Chapter 13

Structural Condition Monitoring with the Use of the Derivative-Free Nonlinear Kalman Filter

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ABSTRACT

The chapter proposes structural condition monitoring for buildings and mechanical structures using a new nonlinear filtering method under the name Derivative-Free Nonlinear Kalman Filtering. The filter makes use of exact linearization of the structure's dynamical model in accordance to differential flatness theory and of an inverse transformation that enables one to obtain estimates for the state vector elements of the initial model. The response of the structure is compared to the response generated by the filter under the assumption of a damage-free model. Moreover, the filter provides estimates of the state vector elements of the structure, which cannot be directly measured, while it can also give estimates of unknown excitation inputs. By comparing the two signals, residuals sequences are generated. The statistical processing of the residuals provides an indication about the existence of parametric changes (damages) in the structure that otherwise could not have been detected.

1. INTRODUCTION

Damages in civil or mechanical structures cannot always be detected by visual inspection. Therefore, it is necessary to develop elaborated methods for structural health monitoring that will be capable of diagnosing the existence of parametric changes and failures (Wu, Zhou, & Yang, 2006), (Campillo & Mevel., 2005). Previous results in the area of Kalman Filter-based structural condition monitoring can be found in (Lei, Wu.& Li, 2012), (Lei, Jiang & Xu, 2012), (Zhou, 2008), (Katkhuda & Hadlar, 2008). In the present chapter, the development of a new structural health monitoring approach is proposed making use of nonlinear Kalman Filtering and of statistical signal processing.

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The multi-DOF building or mechanical structure is modeled as a set of coupled nonlinear oscillators that can be subjected to external excitation. First, it is shown that the dynamic model of the monitored structure is differentially flat and admits static feedback linearization (Sira-Ramirez and Agrawal, 2004), (Rigatos, 2011), (Fliess & Mounier, 1999), (Rouchon, 2005), (Bououden, Boutat, Zheng, Barbot, & Kratz, 2011). It is also shown that the dynamic model can be written in the linear Brunovsky canonical form for which a state feedback controller can be easily designed, thus also enabling active control of the structure. Next, to estimate the building's or mechanical structure's motion characteristics from indirect measurements a new nonlinear filtering method under the name Derivative-free nonlinear Kalman Filtering is introduced (Rigatos, 2012a), (Rigatos, 2012b), (Rigatos & Tzafestas, 2007). The considered filter makes use of the aforementioned exact linearization transformation of the structure's dynamical model, in accordance to differential flatness theory, and of an inverse transformation that enables to obtain estimates for the state vector elements of the initial model. The filter provides estimates of the state vector elements of the structure which cannot be directly measured. Moreover, by redesigning the Derivative-free nonlinear Kalman Filter as a disturbance observer, it is shown that it is possible to estimate unknown external inputs applied to the structure.

The response of the structure is recorded through suitable sensors (in the form of a wireless sensors network deployed at specific measurement points) and is compared against the response generated by nonlinear Kalman Filtering under the assumption of a damage-free model (to improve accuracy it is possible to apply a sensor fusion-based implementation of the Kalman Filter). By comparing the two signals, residuals sequences are generated. The processing of the residuals with the use of statistical decision making criteria provides an indication about the existence of parametric changes (damages) in the structure, which otherwise could not have been detected (Basseville & Nikiforov, 1993), (Zhang, Basseville & Benveniste, 1998), (Rigatos. & Zhang, 2009). Thus, by applying fault detection tests based

Figure 1. Diagram of the n-storey building with elasticity and dissipation elements