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Application of the continuous no-reset switching iterative learning control on a novel optical scanning system

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ABSTRACT

Modern optical scanning systems often use the advanced servo system to enhance the scanning accuracy and to increase the field of view. This paper presents a continuous no-reset switching iterative learning control algorithm for a novel optical scanning system to achieve the requirements of both fast response and wide field of view. In addition, the proposed method overcomes the non-converging reset error problem experienced by most conventional iterative learning control algorithms.

1. Introduction

Modern optical scanning systems emphasize on the scanning range, scanning speed and the scanning resolution. A smart mechanism with very high servo performance is most suitable for these uses; therefore, it has become very popular in the optical scanning applications. Lately, a new step-and-scan path in Fig. 1 has been from based on the knowledge of the previous operations of the same task [2]. Therefore, this study has also chosen the ILC to achieve the high performance servo requirements.

It is noted that the ILC algorithm, assumes that the initial state of the plant is equal to that of the desired trajectory so that perfect tracking can be achieved. While it is very difficult to assign the initial states in practice, many studies had discussed the design of robust ILC input against initial state errors [3]. There are different structures proposed for fixed initial state error or bounded variable initial state error [4–7], even so all the articles have to constrain the initial states to within a region. In 1996, Sison and Chong brought forth an interesting concept of no-rest iterative learning control (NRILC) [8] to convert the iterative procedure in the linear time invariant single-input–single-output (SISO) system into an equivalent system for stability analysis. The stabilizing control in their paper is not structured for practical application and they did not discuss the issue of initial state error nor offer any simulation or experiment results.

This paper first extends the conventional ILC setting to the multi-input–multi-output (MIMO) situation for the application to a novel high-speed optical scanning mechanism system. A continuous iterative learning control (CILC) algorithm is then proposed to suppress the initial state error that often diverges upon ILC. The system architecture and identification results are depicted in Section 2. The traditional ILC control criteria are briefly described in Section 3. This section also proposes the use of the traditional ILC control criterion to simulate the NRILC response, termed the continuous iterative learning control (CILC) to distinguish the NRILC in [8]. The original CILC produces poor system responses because it violates the assumptions for the conventional ILC. Section 3.2.2 then presents a modified CILC strategy noticed in several optical systems, particularly for the long distance and large field scanning systems. There are $4n$ steps in the step-and-scan path. This scanning path is usually arranged for an array of charge coupled devices (CCD) or complementary metal oxide semiconductor (CMOS) detectors. The signal from a single CCD or CMOS detector image displays only a small portion of the front view, and the full view is reconstructed by stitching the images together. To reconstruct a truthful front image, the stepping motion requires not only a precise position control but also a mechanism that can provide a large acceleration upon request. The conventional high torque actuators and its driving mechanisms always take up huge spaces. The proposed novel optical scanning system [1], on the other hand, uses piezo-electric transducers (PZT) with flexure joints and is very compact in size. From the servo point of view, the step-and-scan motion requires sufficient control sampling points during each step; however, there is a hardware limit on the number of usable sampling points. It is both unwise and uneconomic to change the hardware to accommodate for the growing step number n. Thus, making use of the previous control information for self control

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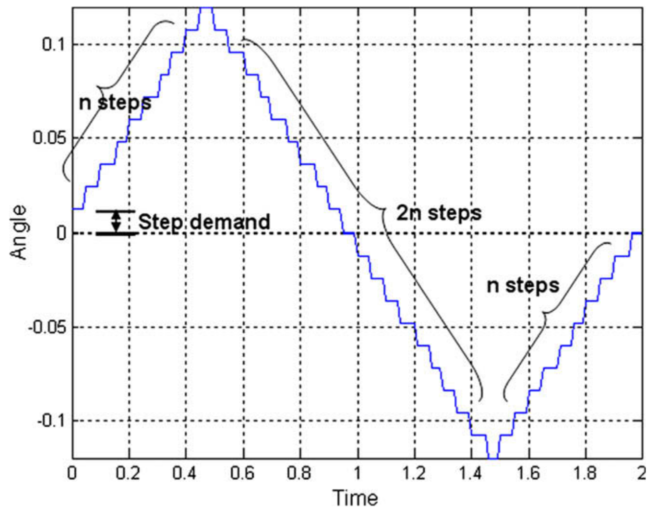

Fig. 1. The step-and-scan path.

tuning would be the best way to suppress the tracking error. There are mainly two types of learning control that serves the purpose: the repetitive control (RC) and the iterative learning control (ILC).

The RC design eliminates the periodic system disturbances and periodic steady state error, but it along does not improve the transient tracking performance. There are many modifications to the RC methods to enhance the steady state error performance, but they all suffer from the compromises between achievable phase compensation and system instability. The ILC is an effective method for reducing tracking errors from repeated operations. The ILC is robust against model uncertainties; it requires no detailed prior knowledge about the system; it modifies an unsatisfactory control input overcome the reset assumption. The modified CILC strategy is then extended to the MIMO case. The simulation outcomes in Section 3.2.3 verify that the modified CILC strategy is efficient. The section then discusses the non-zero initial error problem for some various optical servo systems. Section 4 displays the experimental results. Both simulation and experimental results of this application confirm that the proposed method can effectively suppress the iterative learning error and achieve the desired performance.

