Control of MR Damper Connected Buildings by Output Feedback

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The control of seismic response of buildings connected by a magnetorheological (MR) damper is studied. The desired control force is obtained using Linear Quadratic Gaussian (LQG) control based on the feedback of states estimated via measured outputs or Optimal Static Output Feedback (OSOF) control using the direct feedback of measured outputs. The damper input voltage is predicted using a Recurrent Neural Network (RNN), which proves more effective than the Clipped Voltage Law (CVL). Various sensor configurations and state weightings are considered to obtain effective control. LQG-RNN/OSOF-RNN yield significant reduction in response and base shear and require much less control effort compared to passive-on control with saturation voltage. Compared to passive-off control, they are very effective in attenuating maximum-peak/RMS responses and storeywise responses of the flexible building, except for max-peak accelerations that increase slightly. However, passive-off control is unable to transfer base shear to the stiffer building. LQG-RNN/OSOF-RNN also yield control at least as effective as LQR-RNN by deploying much fewer sensors but using a somewhat higher damper force. They are mostly comparable to each other, but OSOF-RNN requires an order-of-magnitude less CPU time for the control loop. Effective control is possible using few sensors.

1. INTRODUCTION

An earthquake induced response of adjacent buildings can be mitigated by connecting them with dampers. Semiactive devices, such as MR dampers, provide controllable damping with a low power expenditure.

Modelling of MR dampers is notably due to: Song et al.[1] who presented a model of an MR damper using polynomial functions and a first-order filter; Chang and Zhou[2] who proposed a recurrent neural network (RNN) model of an MR damper, which is appropriate for closed loop control; Spencer et al.[3] who proposed the modified Bouc-Wen model, containing additional stiffness and damping elements to model accumulator and low-velocity behavior, respectively; Wang and Kamath[4] who proposed a phase-transition model involving a nonlinear differential equation for damper force with velocity as input; and Jimenez and Alvarez-Icaza[5] who presented a modified LuGre friction model by replacing material dependency with voltage dependency.

Predicting applied voltage to produce a desired damper force is difficult. This is due to the non-invertible force-voltage dynamics of hysteritic models for MR dampers. The controllers considered are notably due to: Xu and Shen[6] who used intelligent bi-state control with a Bingham model and on-off current law and later Xu and Guo[7] who proposed a neuro-fuzzy controller for damper current; Dyke et al.[8] who used the modified Bouc-Wen model with acceleration feedback LQG control for desired damper force and proposed an on-off Clipped Voltage Law (CVL); Yuen et al.[9] who used reliability based robust linear control for desired force and CVL for command voltage; Karamodin and Kazemi[10] who used LQG control for desired force and a semiactive neural controller (using acceleration/velocity feedback) for damper voltage; and Bahar et al.[11] who designed a hierarchical controller with velocity feedback for the desired force and proposed an inverse Bouc-Wen model for voltage.

Control of connected buildings with base excitation is notably due to: Aida and Aso[12] who used a passive connector and showed that damping improves when the connector is placed near the top and the natural frequencies are well separated; Ni et al.[13] who experimentally showed, using an MR damper connector, that the optimum damper location is at the top of the shorter building; Zhu et al.[14] who considered passive/active/semiactive connection elements, albeit without damper dynamics; Qu and Xu[15] who used the Bingham MR model and instantaneous sub-optimal control with the damper relative displacement as the control input to study the whipping of a tall building connected to a podium; Xu et al.[16] and Jing et al.[17] who experimentally verified the results of Qu and Xu[15] using single and multiple dampers, respectively; Christenson et al.[18] who considered a semiactive damper without its dynamics and a clipped optimal controller that yields applied force instead of command voltage; and Cimellaro and Lopez-Garcia[19] who performed constrained optimization design, using multiple passive dampers, to achieve performance equal to an LQR controller for white noise excitation.

In this study, a five-storey and a three-storey building are coupled with a single MR damper placed at the top of the shorter building. The system undergoes earthquake excitation. The objectives of the present study are: (i) Applying LQG control (with full state feedback and an optimal observer for state estimation based on measured outputs), and OSOF control (based directly on measured outputs), to obtain the desired control force. The hysteritic force-velocity behavior is modelled using the more accurate modified Bouc-Wen model. The aim here is to study the effectiveness of LQG/OSOF controllers that use fewer measured outputs than LQR control. (ii) Predicting, via RNN, the damper voltage required to produce the desired damper force obtained from LQG/OSOF control.