Hysteretic model identification for frictional connections using a physics-informed data-driven approach

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Abstract

Experimental data exhibiting various types of hysteretic behaviour can be identified using a variety of data-driven strategies which are either not physics-informed or require running costly numerical simulations. This work presents a new data-driven formulation for the identification of localised nonlinearities exhibiting history-dependent or hysteretic behaviour in mechanical assemblies that allows discovering the nonlinear models directly from measured data without running numerical simulations.

Introduction

Frictional damping in mechanical joints [1] can be characterised by firstly choosing an appropriate interfacial representation such as "patched" whole-joint approach, and then representing the normal and tangential behaviour of the interface through an appropriate contact model. A phenomenological model is normally used as appropriate contact model, based on experimental observations, and relating the output tangential force in the frictional interface with the relative tangential displacements $\boldsymbol{q}$ and velocities $\dot{\boldsymbol{q}}$, and potentially other (hysteretic) state variables $\boldsymbol{z}$. Consider a multi-degree-of-freedom system in the physical domain as follow,

$$\boldsymbol{M}\ddot{\boldsymbol{q}}(t) + \boldsymbol{C}\dot{\boldsymbol{q}}(t) + \boldsymbol{K}\boldsymbol{q}(t) + \sum_{i=1}^{r} \boldsymbol{\rho}_i^T f_{nli}(\boldsymbol{\rho}_i\boldsymbol{q}(t), \boldsymbol{\rho}_i\dot{\boldsymbol{q}}(t), \boldsymbol{\rho}_i\boldsymbol{z}(t)) = \boldsymbol{F}(t) \tag{1}$$

where M, C and K are the $m\times m$ matrices of mass, damping and stiffness, $\boldsymbol{F}$ is the force vector, $\boldsymbol{q}$, $\dot{\boldsymbol{q}}$, and $\ddot{\boldsymbol{q}}$ are, accordingly, the displacement, velocity, and displacement $m\times n$ vectors. Here m is the number of degrees of freedom (DOF) and n is the number of time-domain samples. The nonlinear force vector f_{nl} contains all conservative and non-conservative forces, and $\boldsymbol{\rho}$ is a location vector of the r nonlinear elements.

It was shown in [2] that it is possible to build low-dimensional parametric models from Eq. (1) without the other state variables $\boldsymbol{z}$ via nonlinear modal reduced order modelling (NMROM) where the unknown parameters can be estimated in an algebraic fashion given that the acceleration data are measured, and velocity and displacement derived by integration. To extend this method to a system with history-dependent nonlinear models, it is proposed here that hysteretic state variables $\boldsymbol{z}$ can be computed in a loop given displacement and velocity derived from measurement. As an example, consider the Bouc-Wen model in a SDOF system where the rate of hysteretic state variables $\boldsymbol{z}$ can be calculated based on the displacement increment in each time step, as follows:

$$f_{nl} = \alpha K\boldsymbol{q} + (1-\alpha)K\boldsymbol{z} - K\boldsymbol{q} \qquad (2)\text{a}$$

$$\frac{dz}{dq} = (1-(\beta sign(z\dot{\boldsymbol{q}})+\gamma)|z|^n) \quad \rightarrow \quad dz = (1-(\beta sign(z\dot{\boldsymbol{q}})+\gamma)|z|^n)dq \qquad (3)\text{b}$$

Results and discussion

The results for an SDOF case study are presented here and the application of the proposed approach to the case of the length-modified Brake–Reuß beam (LBRB) with frictional three-bolted lap-joint is discussed in the full paper. The simulation of SDOF system with M=1 kg, C=1.055N.sec/m, K=259020N/m, $\alpha = 0.1$, n=2, $\beta = 5\times10^9, \gamma = 5\times10^9$ was carried out and responses were contaminated with noise before the integration. An optimization problem was solved [2] and the identified hysteretic curve was compared with the true model in Figure 1(b) obtaining excellent results.

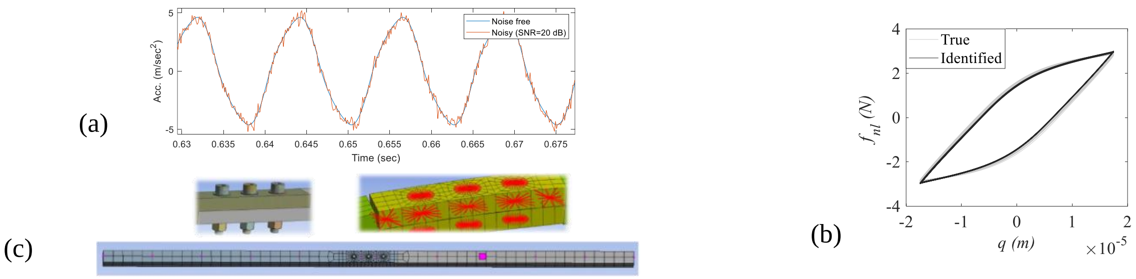

Figure 1: (a) Measured acceleration data, (b) identified hysteretic curve (c) LBRB case study.

References

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