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# Structural damage prognosis of three-dimensional large structural systems

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**ABSTRACT**

A novel procedure for the health assessment of large three-dimensional (3D) structures with several significant attractive features and improved implementation potential is proposed. Structures are represented by 3D finite elements and a substructure concept is used so that acceleration time histories can be measured only at small part(s) of the structure. Just by measuring relatively few noise-contaminated responses in the substructure, the health of the whole structure can be assessed by the system identification (SI) concept by tracking the stiffness parameter of all the elements using a significantly improved unscented Kalman filter (UKF) algorithm. Since measuring excitation time histories can be very problematic and expensive, the UKF algorithm is integrated with 3D iterative least-squares with unknown input algorithm. UKF fails to identify large structures due to convergence-related issues. The authors used short duration responses and multiple global iterations with weight factor and objective function instead of one long duration response generally used in UKF. For the preselected excitation, short duration eliminates multiple sources of excitation beyond the control of inspector. The weight factor helps accurately locate the defect spot. With informative examples, it is documented that the proposed method is superior to various other forms of Kalman filter-based algorithms.

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## 1. Introduction

After a major natural disaster like earthquake and hurricane or man-made disaster like explosion and blasting, the infrastructures are expected to suffer damages with various degrees of severity. Critical decisions must be made very promptly about their suitability for continuing use. Similar decision may also need to be made on the health of existing aged infrastructures considering deterioration for being exposed to weathering and normal use for which they were built. Vibration-based damage prognosis and health assessment (DPHA) of infrastructures has attracted considerable attention from the civil engineering community in recent years. Health assessment of them and taking remedial actions when necessary have become a necessity so that they can be used without exposing public to excessive risk or causing excessive unexpected adverse economic consequences.

Visual inspections are still most commonly used to inspect infrastructures. Since infrastructures are not expected to be defect free from the early stage of their operation and some of the defects may be inaccessible for inspection or hidden behind obstructions, more objective health assessment procedures are necessary. Many vibration-based DPHA methods for civil structures have attracted multidisciplinary attention of scholars. Changes in the modal parameters of structures have been used to assess structural health at the early stage of the development of the DPHA area. The basic idea is that the modal parameters are functions of the physical properties of the structure. Changes in the physical properties will cause changes in the modal properties as pointed out by Doebling, Farrar, Prime and Shevitz (1996) and Chang (1997). They are relatively simple since the modal information can be expressed in countable forms in terms of frequencies and mode shape vectors, but suffered from many deficiencies. They generally assess the overall structural health, i.e. whether it is defect free or defective. They cannot identify defects at the local element level in beams, columns, etc. (Al-Hussein, 2015; Farrar et al., 1994; Haldar, Ling, & Wang, 1998; Zhang, 2010). The modal parameters are not reliable if only the first few modes are measured (Raghavendrachar & Aktan, 1992) and the identification of higher order modes can be very difficult. It is to be noted that a DPHA method based on the changes in modal parameters was proposed to detect and quantify the damage at a substructure level (Jiang & Adeli, 2007).

The authors and their research team members concluded that the time domain methods (TDMs) can also be used to track the changes in the physical properties as structural damage indicator but are more efficient and robust to locate and quantify defects at the local level. To detect defects at the local element level, it is desirable if a structure can be represented using the finite element (FE)-based algorithm. In addition, due to recent advances in sensors, computers, and data acquisition systems, TDMs are becoming more attractive from the implementation point of view. Using TDM as a major building block, several system identification (SI)-based concepts have been pursued to track changes in the

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