Bayesian Identification of Engineering Dynamic Systems Based on Vector Autoregressive Model

Jia-Hua Yang [1]

[1] *College of Civil Engineering and Architecture, Guangxi University*
Scientific Research Center of Engineering Mechanics, Guangxi University
Email: javayang@gxu.edu.cn

Abstract

Due to fast development of sensing technology, a huge amount of data is available every second. This offers a perfect opportunity to improve mathematical modeling based on measured data, but also poses a challenge at the same time, because extracting useful information from data for complex engineering dynamic systems is time consuming. This paper presents a newly developed Bayesian system identification method based on vector autoregressive (VAR) model [1],[2]. A dynamic system is first modeled by a VAR model. Because the information contained in data is always incomplete and there are uncertainties, the identification of the VAR model is formulated as a Bayesian learning problem where the plausible models and the associated uncertainties are learned by identifying the probability density function (PDF) of the VAR model parameters. Following Bayes' theorem, the posterior PDF of the VAR parameter matrices is derived. The most probable values and posterior covariance matrices of the uncertain VAR parameter matrices are then derived in close form for efficient calculation. It is shown that a VAR model is equivalent to the dynamic model of a vibrating structure, so natural frequencies, damping ratios and mode shapes can be obtained from a VAR model by solving the eigenvalue problem of a matrix constructed by VAR parameter matrices. Based on the first-order Taylor's series expansion, the posterior uncertainties of VAR parameters are propagated to modal parameters. Analytical formulas of the posterior uncertainties of modal parameters are derived for efficient calculation in practical applications.

This paper also develops a method for Selecting the most probable model class for a VAR model conditional on measured data, when it is used for system identification. One challenge of using a VAR model for system identification is to select a suitable order, which can be viewed as selecting a suitable model class for a VAR model. Following Bayes' theorem, the model class selection problem is rigorously solved by calculating the evidence of each competing model class and selecting the most probable model class with the largest evidence. The new formulation for evaluating the extremely high-dimensional integral involved in calculating the evidence of a model class is derived analytically based on the Laplace's method of asymptotic expansion. The most probable modal parameters of a structure can be obtained using the identified most probable VAR model class. The proposed method is validated using an experimental case.

The proposed method is applied for a tall office building and a factory building. The results show great potential of this method.

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References

[1] **J.H. Yang, H.F. Lam.** (2019). *An innovative Bayesian system identification method using autoregressive model*. Mechanical Systems and Signal Processing. 1, 133, 106289.
[2] **J.H. Yang, Q.Z. Kong, H.J. Liu., H.Y. Peng** (2021). *Efficient Bayesian model class selection of vector autoregressive models for system identification*. Structural Control and Health Monitoring. e2780