Applied Mathematics and Computation 237 (2014) 438–445

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Iterative learning control for spatially interconnected systems

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ARTICLE INFO

Keywords:
Iterative learning control
Spatially interconnected systems
Trajectory tracking

ABSTRACT

Iterative learning control (ILC) has been successfully employed for trajectory tracking of uncertain dynamic systems with less system information. This paper attempts to adopt the benefits of ILC to improve the trajectory tracking performance of spatially interconnected systems. By utilizing the ILC update law along the iteration domain repetitively, a perfect reference trajectory tracking can be ensured. It is the key benefit of using ILC that less system model information is used in the design of a trajectory tracking controller for spatially interconnected systems. Through a numerical simulation, the validity of the proposed control scheme is illustrated.

1. Introduction

Iterative learning control (ILC) learns a system dynamics from previous operations to improve the performance better and better by repetitions [15]. ILC has been substantially studied due to its potential utility in various engineering problems [16]. Specifically ILC has been used in robot systems, wafer manufacturing process, batch reactor processes, IC welding processes, and various assembly lines and production lines. The benefit of the ILC is that it requires less knowledge about the system dynamics and relatively less computational effort. Without using a full model of dynamic systems, ILC can successfully render the system to follow desired reference trajectory. The most fascinating feature of ILC is that it does not use full dynamic model of the system; but still ensures a perfect trajectory tracking [5]. ILC has been demonstrated to be useful in various form of dynamic systems. It has been tested in linear and nonlinear systems [4], model uncertain systems, mechanical hard nonlinear systems, and multiagent systems. Recently, ILC has been also used to control complex interconnected systems. The interconnected systems can be characterized by a large number of variables representing the system, a strong interaction between the system variables, and a complex structure. In [17], a decentralized iterative learning control was applied to a class of large scale interconnected systems. The decentralized iterative learning controller can guarantee the asymptotic convergence of the local output errors that are defined from the given desired local output and actual local output of each subsystem. The ILC is extended to distributed parameter systems governed by parabolic partial differential equations (PDEs) in [18].

Spatially interconnected systems (SIS) consist of identical units which interact with their neighborhood units. Even though these units have simple models and interact with their neighbors, the behavior of whole systems can be complicated due to temporal or spatial interactions. The spatially interconnected systems (SIS) can be considered as more general ones over interconnected systems. The examples of SIS include airplane formation flight [1], satellite constellations [2], vehicular platoons [3,6], cross-directional control in paper processing applications [7] and deformable mirror in adaptive optics [8]. Also lumped approximations of partial differential equations (PDEs) can be considered as SIS. So, the deflection of beams,

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http://dx.doi.org/10.1016/j.amc.2014.03.123
0096-3003/

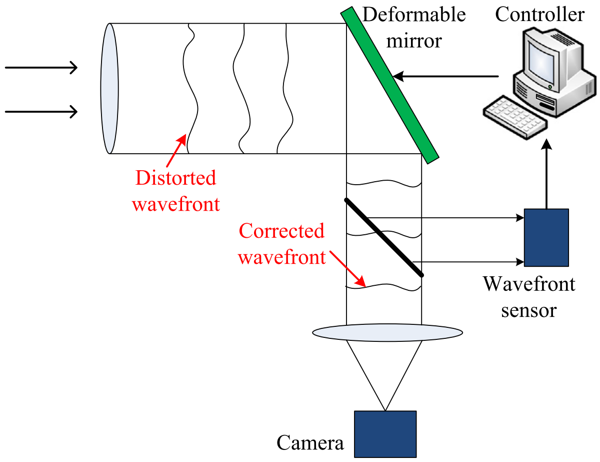

Fig. 1. Adaptive optics system.

plates, and membranes, and the temperature distribution of thermally conductive materials are examples of SIS [9]. Standard control cannot treat these systems because of its high dimension and a large number of inputs and outputs. It is not feasible to control these systems with a centralized control scheme because the centralized scheme requires high levels of connectivity and a significant computation, and are more sensitive to failures and modeling errors than a decentralized controller. Recently for the spatially distributed control of SIS, linear matrix inequality (LMI) conditions are suggested to ascertain well-posedness, stability, and performance of spatially interconnected systems consisting of homogeneous units [10]. Spatially interconnected systems with arbitrary graph and heterogeneous units are studied in [11,12], where the operator-theoretic tools are used to design optimal controller for heterogeneous systems which are not shift-invariant in spatial and temporal domains. It is shown that optimal controllers have an inherent degree of decentralization, and this provides a practical distributed control architecture [13]. For the systems consisting of possibly heterogeneous linear control systems, which are spatially interconnected via certain distant-dependent coupling functions over arbitrary graphs, the structural properties of optimal control problems with infinite-horizon linear quadratic criteria are studied by analyzing the spatial structure of the solution [14].

However, in existing control approaches for spatially interconnected systems, a full model information is required to synthesize the distributed control. Moreover, in existing works, only the stabilization problems have been investigated. However, obtaining an exact system model is not easy in spatially distributed systems because the modeling parameters can be changed according to the segmentation of whole structure in PDEs. Thus, to overcome the weak points of the existing works, this paper employs iterative learning control (ILC) approach for a precise motion tracking of spatially interconnected systems. Furthermore, the ILC algorithm will be designed only using local input and output data; thus it is a decentralized approach. Since the proposed ILC can learn a system dynamics from previous operations, it learns how to reduce the tracking errors in the iteration domain, while leading to a better control performance. This paper is organized as follows. In Section 2, the research motivation and contributions are briefly summarized, and in Section 3, the spatially interconnected systems we study in this paper are roughly reviewed. The main results of this paper are presented in Section 4, and numerical simulation results are presented in Section 5. Conclusions will be given in Section 6.

2. Research motivation and contributions

In a large astronomical telescope such as Giant Margellan telescope (GMT),[1] adaptive optics play important role in capturing a precise space image. The adaptive optics are applied to correct blur image due to atmospheric turbulence [19]. The scheme of adaptive optics is represented in Fig. 1. In adaptive optics, a deformable mirror is used as a corrector to compensate the atmospheric turbulence. The distorted wavefront is corrected by the deformable mirror that is actuated by multiple piezo-actuators attached to the mirror cell. The wavefront sensor measures the corrected wavefront, and feedbacks it to the controller. There are some studies to control the shape of deformable mirror [20–22]. The deformable mirror can be mathematically described by partial differential equations (PDE). In [8], a distributed control is synthesized with SIS modeling of deformable mirrors. As mentioned in the previous section, however, the proposed scheme in [8] requires a full system dynamic model for a H_∞ control synthesis. It is certain that obtaining an accurate system model is not easy. For example, the partial differential equations of deformable mirror can be divided into many differential equations with variables representing the complicated interconnections. Thus, it looks quite difficult to obtain an exact dynamic model of a spatially distributed system, which means that a less model-dependent control law should be developed for spatially interconnected systems.

[1] See http://www.gmto.org/