2. The novel optical mirror scanning system

The optical scanning system uses a quick scanning mirror to reflect pieces of images from different part of the field-of-view onto the CCD array. To truthfully represent the original image, the scanning mirror must be fast to scan the entire field-of-view and precise to determine the position of each pixel. It is thus import to design a high performance servo mechanism for the scanning mirror. Fig. 2 shows the architecture of the novel mirror scanning system; two multilayer piezo actuators "A", "B" are connected to the flexure joints "a", "b" of the scanning stage to drive the mirror. The flexure joint helps avoid mechanical problems such as backlash, friction and lubrication. The multilayer PZT helps attain high output displacements and high scanning speed. Applying different driving voltages to "A" and "B" induce an elongation difference which twists the scanning mirror through the flexure joints to produce the desired mirror scanning angle. Two linear variable differential transformers (LVDT), "C" and "D", measure the actuator elongations for the control feedback. The control system is illustrated in Fig. 3.

The proposed novel optical scanning system is an MIMO scanning system. The experiment used an Agilent 35670A dynamic

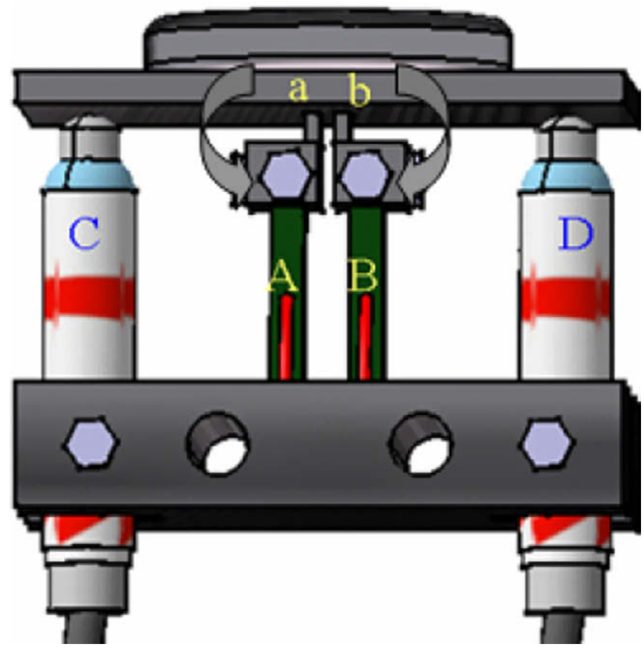

Fig. 2. Mechanism diagram.

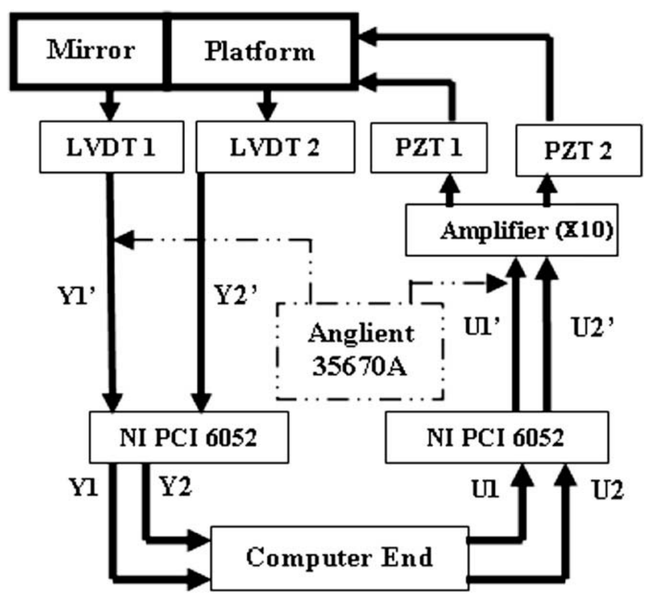

Fig. 3. System control process.

signal analyzer to measure the responses and to carry out data regression. The Agilent 35670A is a SISO instrument. It is also necessary to verify the system linearity by examining the superposition relationships among the transfer functions relating different input–output pairs [9]. Eqs. (1)–(4) lists the system transfer functions where $G_{11}(s)$ stands for the transfer function between input–output pair U_1 to Y_1 and so forth. Ref. [9] also presented the comparisons between the simulations and the experimental results of the SISO subsystem and the overall MIMO system to show good agreements.

$$G_{11}(s) = \frac{-12.77s + 4.068e4}{s^2 + 1015s + 8.162e6} + \frac{13.43s - 5.316e4}{s^2 + 1171s + 3.869e5} \tag{1}$$