2021 DSTA dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Implementation of state observer-based conditioned reverse path method to the identification of a nonlinear system

UMAARAN GOGILAN[1*], ATTA OVEISI[2], TAMARA NESTOROVIĆ[3]

1. Mechanics of Adaptive Systems, Institute of Computational Engineering, Ruhr University Bochum, Germany
2. Mechanics of Adaptive Systems, Institute of Computational Engineering, Ruhr University Bochum, Germany [ORCID: 0000-0002-6507-9448]
3. Mechanics of Adaptive Systems, Institute of Computational Engineering, Ruhr University Bochum, Germany [ORCID: 0000-0003-0316-2171]

* Presenting Author

Abstract: The conditioned reverse path (CRP) method is a method for the frequency response estimation nonlinear systems to extract the properties of an underlying linear model (ULM). This method recalculates the nonlinearity coefficients by using spectral techniques and recovers the frequency response function (FRF) of the ULM [1]. However, applying the CRP method is challenging if the system states are not accessible for measurement. For this reason, a state estimation process is integrated with the CRP method resulting into observer-based conditioned reverse path (OBCRP) method. The state estimation process based on the Kalman filter technique is employed in this work to reconstruct the system states. Applying spectral techniques with the CRP/OBCRP method, the resulting nonlinear spectra consist of real and imaginary parts. Since imaginary parts have no physical meaning, the nonlinear coefficients based only on the real parts of the spectra are thus distorted. To minimize the distortion of nonlinear coefficients the OBCRP method is extended by a novel weighting scheme. In the present study, this method is exemplarily applied in a simulation. The OBCRP method successfully recovered the FRF of the ULM and accurately parameterized the nonlinearities of the system.

Keywords: nonlinear system identification, Kalman filter, reverse path method

1. Introduction

Analysis of dynamic structures may be performed in frequency domain using the frequency response estimation as a basis. With growing requirements on dynamical systems analysis, influences of the nonlinearity should be taken into account. The CRP method parameterizes the nonlinearities of the system and recovers the FRF of the nonlinear model. However, the application of this method requires the measurement of all states at the same time. In large-scale structures, the frequency range of operation may encompass several hundreds of states, so that the measurement of all system states may become impossible due to the deficiency of appropriate sensors. The state estimation based on the Kalman filter technique provides the access to all required system states resulting in turn into reduction of the required number of sensors. This combination of the CRP method and the system states estimation is refered to as the observer-based conditioned reverse path method (OBCRP). By using the CRP method, some information of the nonlinear spectra is lost due to the presence of imaginary parts, and the resulting nonlinear coefficients are distorted. A novel frequency-dependent weighting scheme is applied to the nonlinear coefficients, which leads to better extraction of the FRF of the nonlinear system.

Address: Ruhr-Universität Bochum, AG Mechanik adaptiver Systeme, Gebäude ICFW 03-725, Fach 2, Universitätsstr. 150, D-44801 Bochum
E-mail: Umaaran.gogilan@ruhr-uni-bochum.de, atta.oveisi@gmail.com, tamara.netsorovic@ruhr-uni-bochum.de

2. Results and Discussion

The performance of the OBCRP method is investigated in the simulation of a nonlinear mass-spring-damper system with five degrees of freedom, shown in Fig. 1. The parameters for mass, stiffness and damping are given, and the observability and controllability conditions are fulfilled. The system possesses nonlinear stiffnesses depicted as spring elements with an arrow. Mass m_1 is excited by an external multisine force f_1. At the two masses m_1 and m_5, the velocity and acceleration measurements are carried out, while the state estimation process of the OBCRP method is applied to estimate the displacements x_2, x_3 and x_4.

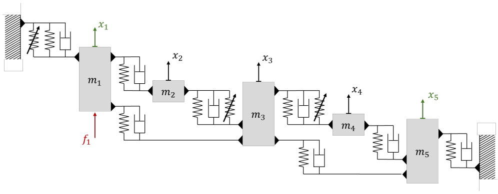

Fig. 1. Mass-spring-damper system with five degrees of freedom

Based on the estimated states, the frequency-dependent spectra for the estimation of the nonlinear coefficients are calculated by the application of the OBCRP method. To present the estimation quality of the proposed novel weighting scheme, the estimation errors of the weighted and unweighted nonlinear coefficients are compared in Table 1. Finally, the FRF between f_1 and x_1 obtained by the OBCRP method is compared to the FRF based on the classical H_1 method, as shown in Fig. 2. The FRF based on the OBCRP method is significantly less distorted, and the conditioned spectral analysis of the OBCRP method recovers the ULM correctly.

Table 1. Estimation error of the weighted and unweighted nonlinear coefficients

Coefficients	True value	Estimation error (%)	
		Unweighted	Weighted
α_1	-500kN/m³	23.38	4.02
α_2	100kN/m³	48.1	13.58
β_1	3 MN/m³	22.32	1.09
β_2	-0,2 MN/m³	407.22	0.79
γ_1	4 MN/m³	18.72	27.4

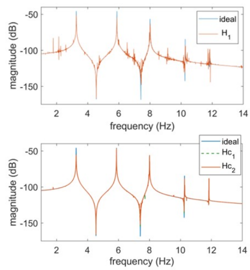

Fig. 2. Unconditioned and conditioned FRFs

3. Concluding Remarks

The OBCRP method has been successfully applied to a nonlinear lumped-mass model problem in a simulation. Based on the state estimation and input design, the nonlinear coefficients are calculated using the spectral estimation techniques of the OBCRP method. To reduce the distortion due to imaginary parts, the nonlinear coefficients are subjected to a novel weighting scheme. The FRF of the ULM is then successfully recovered by the OBCRP method, It furthermore accurately parameterizes the nonlinearities within the model. Validation of the method on an experimental setup is in prospect.

References

[1] RICHARDS C. M., SINGH R.: Identification of multi-degree-freedom non-linear systems under random excitations by the 'Reverse Path' spectral method. *J. Sound Vib.1989*, pp. 673–708.