

Abstract

Modern civil/military/aviation infrastructures demand continual monitoring of their health preferably in ambient/operational conditions. Existing approaches to structural health monitoring (SHM) generally ignore system uncertainties (arising from the measurement noise and model inaccuracies) in the health estimation. In system research, control theory based fault identification under uncertainty has been prevalent over last few decades. Adoption of such control based techniques in SHM is challenging owing to the relatively large system sizes and the imperative requirement of system identification in an uncontrolled noisy environment. This study aims to develop efficient and economical control based SHM schemes in order to estimate response and parameters from the system's ambient response allowing system parameters to be Gaussian or non-Gaussian.

Modern control theory is defined in state space. In this work, for systems with observable states (fully observed system), an Eigenstructure assignment (ESA) based model updating is proposed. This method considers the system to be stochastic for identification purposes while the model updating is performed in deterministic environment. The requirement in this method that the system states be observable and the system matrices be available a priori restricts its application in large systems. An alternate way to describe the state space system dynamics uses black box input-output models with parameters as unobservable states. Commonly, an observer model, notably Kalman Filter (KF), is employed to estimate the unobserved states through stochastic data assimilation.

This study aims to mitigate certain limitations of KF in the context of SHM (e.g., slow convergence, instability in joint estimation of response-parameter, forced assumption on Gaussianity in states) by incorporating necessary modifications within the basic structure of KF. An adaptive selection strategy for noise covariance matrices is developed for fast and steady convergence of states. For online damage identification in time varying systems, dual yet separate estimation schemes for parameters and response are developed employing two concurrent Extended KFs (EKF). The possibility of divergent solution due to high dimensionality in the formulation is handled by a constrained estimation approach by forcing the solution to stay within realistic bounds. This study also developed an online reduced order system estimation scheme. Finally, the capability of KF based system estimation is extended for non-Gaussian parameters by coupling EKF with Polynomial Chaos Expansion (PCE). In this approach, the system uncertainty propagation is defined using PCE while EKF estimates the PCE coefficients of parameters as states using the output variability information.

Efficacy and robustness of the proposed algorithms are demonstrated through numerical and laboratory experiments and their noise sensitivities are explored for most cases.

Keywords

Stochastic data assimilation, Eigenstructure assignment, Control theory, Kalman filter, Extended Kalman filter, Unscented Kalman filter, Damage identification, Structural health monitoring.