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Feasibility issues in static output-feedback controller design with application to structural vibration control

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Abstract

Recent results in output-feedback controller design make possible an efficient computation of static output-feedback controllers by solving a single-step LMI optimization problem. This new design strategy is based on a simple transformation of variables, and it has been applied in the field of vibration control of large structures with positive results. There are, however, some feasibility problems that can compromise the effectiveness and applicability of the new approach. In this paper, we present some relevant properties of the variable transformations that allow devising an effective procedure to deal with these feasibility issues. The proposed procedure is applied in designing a static velocity-feedback H_∞ controller for the seismic protection of a five-story building with excellent results.
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1. Introduction

Limited access to the state variables information is a common problem in most practical control applications. In this context, static output-feedback controllers are a very interesting option [1,2]. To synthesize static output-feedback controllers, a variety of multi-step numerical algorithms have been proposed, as those based on random search [3], or those consisting in iterative procedures [4–6]. Typically, these methods require solving complex matrix equations or linear matrix inequality (LMI) optimization problems at each step. To avoid the high computational cost associated to the multi-step methods, some single-step strategies have also

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been proposed [7–10]. These single-step methods are based on a proper transformation of the state variables and formulate the static output-feedback controller design in terms of a single LMI optimization problem. Nevertheless, this second line of solution presents the drawback of being highly problem-dependent, in the sense that most controller designs require a complete derivation of the associated LMI optimization problem.

The latest trends in vibration control of large structures consider distributed control systems formed by a large number of sensors and actuation devices, together with a wide and sophisticated communications network [11,12]. This kind of control systems present particularly challenging design characteristics, such as high dimensionality, severe information constraints and fast real-time operation requirements [13–16]. Clearly, static output-feedback strategies can play a major role in this scenario. However, it also becomes apparent that effective numerical algorithms are of critical importance for the practical applicability of this approach to large scale control problems.

Following the ideas presented by Zečević and Šiljak [17–19], a new control design strategy for seismic protection of large structures has been proposed in [20–22]. The new approach allows computing static output-feedback controllers by solving a single-step LMI optimization problem, which can be easily derived from the associated state-feedback LMI formulation through simple transformations of the LMI variables. In all these works, however, the LMI optimization problems associated to the output-feedback controller designs are initially reported to be infeasible by the MATLAB LMI optimization tools [23], and a slightly perturbed state matrix has to be used to overcome this computational difficulty. Recently, more general transformations of the LMI variables have been proposed in [24]. In the present paper, an effective line of solution to the aforementioned feasibility issues is obtained by taking advantage of the additional design flexibility provided by these generalized LMI-variable transformations.

The paper is organized as follows: In Section 2, the fundamental elements of the new output-feedback controller design strategy are provided. In Section 3, an accurate study of some relevant properties of the generalized LMI-variable transformations is presented, and a two-step design procedure is devised to deal with the feasibility issues. In Section 4, the effectiveness of the proposed two-step procedure is demonstrated by designing a static velocity-feedback H_∞ controller for the seismic protection of a five-story building. Finally, some conclusions and future research directions are presented in Section 5.

2. Theoretical background

Let us consider a control problem with state vector $x(t) \in \mathbb{R}^n$ and control vector $u(t) \in \mathbb{R}^m$. A wide variety of advanced state-feedback control designs can be formulated as an LMI optimization problem of the form

$$P_s : \begin{cases} \text{minimize } h(\eta) \\ \text{subject to } X > 0, \quad F(X, Y, \eta) < 0, \end{cases} \tag{1}$$

where $X \in \mathbb{R}^{n \times n}$ is a symmetric positive-definite matrix, $Y \in \mathbb{R}^{m \times n}$ is a general matrix, $\eta \in \mathbb{R}^p$ is a vector that collects the free entries not contained in X and Y, h is a real linear function, and F is an affine map that makes the matrix inequality $F(X, Y, \eta) < 0$ an LMI. In this case, an optimal state-feedback controller $u(t) = G_s x(t)$ is usually obtained by computing an optimal triplet $(\tilde{X}_s, \tilde{Y}_s, \tilde{\eta}_s)$ for the LMI problem in Eq. (1), and by setting $G_s = \tilde{Y}_s \tilde{X}_s^{-1}$.

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