Mechanical Systems and Signal Processing 25 (2011) 575–590

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Wavelet spectrum analysis approach to model validation of dynamic systems

Xiaomo Jiang [a,*], Sankaran Mahadevan [b]

[a] 4200 Wildwood Parkway, 42-3-12C-6, GE Energy, Atlanta, GA 30339, USA
[b] Department of Civil and Environmental Engineering, Box 1831-B, Vanderbilt University, Nashville, TN 37235, USA

ARTICLE INFO

Article history:
Received 19 October 2009
Received in revised form
8 April 2010
Accepted 17 May 2010
Available online 1 June 2010

Keywords:
Wavelet coherence analysis
Wavelet cross-spectra
Model validation
Hypothesis test
Dynamic system

ABSTRACT

Feature-based validation techniques for dynamic system models could be unreliable for nonlinear, stochastic, and transient dynamic behavior, where the time series is usually non-stationary. This paper presents a wavelet spectral analysis approach to validate a computational model for a dynamic system. Continuous wavelet transform is performed on the time series data for both model prediction and experimental observation using a Morlet wavelet function. The wavelet cross-spectrum is calculated for the two sets of data to construct a time–frequency phase difference map. The Box-plot, an exploratory data analysis technique, is applied to interpret the phase difference for validation purposes. In addition, wavelet time–frequency coherence is calculated using the locally and globally smoothed wavelet power spectra of the two data sets. Significance tests are performed to quantitatively verify whether the wavelet time-varying coherence is significant at a specific time and frequency point, considering uncertainties in both predicted and observed time series data. The proposed wavelet spectrum analysis approach is illustrated with a dynamics validation challenge problem developed at the Sandia National Laboratories. A comparison study is conducted to demonstrate the advantages of the proposed methodologies over classical frequency-independent cross-correlation analysis and time-independent cross-coherence analysis for the validation of dynamic systems.

© 2010 Elsevier Ltd. All rights reserved.

1. Motivation

Systematic model validation needs quantitative methods to compare model prediction with experimental observations, both under uncertainty, and to quantify the confidence in model predictive capability. During the past decade, fundamental concepts and methodologies for the validation of large-scale computational models and numerical simulations have been studied by organizations such as the United States Department of Defense [1], American Institute of Aeronautics and Astronautics [2], Advanced Simulation and Computing (ASC) program of the United Sates Department of Energy [3], and American Society of Mechanical Engineers (ASME PTC#60 [4]). Detailed discussion of model verification and validation concepts and methods can also be found in the literature (see e.g., [5–24]).

Within the context of model validation, decisions need to be made to accept or reject the model with certain preferences, based upon available information and prior knowledge. In order to minimize the decision error and enhance the validation accuracy, all available data and information as well as the corresponding uncertainty should be taken into

* Corresponding author. Tel.: +1 678 844 3690; fax: +1 678 844 6748.
E-mail addresses: xiaomo.jiang@ge.com, jiang.xiaomo@gmail.com (X. Jiang).

0888-3270/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ymssp.2010.05.012