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A design method for indirect iterative learning control based on two-dimensional generalized predictive control algorithm

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ABSTRACT

Indirect iterative learning control (ILC) facilitates the application of learning-type control strategies to the repetitive/batch/periodic processes with local feedback control already. Based on the two-dimensional generalized predictive control (2D-GPC) algorithm, a new design method is proposed in this paper for an indirect ILC system which consists of a model predictive control (MPC) in the inner loop and a simple ILC in the outer loop. The major advantage of the proposed design method is realizing an integrated optimization for the parameters of existing feedback controller and design of a simple iterative learning controller, and then ensuring the optimal control performance of the whole system in sense of 2D-GPC. From the analysis of the control law, it is found that the proposed indirect ILC law can be directly obtained from a standard GPC law and the stability and convergence of the closed-loop control system can be analyzed by a simple criterion. It is an applicable and effective solution for the application of ILC scheme to the industry processes, which can be seen clearly from the numerical simulations as well as the comparisons with the other solutions.

1. Introduction

It is well known that iterative learning control (ILC) is an effective control scheme for the repetitive/batch/periodic processes. The major feature of ILC scheme is the repetitive or periodic nature of the process is utilized to refine the control or parameters of the system for the improvement of the control performance from cycle to cycle. Since the key idea of ILC was presented in 1984 [1], it has been attracted extensive attention not only in theoretical researches but also in many industrial applications, as having been surveyed in several papers [2–6].

According to the process information utilized by the control law, ILC schemes can be classified into two types. One is called *simple type*, in which the ILC algorithms only use the process information of historical cycles to determine the control of current cycle [1,7]. It is essentially an open-loop feed-forward control for each cycle such that the real-time control performances, such as robustness and disturbance rejection, may not be guaranteed. The other one may be termed, in this paper, *complex type*, including all ILC algorithms that use the process information of both historical cycles and current cycle to determine the control output. Obviously, not only a real-time feedback control loop but also a learning-type control loop is included in the complex type ILC system. According to the system structure, the complex type ILC can be further classified into direct ILC and indirect ILC. According to the definition given in the survey paper [2] ("*In the case of indirect learning-type control, there are two loops in the closed-loop system: the inner loop is the local controller and while the outer loop is the learning-type control algorithm. In this case, the learning-type control acts as a supervision or optimization module for the closed-loop system under the local controller*".), an ILC can be termed as an indirect ILC only if the closed-loop control system can be depicted as a cascade control system with a real-time feedback control in inner loop and an ILC in outer loop, as shown in Fig. 1 [8], otherwise it should be regarded as a direct ILC.

Compared with the direct ILC, the major advantage of the indirect ILC [2,9] is the cascaded structure of control system facilitating the controller design and implementation in some practical situations. The indirect ILC scheme is very suitable for the low-cost renovation of

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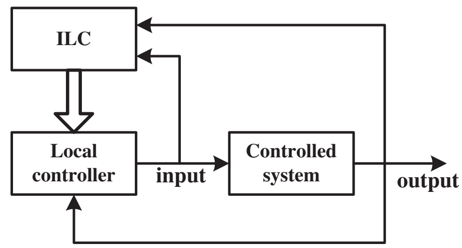

Fig. 1. Block diagram of indirect ILC given by Wang et al. [9].

the repetitive/batch/periodic processes with a local feedback control already, because it is not necessary to make any change to the existing system except for a simple ILC module to be designed and implemented as the outer loop controller.

