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B-spline network-based iterative learning control for trajectory tracking of a piezoelectric actuator

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ABSTRACT

This paper presents the trajectory tracking approach of a piezoelectric actuator using an iterative learning control (ILC) scheme based on B-spline network (BSN) filtering. The ILC scheme adopts a state-compensated iterative learning formula, which compensates for the state difference between two consecutive iterations in order that the iterative learning can learn from the tracking errors of the previous iteration effectively. The BSN is used to attenuate the noises and retrieve the signals of the tracking errors for the ILC. The BSN serves as a unique filter which generally does not have zero-phase responses. Design details on the ILC scheme using BSN filtering are discussed in the paper. Extensive experiments of tracking two desired trajectories for a piezoelectric actuator are presented. The experimental results show that the state-compensated ILC scheme using BSN filtering can achieve fast error convergence and keep small steady-state tracking errors close to the system noise level. This research thus relaxes the restriction of the zero-phase criterion commonly applied to the ILC filtering in the literature.

1. Introduction

Owing to the advantages of infinite small displacement, high stiffness, and wide bandwidth, piezoelectric actuators have been commonly used for precision positioning in various engineering fields, such as positioning of diamond machine tools, positioning of optical lenses, and positioning of masks in semiconductor manufacturing. However, the piezoelectric actuators are nonlinear devices, and can be characterized by certain hysteresis phenomena between their input voltages and output displacements. Various control schemes have been proposed in the literature to compensate for the nonlinear behaviors of the actuators. For example, there were schemes using the Preisach model-based control [1] and the neural sliding-mode control [2].

Differing from other endeavors of control complexities, some studies initiated the simpler approach using the iterative learning control (ILC) [3]. Certain degrees of success were achieved in tracking control of piezoelectric actuators by using the P-type ILC, the current-error-assisted D-type ILC, the model-assisted ILC, and the state-compensated ILC schemes [4–8]. The state-compensated ILC (SCILC) proposed by the authors [8] is a novel scheme, which enhances the traditional ILC by adding a state compensation enhancement to the iterative learning. In [8], a zero-phase (ZP) finite impulse response (FIR) filter was used to filter the learnable errors for the ILC. The major goal of this paper, on the contrary, is to relax the restriction of ZP filtering by adopting the B-spline network (BSN) for error filtering. The BSN consists of a number of

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B-spline basis functions to realize an input–output mapping. The mapped output is a linear combination of these basis functions. The BSN structure has been proposed in the learning feed-forward control (LFFC) [9–15] to enhance the performance of feedback control systems. The BSN in the LFFC is tuned by the feedback control effort of the previous iteration to generate a feed-forward control effort in the current iteration. The feed-forward control effort is thus modified iteratively in order that the system output will approach the desired trajectory eventually. The BSN is basically a function approximator [15], and the tuning mechanism of the BSN is in essence a general non-ZP filter [10]. The BSN is adopted in this research to filter the learnable errors of the previous iteration without a zero phase in general. The filtered errors are then used for learning in the current iteration.

The remainder of the paper is organized as follows. Section 2 describes the experimental setup. Section 3 introduces the SCILC. In Section 4, the BSN filtering is discussed. In Section 5, a convergence analysis is performed for the SCILC. Section 6 addresses the time-frequency analysis of tracking errors. Section 7 presents the controller design details and the experimental results. Finally, Section 8 concludes this paper.

2. Experimental setup

The experimental platform in this research consists of a piezoelectric actuator unit, an electronics unit, a data acquisition device, and a personal computer, as shown by Fig. 1. The piezoelectric actuator has the displacement from −8 to 40 μm corresponding to the input voltage from −30 to +150 V. The actuator has a built-in strain gauge which is connected to the sensor amplifier of the electronics unit. The amplifier outputs a sensing voltage ranging from +0.2 to −1 V. The data acquisition device samples the sensing voltage for the control program and delivers the control effort to the power amplifier, which has a gain of 30 to drive the actuator. The data acquisition device has 12-bit A/D and D/A converters with a maximum sampling rate of 100 K-samples per s for input and 1 K-samples per s for output.

The control program is written in MATLAB, and it utilizes Data Acquisition Toolbox functions of MATLAB to perform online learning control within the Windows operating system. The program implements the SCILC scheme using the B-spline network filtering technique, as introduced in the following.

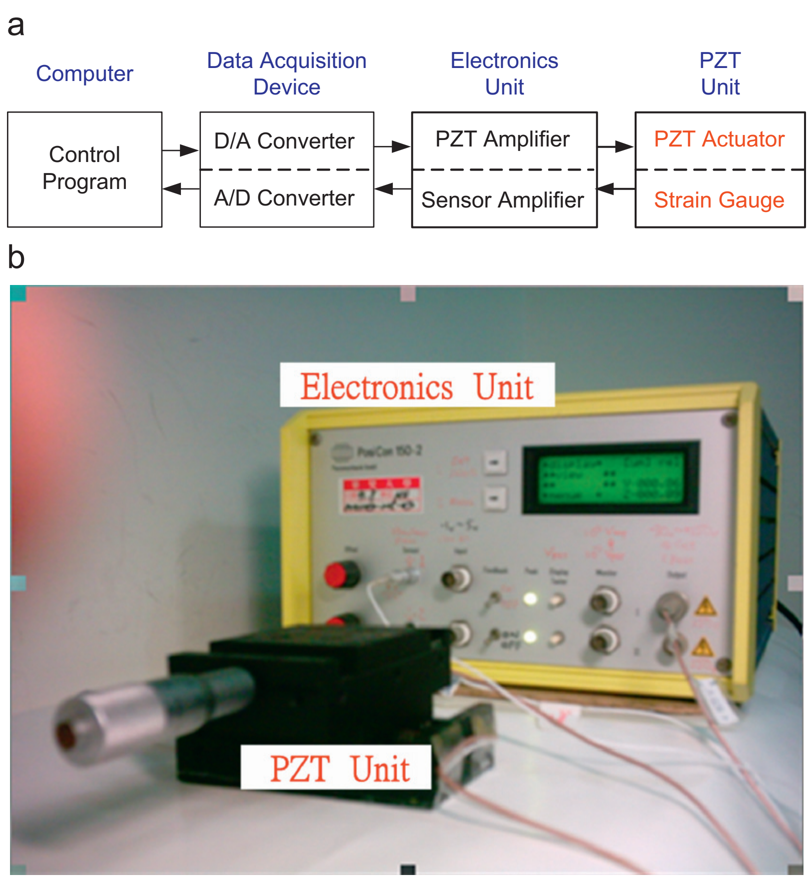

Fig. 1. (a) Block diagram of the experimental setup. (b) Picture of the electronics unit and the PZT unit.