Identification of Linear and Nonlinear Systems using Signal Processing Techniques

G. Kerschen, F. Poncelet, J.C. Golinval
Aerospace and Mechanical Engineering Department, University of Liège, Belgium
g.kerschen,fponcelet,jc.golinval@ulg.ac.be

A.F. Vakakis
Division of Mechanics, National Technical University of Athens, Greece
vakakis@central.ntua.gr

L.A. Bergman
Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, USA
lbergman@uiuc.edu

Identification of linear and nonlinear mechanical systems is achieved using two signal processing techniques, namely the second-order blind identification (SOBI) method and the Hilbert-Huang transform (HHT). Although unrelated, these techniques share the common feature of decomposing a measured signal in terms of elemental components.

1 Blind Source Separation

Recovering unobserved source signals from their observed mixtures is a generic problem in many domains and is referred to as blind source separation (BSS) in the literature [1]. One well-known example is the cocktail-party problem, the objective of which is to retrieve the speech signals emitted by several persons speaking simultaneously in a room using only the signals recorded by a set of microphones located in the room. BSS techniques proved useful for the analysis of multivariate data sets such as financial time series, astrophysical data sets, electrical and hemodynamic recordings from the human brain, and digitized natural images. In this presentation, we show that the SOBI method, which belongs to the class of BSS techniques, may be useful in linear structural dynamics. Specifically, for free and random vibrations, a one-to-one relationship between the vibration modes and the mixing matrix computed through SOBI is demonstrated using the concept of virtual source. Based on this theoretical link, a new method for the extraction of the mode shapes, natural frequencies and damping ratios directly from the measured system response (i.e., operational modal analysis) is proposed. The method is then validated using numerical and experimental applications. In particular, modal analysis of a compressor blade of a turbojet engine is carried out [2, 3].

2 Hilbert-Huang Transform

The HHT has been shown to be effective for characterizing a wide range of nonstationary signals in terms of elemental components through what has been called the empirical mode decomposition (EMD) [4]. It has been utilized extensively despite the absence of a serious analytical foundation, as it provides a concise basis for the analysis of strongly nonlinear systems. In this presentation, we attempt to provide the missing theoretical link, showing the relationship between the EMD and the slow-flow equations of a system. The slow-flow reduced-order model is established by performing a partition between slow and fast dynamics using the complexification-averaging technique in order to derive a dynamical system described by slowly-varying amplitudes and phases. These slow-flow variables can also be extracted directly from the experimental measurements using the Hilbert transform coupled with the EMD. The comparison between the experimental and analytical results forms the basis of a novel nonlinear system identification method, termed the slow-flow model identification (SFMI) method. Through application examples, we demonstrate that the proposed method is effective for characterization and parameter estimation of nonlinear systems [5].

References

[1] P. Comon, Independent component analysis: a new concept ?, *Signal processing* 36 (1994), 287-314.

[2] G. Kerschen, F. Poncelet, J.C. Golinval, Physical interpretation of ind. component analysis in structural dynamics, *Mechanical Systems and Signal Processing*, in press.

[3] F. Poncelet, G. Kerschen, J.C. Golinval, D. Verhelst, Output-only modal analysis using blind source separation, *Mechanical Systems and Signal Processing*, in press.

[4] N.E. Huang, M.L. Wu, W.D. Qu, S.R. Long, S.S.P. Shen, *Hilbert-Huang Transform and Its Applications*, World Scientific, Singapore, 2003.

[5] G. Kerschen, A.F. Vakakis, Y.S. Lee, D.M. McFarland, L.A. Bergman, Toward a fundamental understanding of the Hilbert-Huang transform in nonlinear dynamics, *Journal of Vibration and Control*, in press.