Mechanical Systems and Signal Processing 25 (2011) 2938–2947

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

A natural observer for optimal state estimation in second order linear structural systems

Eric M. Hernandez *

Department of Civil and Environmental Engineering, College of Engineering and Mathematical Sciences, University of Vermont, United States

ARTICLE INFO

Article history:
Received 28 April 2010
Received in revised form
6 April 2011
Accepted 5 June 2011
Available online 2 July 2011

Keywords:
Kalman filter
Observers
Estimation
Finite element models
Structural dynamics

ABSTRACT

A state observer for mechanical and structural systems is derived in the context of the second order differential equation of motion of linear structural systems. The proposed observer possesses similar characteristics to the Kalman filter in the sense that it minimizes the trace of the state error covariance matrix within the predefined structure of the feedback gain. The main contribution of the paper consists of the fact that the proposed observer can be implemented directly as a modified linear finite element model of the system, subject to collocated corrective forces proportional to the measured response. The proposed algorithm is effectively illustrated in two different types of second order systems; a close-coupled spring–mass–damper multi-degree of freedom system and a plate subject to transverse vibrations.

1. Introduction

Observers constitute a powerful tool to maximize the amount of information that can be extracted from measured vibration signals in mechanical and structural systems. Specifically, observers allow for the estimation of unmeasured response quantities in a system, given sparsely measured time history response and a model of the system. The vast majority of the existing body of theory regarding observers [7,8,14,16,17,21] have been developed almost entirely in the context of first order state-space formulation.

First order state-space formulation is the most general and unified approach to treat estimation problems in diverse engineering and non-engineering applications. In practice, however, to implement standard first order observers in structural and mechanical systems modeled through finite element (FE) models significant pre- and post-processing is necessary. The system matrices need to be assembled from the FE model, the observer gain matrix computed and a simultaneous first order differential equation solver needs to be implemented separately. As has been noted by previous authors [9,13], it makes the implementation in large scale FE models, typical of large space and civil structures, cumbersome, computationally inefficient and sometimes prohibitive for real-time applications, such as state feedback control [20].

In addition to the implementational issues, theoretical issues have also been raised by some authors related to the consistency of first order observers when applied to second order symmetric systems; especially loss of symmetry, definiteness and the fact that first order observers might yield an estimate of the state that does not correspond to the physical state sought. This was clearly demonstrated by Balas [2]. He concluded that unless certain restrictions are placed on the feedback gain matrix, estimates of the velocity generated by first order observers do not correspond to derivatives

* Tel.: +1 802 656 3334.
E-mail address: eric.hernandez@uvm.edu

0888-3270/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ymssp.2011.06.003