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DISTRIBUTED CONTROL OF MODULAR STRUCTURES BASED ON THE IDENTIFICATION OF THE INTERACTION FORCES

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1 INTRODUCTION

The majority of the distributed controllers designed for structural control have been based on the idea of isolated subsystems corresponding to the parts of a vibrating structure and designing a set of state-feedback local controllers, where each relies solely on the state information of its adjacent subsystem. In the work [1], the authors adopt the linear quadratic Gaussian controller in the active stabilization of a large-scale building. They suggested partitioning the structure into a set of independent subsystems, treating the coupling forces as external random disturbances. A similar idea was adopted in designing a distributed controller to enhance the positioning of a robotic manipulator [2]. In [3], the authors present a decentralized method to mitigate the vibration of a slender structure using a set of LQR based controllers that employ the clusters of adjacent states defined by an overlapping decomposition of the structure.

In the present work, we propose a distributed collaborative controller to stabilize the vibration of modular systems. The method relies on the partitioning the structure, in a way that leads to a set of dynamically interconnected subsystems, each operated with an individual subcontroller. The key novelty in the proposed approach lies in the introduction of a collaboration between the neighboring subcontrollers. This collaboration is realized by exchanging some of the state information, allowing the establishment of short-term predictions of the interaction forces, identifying the boundary conditions for the subsystems. For the predictions, we employ autoregressive linear dynamical models which preserve the linear representation of the subsystems' dynamics. This allows, for each of the subsystems, defining and solving the problem of optimal stabilization based on the LQR method. The proposed method is examined for an actively controlled cantilever structure equipped with electromagnetic actuators. The performance of the designed controller is tested by comparing it to the optimal controller established by the solution to the centralized LQR problem. In addition, the distributed controller is compared to the decentralized case, where we assume a set of local independent subcontrollers, as suggested in [3]. The computational complexity of the distributed control method is analyzed for different settings in the modeling of the predictions of the interaction forces.

2 DISTRIBUTED CONTROLLER DESIGN

We consider vibrating modular structures composed of the subsystems $S_1(x_1)$, ..., $S_K(x_K)$ (x_k stands for the state of the subsystem k) interacting accordingly to the connectivity sets

$\mathcal{G}_1, ..., \mathcal{G}_K$, and a distributed controller $C_1(u_1), ..., C_K(u_C)$ (u_k stands for the control decision of the subcontroller k) governed by the following dynamical equation:

$$\dot{x}_k(t) = A_k\, x_k(t) + B_k\, u_k(t) + \sum_{j\in\mathcal{G}_k} D_{k,j}\, F_{k,j}(t),\ \ x_k(0) = x_k^0. \tag{1}$$

The distributed controller $C_1(u_1), ..., C_K(u_K)$ relies on the functions $u_k = u_k^\star$ that represent the solution to the following receding horizon optimal control problem:

$$\text{Find}\ \ u_k^\star(t) = \text{argmin}\, J(x_k, u_k) = \tfrac{1}{2}\int_{t_z}^{t_z+T} \left(x_k^T(t)Q_k x_k(t) + u_k^T(t)R_k u_k(t)\right)\, \mathrm{d}t, \tag{2}$$

$$\text{subject to}\ \ \dot{x}_k(t) = A_k\, x_k(t) + B_k\, u_k(t) + \textstyle\sum_{j\in\mathcal{G}_k} D_{k,j}\, F_{k,j}(t),\ \ x_k(t_z) = x_k^{t_z}, \tag{3}$$

$$u_k(t) \in \mathcal{U}_k,\ \ t\in[t_z, t_z+T],\ \ k = 1, ..., K. \tag{4}$$

In order to solve the problem (2)-(4), we build a dynamical Autoregressive (AR) model that allows C_k to predict the evolution of the functions $F_{k,j},\ j\in\mathcal{G}_k$ over the time period $t\in[t_z, t_z+T]$: $\dot{F}_{k,j}(t) = \bar{A}_{k,j}\bar{F}_{k,j}(t)$. The estimation of the entries of the matrices $\bar{A}_{k,j}$ is based on the Burg method. In order to investigate the influence of the predictor parameters on the computational effort and the controller's performance, we employ several selections for the measurement horizon and order of the AR model.

3 SUMMARY OF THE RESULTS

The optimality of the distributed designed controller has been examined for a series of the free-vibration scenarios by comparisons to the centralized strategy. For each scenario, the distributed method has exhibited a fair efficiency, being marginally outperformed by the centralized control by 0.2%–1.4%. The distributed controller has also been compared to the decentralized control, where an identical system partitioning has been assumed, but unlike in the distributed case, the decentralized controller has not employed any communication between the subcontrollers. Following the results for the decentralized controller, we have observed a notable performance loss of 171%–555% compared to the distributed strategy. It should be also pointed out that the amounts of energy consumed by the actuators have been significantly lower for the distributed control. This brings us to the conclusion that the communication between the subcontrollers which allows estimating the subsystems' boundary conditions is the key in designing an effective distributed stabilizing control.

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