS

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Abstract

Cracks emerging from geometrically discontinuous locations under cyclic environmental loadings are critical concerns for the safety of the existing structural components. The crack-based fatigue assessment is essential for the evolving digital twin of sustainable infrastructures, including bridges, ships, and offshore platforms, to optimize the lifetime cost of these structures. This study presents an enhanced neural network-bootstrap particle filtering algorithm to construct the complex relationship between the normalized strain relaxation indicators and the crack profiles based on the numerical simulation and experimental validation. The high-cycle fatigue bending test of the welded plate connections confirms the robustness of the proposed approach in estimating the fatigue crack initiation and propagation through both strain measurement and nondestructive testing data. To overcome the uncertainties caused by the limited strain measurement, crack measurement, and different non-destructive techniques, this study combines a bootstrap particle filtering approach with an interpolation method to update the crack prediction algorithm. As validated by the experimental results, the intelligent crack sizing approach demonstrates a potential solution for crack size forecasting through affordable strain gauges in the broad framework of digitally twinning the next-generation infrastructure.

1. Introduction

The capability to forecast small surface cracks has clear advantages in reducing the maintenance cost of structures and in preventing cascading failures in large-scale infrastructure. The determination of the crack initiation and propagation relies on advanced crack-measurement technologies, such as the alternating current potential drop (ACPD) approach3, 4, acoustic emission approach5, 6, ultrasonic phased array (UPA) approach7, 8, eddy current3, 9, etc. While offering engineering approaches to nondestructively size the cracks in civil engineering infrastructures, deploying these techniques is often costly and requires special technical skills. In contrast, strain gauges 10-13 provide cheap and accurate strain measurement in concrete, steel and composite structures. In addition, strain data via strain gauges or other strain sensors provide real-time fast-speed data acquisition and long-term durability for the entire life span of the structures. However, the research on crack sizing based on strain measurement is limited.

2. Results

This study adopts the Bootstrap Particle Filtering approach to update the weighted parameters in the trained regression NN model, as

$$\begin{aligned} \theta_t &= \theta_{t-1} + \mathrm{N}_1(\mu_1, \delta_1) \\ C_t &= f(\theta_t, \overline{\varepsilon}_t) + \mathrm{N}_2(\mu_2, \delta_2) \end{aligned} \tag{1}$$

where θ_t and θ_{t-1} represent the parameters (ω and ξ) in the trained NN models at time *t* and *t-1*; $\mathrm{N}_1(\mu_1, \delta_1)$ and $\mathrm{N}_2(\mu_1, \delta_2)$ denote the normal distribution with the mean value of μ_1, μ_2 and the standard deviation of δ_1, δ_2 ; $f(\theta_t, \overline{\varepsilon}_t)$ represents the previously trained NN models; C_t is the predicted crack depth based on different sets of θ_t. The predicted crack depth C_t entails an uncertainty distribution N_2. Based on the crack measurement techniques (ACPD and UPA nondestructive approaches), the uncertainty distribution tends to have a normal distribution with a mean value of zero. The candidate parameters leading to the best-predicted crack depth closest to the crack measurement data have the highest assigned weight in the BPF algorithm. Based on the BPF procedure, this study selects the uncertainty characterized by

$$\theta_t = \theta_{t-1} + \varsigma_t \tag{2a}$$

$$\varsigma_t \sim N(0, 0.1) \tag{2b}$$

The bias parameter (ς_t) assumes a normal distribution with the mean value of 0.0 and a standard deviation of 0.1. For the ANN model, this study assign the noise terms in the bias parameters (ξ).

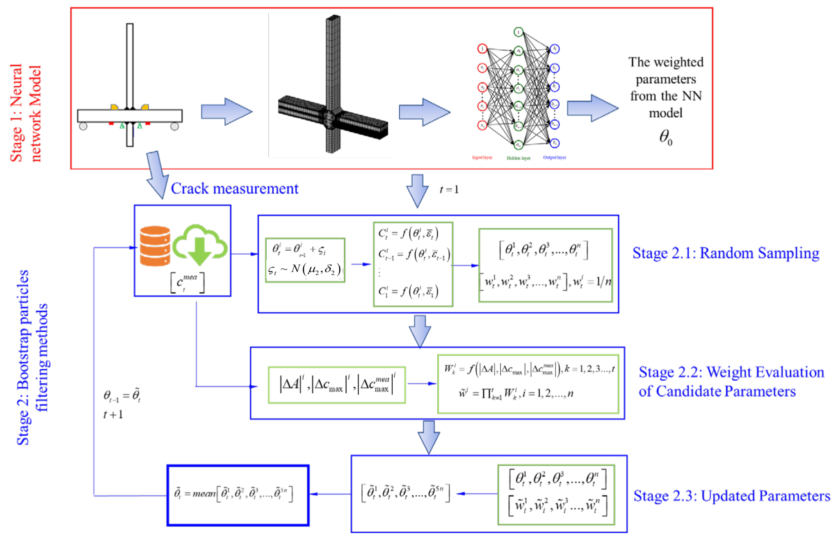

Fig. 1. The framework of the BPF algorithm to update the crack forecast.

3. Conclusions

This paper presents a neural-network bootstrap particle filtering algorithm for crack forecasting in welded plate connections.

This study develops an improved NN model to build the metamodel of the normalized strain indicators and the crack front profile. Two critical indicators: the area enveloped by the crack and the maximum depth of the crack, confirm the good performance of the trained NN model.

The effectiveness of the BPF in this study is verified based on the measured strain values and the crack measured by the ACPD. With limited strain measurement, this study adopts an interpolation method to construct the 21 strain input variables.

This study examines the performance of the NN-BPF under the limited information on the number of crack measurement points, the number of strain measurement points and different measurement techniques. Fewer crack measurement points provide a worse description of the crack front profile only based on the NN model without the updating algorithm. The number of crack measurement points does not affect these three critical indicators significantly using the proposed NN-BPF algorithm.

Acknowledgements

The authors would like to acknowledge the financial contribution provided by the ENSURE PROJECT (Grant no. A19F1a0104) under RIE2020 Advanced Manufacturing and Engineering (AME) Industry Alignment Fund-Pre-Positioning.