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Prediction of unmeasured mode shapes and structural damage detection using least squares support vector machine

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Abstract. In this paper, a novel and effective damage diagnosis algorithm is proposed to detect and estimate damage using two stages least squares support vector machine (LS-SVM) and limited number of attached sensors on structures. In the first stage, LS-SVM1 is used to predict the unmeasured mode shapes data based on limited measured modal data and in the second stage, LS-SVM2 is used to predicting the damage location and severity using the complete modal data from the first-stage LS-SVM1. The presented methods are applied to a three story irregular frame and cantilever plate. To investigate the noise effects and modeling errors, two uncertainty levels have been considered. Moreover, the performance of the proposed methods has been verified through using experimental modal data of a mass-stiffness system. The obtained damage identification results show the suitable performance of the proposed damage identification method for structures in spite of different uncertainty levels.

Keywords: unmeasured mode shapes; two stages method; LS-SVM; sparse sensors; uncertainty levels

1. Introduction

Damage detection and estimation in engineering structures during their service life has received increasing attention in the last few decades. One of the many nondestructive evaluation methods is based on the change of vibration parameters with a change in the structural properties (Carden and Fanning 2004, Fan and Qiao 2011).

As the number of sensors used to measure modal data is normally limited and usually are less than the number of DOFs in the finite element model, either the model reduction method should be used to match with incomplete measured mode shapes or the measured mode shapes must be expanded to the dimension of the analytical mode shapes (Kourehli *et al.* 2012). Therefore, it is essential to develop algorithms for damage diagnosis using modal data obtained by a limited number of sensors, which means using an incomplete set of modal data (Hosseinzadeh *et al*. 2014). Some researchers used the mode shape expansion methods for structural damage detection (Chen and Bicanic 2000, Au *et al*. 2003) in which others used the model reduction methods (Kourehli *et al*. 2013, Li *et al*. 2008, Kourehli 2015, Rasouli *et al*. 2014). Also, Goh *et al.* (2013) presented an approach combines a two-stage ANN model and statistical method to detect damage based on the limited number of sensors with consideration of uncertainties.

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Chen, H.P. and Bicanic, N. (2000), "Assessment of damage in continuum structures based on incomplete modal information", *Comput. Struct.*, **74**(5), 559-570.
Duffey, T.A., Doebling, S.W., Farrar, C.R., Baker, W.E. and Rhee, W.H. (2001), "Vibration-based damage identification in structures exhibiting axial and torsional response", *J. Vib. Acoust.*, **123(**1), 84-92.
Fan, W. and Qiao, P. (2011), "Vibration based damage identification methods: a review and comparative study", *Struct. Health Monit.*, **10**, 83-111.
Goh, L.D., Bakhary, N., Rahman, A.A. and Ahmad, B.H. (2013), "Application of neural network for prediction of unmeasured mode shape in damage detection", *Adv. Struct. Eng.*, **16**, 99-113.
Hosseinzadeh, A.Z., Bagheri, A., Ghodrati Amiri, G. and Koo, K.Y. (2014), "A flexibility-based method via the iterated improved reduction system and the cuckoo optimization algorithm for damage quantification with limited sensors", *Smart Mater. Struct.*, **23**(4), 045019.
Kourehli, S.S. (2016), "Structural damage diagnosis using incomplete static responses and LS-SVM", *Inverse Problems in science and engineering*, DOI: 10.1080/17415977.2016.1169277.
Kourehli, S.S. (2016), "LS-SVM regression for structural damage diagnosis using the iterated improved reduction system", *Int. J. Str. Stab. Dyn.*, **16**(6), 1550018. DOI: 10.1142/S0219455415500182.
Kourehli, S.S. (2015), "Damage assessment in structures using incomplete modal data and artificial neural network", *Int. J. Str. Stab. Dyn.*, **15**(6), 1450087. DOI: 10.1142/S0219455414500874.
Kourehli, S.S., Ghodrati Amiri, G., Ghafory-Ashtiany, M. and Bagheri, A. (2012), "Structural damage detection based on incomplete modal data using pattern search algorithm", *J. Vib. Control*, **19**, 821-833.
Kourehli, S.S., Bagheri, A., Ghodrati Amiri, G. and Ghafory-Ashtiany, M. (2013), "Structural damage detection using incomplete modal data and incomplete static response", *J. Civil Eng.-KSCE*, **17**(1), 216-223.
Li, H., Wang, J. and Hu, S.L.J. (2008), "Using incomplete modal data for damage detection in offshore jacket structures", *Ocean Eng.*, **35**(17-18), 1793-1799.
MATLAB (2016), Matlab User Manual, Mathwork Inc. Lowell, MA, U.S.A.
Rasouli, A., Ghodrati Amiri, G., Kheyroddin, A., Ghafory-Ashtiany, M. and Kourehli, S.S. (2014), "A new method for damage prognosis based on incomplete modal data via an evolutionary algorithm", *Eur. J. Environ. Civil Eng.*, **18**(3), 253-270.
Shyamala, P., Mondal, S. and Chakraborty, S. (2018), "Numerical and experimental investigation for damage detection in FRP composite plates using support vector machine algorithm", *Struct. Monit. Maint.*, **5**(2), 243-260.
Suykens, J.A.K. and Vandewalle, J. (1999), "Least squares support vector machine classifiers", *Neural Process. Lett.*, **9**(3), 293-300.
Tang, H.S., Xue, S.T., Chen, R. and Sato, T. (2006), "Online weighted LS-SVM for hysteretic structural system identification", *Eng. Struct.*, **28**(12), 1728-1735.
Xie, J. (2010), "Improved least square support vector machine for structural damage detection", *Proceedings of the 2nd International Conference on Computer Engineering and Technology*, 6:V6-237-V6-240.
Xie, J.H. (2010), "Structural damage detection based on fuzzy LS-SVM integrated quantum genetic algorithm", *Appl. Mech. Mater.*, **20-23**, 1365-1371.

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