ABSTRACT OF PHD THESIS VIVA-VOCE

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Engineering structures, including bridges, undergo fatigue loads over time, leading to material degradation, reduced resistance, and increased risk of failure. Regular local inspections or structural health monitoring (SHM) are crucial to identify potential failures and predict fatigue life. However, challenges arise in predicting the remaining useful life (RUL) of structures, such as limited data, large structural dimensions, and estimating vehicle-induced loading. This study addresses these challenges by employing Bayesian filtering-based SHM frameworks for fatigue life prediction. Two conditions are considered: structures with visible fatigue cracks and those without visible cracks. Cost-efficient and practical detection algorithms are developed for both conditions. In structures without visible cracks, RUL estimation utilizes Miner's rule and the S-N curve of the material, using stress data obtained through SHM. For structures with visible cracks, RUL estimation focuses on crack length prognosis based on crack growth history. The updated Paris model is used to simulate fatigue crack propagation, with model parameters estimated using SHM data while accounting for uncertainties.

For the structures with visible cracks and available crack growth history, an online model-based approach is proposed to provide a probabilistic estimate for fatigue life by jointly inferring fatigue parameters from available SHM data using a Joint Extended Kalman Filter (JEKF). The effectiveness of the proposed method is validated through numerical studies on two fracture scenarios: edge and center cracks in a finite plate subjected to mechanical and thermal loading conditions. Additionally, numerical simulations are performed to study the RUL for a welded joint of a bridge based on its worst operational scenario. To validate the accuracy of the proposed approach, an experimental study is conducted on compact tension (CT) specimens, confirming its consistency in estimating fatigue model parameters and subsequently predicting the RUL.

Further, to address the practical challenges in infrastructure fatigue monitoring, wherein the structures are high-dimensional enhancing computational and instrumentation expenses, probabilistic substructure monitoring approaches powered by interacting filtering algorithms, such as particle and ensemble Kalman filters (IP-EnKF) are employed to focus on critical segments or members of the structure, thereby reducing computational complexity and improving efficiency. The efficiency of the algorithm in estimating substructural health is rigorously demonstrated through both numerical and experimental studies. Further, the unknown substructure boundary forces, required for estimating the fatigue life of the substructure, are also reconstructed through post-processing. Numerical experiments conducted on a bridge structure modelled with vehicle-structure interaction aspect validate the proposed method. Several real-life experiments are also done wherein the damage is however required to be simulated in its calibrated digital twin.

Moreover, a similar substructure algorithm is employed to estimate the RUL of a crack-free bridge structure. Numerical experiments are conducted on a reinforced concrete box girder bridge, considering vehicle-bridge interaction. A parametric analysis investigates the relationships between the FDI and factors such as surface roughness, vehicle speed, weight, and category, with the aim of identifying dominant stimuli. The results demonstrate an accurate estimation of health parameters and RUL. Additionally, a novel decomposed approach for RUL estimation is developed, enabling the mapping of traffic information to fatigue damage without the need for costly simulations. A case study is presented, focusing on a reinforced concrete box girder bridge in Kamand, Himachal Pradesh, India, to highlight the practical applicability of the approach in real-world scenarios.

Keywords: *Fatigue, structural health monitoring, remaining useful life, limited data, large structural dimensions, Bayesian filters, critical element, substructure, vehicle-bridge interaction.*