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A new approach for structural health assessment using unscented Kalman filter

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ABSTRACT: A time-domain System Identification (SI)-based Structural Health Assessment (SHA) procedure using Extended Kalman Filter (EKF) concept is presented in another paper. Unscented Kalman Filter (UKF) concept is presented in this paper. Both procedures can be used to assess health of existing or newly built structures exhibiting nonlinear behavior. To apply these procedures, the structures are represented by finite elements. The locations and the rates of degradation of the elements are tracked to assess the structural health. Both EKF and UKF-based formulations are expected to assess health for nonlinear structures. Since the mathematical formulations are different, their application potentials to identify health of structures with different types of nonlinearities are expected to be different. The most important attribute of the UKF-based procedure is that it will not require the linearization of nonlinear responses as required by the EKF-based procedure. A comparative study of the two procedures is presented in this paper. It is shown that one method may be superior to the other to assess structural health in the presence of different defect scenarios and associated nonlinearities.

1 INTRODUCTION

Civil infrastructure systems are expected to deteriorate with time and accumulate damage throughout the service life due to natural aging process, lack of maintenance, exposed to natural hazards such as earthquakes, strong winds, storms, hurricane, fires etc. or man-made events such as blasts, explosions, impact, etc. If the location and seriousness of the defects are not identified and mitigated appropriately, they may cause more damage and eventually lead to catastrophic structural failure with loss of human life. Even when there is no loss of human life, economic loss could be significant if the structure is partially or completely out of service. In order to ensure the serviceability and safety of structures, structural damage detection is necessary at the earliest possible stage. However, at present we do not have well accepted inspection procedures to objectively detect locations of defect spots and severity of the defects.

The necessity for cost-effective damage detection methods suitable for large complex structure has led to the development of several multi-disciplinary structural health assessment methods and necessary technologies to implement them. The research team at the University of Arizona has been trying to develop different procedures to find the most appropriate structural health assessment (SHA) procedure considering many implementation issues. It is not possible to discuss these techniques developed by the team in this paper (Wang & Haldar 1994, 1997; Ling & Haldar 2004; Katkhuda et al. 2005; Katkhuda & Haldar 2008; Haldar & Das 2010 and Das et al. 2012). The team's most recent work in developing a SHA technique using the Extended Kalman Filter (EKF)-based concept is known as Generalized Iterative Least-Squares Extended Kalman Filter with Unknown Input (GILS-EKF-UI). It is presented in another paper in this conference.

It is known in the profession that EKF-based system identification (SI) procedures can identify mildly nonlinear structures. However, the threshold of nonlinearity when they fail to identify is not well understood. Real structures are expected to have some degree of nonlinearity depending on the level of excitation or severity of damages in them. In the process of developing the EKF and Unscented Kalman Filter (UKF)-based procedures, the authors recognized that there may be a limit of severity of nonlinearities in the response information without quantifying where EKF-based procedure will fail to identify a structure. However, it is not easy to deal with nonlinear systems. There are many sources of uncertainties to deal with in the state of the system; model uncertainties, measurement uncertainties and uncertainties due to different sources of noise acting in the system. Many techniques have been developed to identify nonlinear structural systems (Kerschen et al. 2006).

For civil engineering applications, several methods are available including the Extend Kalman Filter (EKF), the Unscented Kalman Filter (UKF), the Sequential Monte Carlo or Particle Filter (PF) Methods. The basic drawback of the Sequential Monte Carlo Methods is that it often requires a very large number of samples thus making the PF analysis computationally expensive (Chatzi & Smyth 2009). The EKF is