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# Decentralized simple adaptive control for large space structures

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## ABSTRACT

A decentralized simple adaptive control is proposed for the vibration suppression of large space structures (LSS) with distributed actuators and sensors. The LSS is viewed as a set of connected substructures so that the dynamic substructuring method can be applied to establish the equations of motion for the LSS. Then, extraction and contraction of the subsystems are performed to form the perturbed equations of motion for each substructure. An output feedback control law only requiring the information of the local sensors is designed based on the simple adaptive control method. The stability of the overall system is rigorously proven.

## 1. Introduction

Large space structures (LSS), such as solar panels, trusses, and antennae, have been widely used in the space industry. In recent years, there are continuing interests in large space stations and space power satellites [1], whose sizes could be on the order of hundreds of meters or even kilometers. To suppress the vibrations induced by attitude maneuvers or thermal excitations, active control schemes that utilize distributed actuators and sensors have been developed, such as distributing thrusters on the structure [2,3], embedding small angular momentum exchange devices for active control torques [4–8]. Piezoelectric materials have also been bounded on the structure for vibration suppression [9–11]. Meanwhile, various novel control strategies [12–16] of the large flexible spacecraft have always been a hot topic and rise a great attention. However, most of the present studies [2–16] are based on the global dynamics of the system, which means the LSS is viewed as a single structure in the formulation. When adopting numerous distributed actuators and sensors for the LSS, solving for the control commands for all the actuators simultaneously would lead to high computational burden. Moreover, since the LSS is normally constructed on orbit, the dimension of the control and the measurements would be changed when certain components or substructures were assembled. The control laws based on the global model have to be adjusted or even redesigned for the new system. Therefore, it is anticipated the control can be in a decentralized form, that is to say, the control commands for a group of adjacent actuators are computed based only on the local measurements on a substructure. In this way, the

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## Nomenclature

| | |
|---|---|
| $\mathbf{0}$ | null matrix |
| $\overline{\mathbf{A}}_i$ | system matrix in first-order form |
| $\widehat{\mathbf{B}}$, $\overline{\mathbf{B}}_i$, $\mathbf{B}_i$ | input matrix |
| $\widehat{\mathbf{C}}$, $\overline{\mathbf{C}}_i$, $\mathbf{C}_i$ | output matrix |
| $\mathbf{D}_i$ | damping matrix of the $i$th substructure |
| $\mathbf{e}_i$ | error vector |
| $\mathbf{E}$ | signed Boolean matrix |
| $\mathbf{f}_i$ | external forces for the $i$th substructure |
| $\mathbf{g}_i$ | constraint forces for the $i$th substructure |
| $\mathbf{I}$ | identity matrix |
| $k_i$ | related with the bound of $\Delta_i$ |
| $\widehat{k}_i$ | estimation of $k_i$ |
| $\mathbf{K}_i$ | stiffness matrices of the $i$th substructure |
| $\mathbf{K}_p$, $\mathbf{K}_I$ | the proportional and integral gains |
| $\mathbf{M}_i$ | inertia matrix of the $i$th substructure |
| $n$ | the number of substructures |
| $\mathbf{N}$ | the null space of $\mathbf{E}$ |
| $p$ | a positive integer |
| $S$, $S_e$ | system, extension of the system |
| $\widehat{\mathbf{T}}$, $\widehat{\mathbf{L}}$, $\widehat{\mathbf{G}}$ | full-rank transformation matrices |
| $\widehat{\mathbf{u}}$, $\mathbf{u}_i$ | control input |
| $\mathbf{U}_i$ | generalized coordinates of a substructure |
| $\mathbf{x}_i$ | interface DOFs of a substructure |
| $\mathbf{X}_i$ | system states in first-order form |
| $\mathbf{y}$, $\mathbf{Y}_i$ | output of the system |
| $\beta$, $\beta_i$ | a positive constant scalar |
| $\Delta_i$ | interactions for the $i$th substructure |
| $\varepsilon_i$ | positive scalar |
| $\sigma_i$, $\rho_i$ | design parameters in the adaptions of perturbation bounds |
| $\varsigma_i$, $\xi_i$ | residual errors |
| $\tau_i$ | internal DOFs of a substructure |

*Subscripts and superscripts*

| | |
|---|---|
| $f$ | flexible |
| $i$ | substructure number |
| $e$ | extension of the system |
| $+$ | Moore-Penrose inversion |
| $m$ | reference model |
| $p$ | perfect tracking |

computational cost of the control would be reduced, whereas the structure of the control logic is not influenced by the change of the dimension of the control input and the measurements.

In fact, when establishing the equations of motion of such systems, dynamic substructuring (DS) has been widely used as an effective solution [17–20]. DS analyzes the system component-wise so it is applicable to LSSs that are too large or complex to be analyzed as a whole structure. In addition, the components of an LSS might be designed by different groups and separately sent into orbit, but the DS can combine the substructures together so that the modeling and analysis process of the entire system can be realized and simplified. Theoretically, the controller can also be designed component-wise based on the DS model, whereas the stability of the entire system should be guaranteed. This decentralized control strategy would inherit all the merits of the DS for the modeling.

Based on the above idea, several works have been published in recent years. Kobayashi et al. [21] investigated the LSS composed of several subsystems interconnected by flexible links modeled as springs and dampers, while a dynamic