For an indirect ILC scheme, two important issues [9] should be firstly considered: what design algorithm is used for the local control; and which accessible information of the local control system is updated by the ILC law. For the second issue, two kinds of information were commonly considered: one is the parameters of the local controller, resulting in an *ILC based adaptive control* scheme [10]; another is the set-point for local control system, resulting in a *ILC-based cascaded control* scheme, as shown in Fig. 2. No matter what information updated by the ILC law, as there are two controllers to be designed in the indirect ILC system, the design work is seemed to be more complicated than the direct ILC. According to the statistics of the survey paper [2], in the last two decades, the reported results on indirect ILC are scare, especially for the case of ILC based cascaded control scheme [8,11,12]. In paper [11], an ILC was used to update the set point for PID controller, and then a standard PID with adaptive gains was used to replace this ILC-based PID. In work [12], an anticipatory-type ILC (A-ILC) was utilized to adjust the set-points for PID and the proposed scheme was implemented on an *X–Y* platform. In 2009, based on a well-designed MPC, Wang et al. [9] proposed an indirect ILC, *named as ILC-based MPC*, for the control of artificial pancreatic β-cell. They also provided stability analysis for the proposed indirect ILC system when a P-type ILC was adopted as the outer loop module [13]. For all of these researches, the design works are based on a two-step design algorithm: design a feedback controller for the process to guarantee the real-time control performance in each cycle firstly, and then, above which a simple ILC scheme is designed and implemented to adjust the set-points of the feedback control system for the improvement of the control performance form cycle to cycle. Obviously, the main problem for the two-step design algorithms is the inner and outer control loops are optimized and designed separately, that may not ensure the optimal control of the whole system.

Essentially, an ILC law always results in a control system with dynamics along both time and cycle indices, referred to as a two-dimensional (2D) system. Therefore, an ILC system can be synthesized in the framework of 2D control system. In 2012, under the framework of 2D system, a design method for an indirect ILC, named as advanced PI control with simple learning set-point, was developed for a batch CSTR process [14], realizing the integrated design of a robust PI control in inner loop and a simple ILC in outer loop. The advantages of designing an ILC system under the framework of 2D control theories is that the real-time feedback control and the simple ILC can be naturally designed and optimized together. In 2007 [15], based on the generalized predictive control developed for the 2D systems (2D-GPC), author and his colleagues has proposed a complex ILC scheme, termed as two-dimensional generalized iterative learning control (2D-GPILC). Through the system structure analysis, it has been shown that the resulted control system can be decomposed into a model predictive control (MPC) and a simple ILC *parallel* connected. In other word, the control strategy is a direct ILC.

In this paper, the design for the ILC based cascaded control system, as shown in Fig. 2, is concerned. It is assumed from the point of practice that the control system of inner loop has been equipped without permission to make any change to the hardware and software except for parameter optimization of the feedback control law. Based on the 2D-GPC scheme developed in our previous studies [15–18], a new design method is proposed. The main advantage of the proposed design algorithm is the integrated design of the feedback control loop and the ILC loop in the framework of 2D-GPC, resulting in an optimal control performance in sense of the 2D model predictive control. From the analysis of the control law, it is also revealed in this paper that the proposed indirect ILC law can be directly derived from a well-designed GPC system and the convergence of the closed-loop control system can be easily analyzed. From the comparisons of numerical simulation results, it is seen that the proposed design method is easy for implementation and the control performances superior to other solutions.

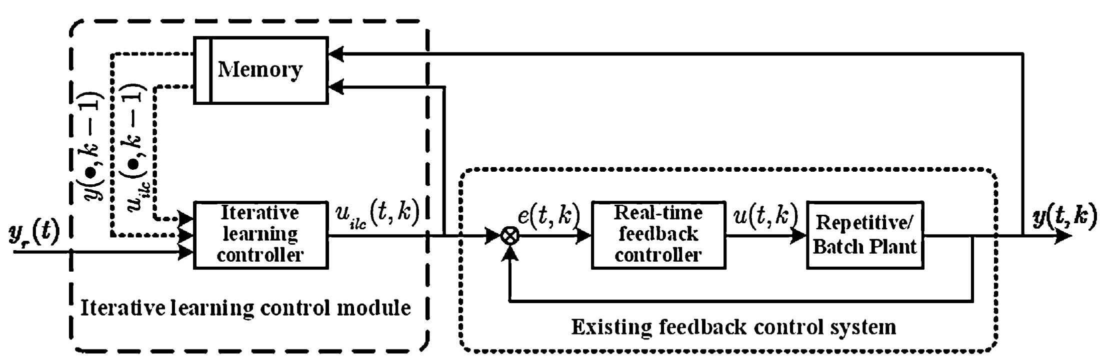

Fig. 2. Block diagram of the indirect ILC system considered in this paper. The dot-line block indicates the existing real-time feedback control system with only set-points and output of the process accessible and the optimization to controller admissible. The dash-line block indicates a simple ILC algorithm to be designed based on the available information of previous cycle only.