A new extension of unscented Kalman filter for structural health assessment with unknown input

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ABSTRACT

A time-domain nonlinear system identification (SI)-based structural health assessment (SHA) procedure, using Unscented Kalman Filter (UKF) concept, is presented in this paper. It is a two-stage procedure. It integrates an iterative least squares technique and the unscented Kalman filter concept. The authors believe that the integrated procedure significantly improves the basic UKF concept. The procedure can assess the health of a structure using only a limited number of noise-contaminated acceleration time-histories measured only at a small part of a structure and does not need information on input excitation. The structures are represented by finite element models and the location and severity of defect(s) are assessed by tracking the changes in the stiffness properties of individual elements from their expected values. With the help of examples, it is demonstrated that the method is capable of accurately identifying defect-free and defective states of structures. Small and relatively large defects are introduced at different locations in the structure and the capability of the method to detect the health of the structure is examined. It is demonstrated that the accuracy of the method is much better than the other methods currently available for the structural health assessment. It is also superior to the extended Kalman filter. Considering the accuracy and robustness, the procedure can be used as a nondestructive structural health assessment procedure.

Keywords: Unscented Kalman filter, structural heath assessment, nonlinear system identification, damage detection, unknown input

1. INTRODUCTION

During normal use or after a natural disaster like strong earthquakes, destructive hurricanes, etc., health assessment of structures is necessary to ensure their reliability and safety. The predominant inspection method generally used is visual inspection. However, visual inspections may not be conclusive. They are expected to be dependent on the expertise of the inspector. In some cases, defects may be hidden behind obstructions like fire proofing materials, false ceiling, etc. or inaccessible. Detecting damage in structural elements can also be performed using localized experimental methods such as radiographs, magnetic or ultrasonic methods. These methods focus on the detection of localized damage, requiring that approximate damage locations be known a *priori*. The necessity for cost-effective damage detection methods suitable for large complex structures has led to the development of several multi-disciplinary structural health assessment (SHA) methods. The health assessment of civil structures using dynamic response information has received significant recent attention by researchers. Many techniques also have been developed to identify nonlinear structural systems[1].

For civil engineering applications, several methods are available for SHA including the extended Kalman filter (EKF) and the unscented Kalman filter (UKF). EKF is the most widely used state estimation algorithm for nonlinear systems. The research team at the University of Arizona developed a number of EKF-based procedures and verified them theoretically[2, 3, 4, 5] and experimentally[6, 7]. The EKF algorithm, however, provides only an approximation to the optimal nonlinear estimation. The EKF applies the Kalman filter to nonlinear systems by simply linearizing all the nonlinear models so that the traditional Kalman filter equations can be applied. However, in practice, EKF suffers two well-known drawbacks. First, the derivation of the Jacobian matrices is nontrivial in most applications and often lead to significant implementation difficulties. Second, the filter can be unstable if sampling times are not sufficiently small. An alternative

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