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On optimal distributed semi-active control of vibrating structures

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Abstract

A novel semi-active control method for mitigation of structural vibration is studied. The method relies on distributed state information patterns and solutions to optimal control problem that aims at replicating the structures of the optimal open-loop switched stabilizing controls. The performance of the designed method is validated by means of numerical experiments performed for a double cantilever system equipped with a set of semi-active elastomers with controlled viscoelastic properties.

Keywords: Distributed control, optimal control, stabilization, semi-active structure

1 Introduction

Distributed control has its roots in the field of distributed computing when the consensus algorithms emerged during the 1960s and 1970s. Recently, distributed consensus algorithms have been adopted by the control and robotics communities for cooperative management of multi-agent systems [1]. By employing parallel computing procedures, distributed controllers can provide the benefit of an efficient and robust realization of optimal processes. The use of distributed methods in structural vibration control has not been extensively studied so far. In the existing literature, we can find the work [2], where the authors examine a distributed linear-quadratic-Gaussian controller in stabilizing a large-scale building. They suggested partitioning the structure into a set of subsystems controlled by independent sub-controllers. The interaction between the subsystems was treated as an external random disturbance. An analogous system partitioning was adopted in designing a distributed controller to stabilize the motion of a robot manipulator [3]. In [4], the authors demonstrated an experimental study of a heuristic fully decentralized control algorithm with local state feedback for semi-active mitigation of free vibrations in frame structures. The proposed algorithm relies on the prestress-accumulation release principle and aims at transferring the vibration energy into high-frequency modes of vibration.

In this present work, we study two distributed control designs for a bilinear system representing a class of semi-active vibrating structures. In both designs, the control relies on a parameterized state-dependent function that allows for an arbitrary selection of distributed architecture. In the first design (heuristic), the underlying assumption is to provide best instantaneous dissipation of system's local energies. The resulting control is given in a switched state-feedback form. A desired distributed architecture is to be arranged by a relevant selection of the local energy functions associated with local sub-controllers. The second design (optimal) generates a distributed control that stabilizes the structural vibrations with an optimal state's convergence measure. First, we investigate the structure of the control acting as a solution to a convergence-related finite-horizon optimal control problem. Based on this structure, for each of the local sub-controllers, we construct a parameterized state-dependent control function. The selection of the control function's parameters is made based on the preferred distributed architecture and the solution to an optimal control problem.

2 Controller setting

The comparative study is carried on for bilinear system representing semi-active double beam cantilever structure introduced in [5]. The state of the structure is measured by 14 sensors distributed along the beams. For the actuators, we assume 3 controlled damping blocks, each operated with an individual sub-controller. For such a setting we assume the following controller's architectures: centralized (where each sub-controller employs all 14 sensors), distributed (each sub-controller employs 6 neighboring sensors), decentralized (each sub-controller uses only 2 closest sensors).

3 Summary of the results

In the first part of the numerical study, we focus on the stabilization of the cantilever structure where for the initial condition we assume the deflection corresponding to the shape of the Euler-Bernoulli beam first natural mode. Implementing the optimal control, for each of the assumed controller's architectures, we observe a significant 50-53% reduction of the energy metric compared to the corresponding best passive damping case. For the heuristic control, this reduction is 41-45%. Next, both control designs are examined for their robustness by assuming a series of perturbed initial deflections, where the shape of the first mode is combined with the second and third modes. In these cases, the optimal control results in 36-52% reduction of the energy metric. It is worth noting that in the most perturbed case, the distributed control outperforms the centralized one. A similar observation is made for the heuristic control.

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