

Iterative Learning Control by Linear Repetitive Processes Theory

Wojciech Paszke

Department of Mechanical Engineering

Eindhoven University of Technology

P.O. Box 513, 5600 MB Eindhoven

The Netherlands

Email: W.Paszke@tue.nl

Abstract

Iterative learning control (ILC) is relatively well-known technique for controlling systems operating in a repetitive (or pass-to-pass) mode with the requirement that a given reference trajectory $y_{ref}(t)$ defined over a finite interval $0 \leq t \leq \alpha$ (where $\alpha < \infty$ and $\alpha = \text{const}$) is followed to a high precision. Examples of such systems include robotic manipulators that are required to repeat a given task, chemical batch processes or, more generally, the class of tracking systems [1].

In ILC, a major objective is to achieve convergence of the trial-to-trial error and often this has been treated as the only one that needs to be considered. In fact, it is possible that enforcing fast convergence could lead to unsatisfactory performance along the trial. One way of preventing this is to exploit the fact that ILC schemes can be modeled as linear repetitive processes and design the scheme to ensure stability along the pass (or trial). Also, since the time and trial directions in ILC are decoupled, ILC is often applied by separately designing a feedback and a learning controller. The feedback controller stabilizes the system in the time domain and suppresses unknown disturbances. The feedforward (learning) controller is designed to guarantee convergence in the trial-to-trial domain. However, currently such an integration, of the feedforward control to the feedback control, is performed separately, and may not lead to an optimal complementation of the feedback control with the feedforward control. One of the option to obtain such an optimal complementation is to exploited the inherent two-dimensional/repetitive system structure of ILC in a method that yields in a one step synthesis both a stabilizing feedback controller in the time domain and an ILC controller which guarantees convergence in the trial domain.

The contribution of this work is the development of approach to design ILC schemes with use of linear repetitive processes theory. To date most of existing works, (see, for example [4, 5]) assume that all state variables are available for measurement. In practical applications, it is not always the case. Furthermore, there is no link between these results and practical requirements for ILC schemes which are usually described by multiple frequency domain inequalities (FDIs) in (semi)finite frequency ranges. To overcome

these problems, this paper proposes to apply full order controllers (feedback and feedforward) and make extensive use of the Kalman-Yakubovich-Popov (KYP) lemma that allows us to establish the equivalence between FDIs for a transfer function and an LMI defined in terms of its state space realization [2]. Unfortunately, it is not easy task to convert joint feedback and feedforward controller design with FDI specification on transfer function of ILC scheme. Therefore the paper aims at filling this gap.

The approach to be presented is based on result [3] which states that KYP synthesis theory can be developed for direct treatment of multiple FDI specifications on closed-loop transfer functions in various frequency ranges. The problem of determining required feedback and feedforward controllers is reduced to that of checking the existence of a solution to a set of linear matrix inequalities (LMIs). Testing the resulting conditions only requires computations with a matrices and is consequently computationally attractive when compared alternatives. Finally, the theoretical findings will be validated by numerical examples.

References

- [1] D. A. Bristow, M. Tharayil, and A.G. Alleyne. A survey of iterative learning control. *IEEE Control Systems Magazine*, 26(3):96–114, 2006.
- [2] T. Iwasaki and S. Hara. Generalized KYP lemma: unified frequency domain inequalities with design applications. *IEEE Transactions on Automatic Control*, 50(1):41–59, 2005.
- [3] T. Iwasaki and S. Hara. Feedback control synthesis of multiple frequency domain specifications via generalized KYP lemma. *International Journal of Robust and Nonlinear Control*, 17:415–434, 2007.
- [4] J. E. Kurek and M. B. Zaremba. Iterative learning control synthesis based on 2-D system theory. *IEEE Transactions on Automatic Control*, 38(1):121–125, 1993.
- [5] W. Paszke, R. Merry, and R. van de Molengraft. Iterative learning control by two-dimensional system theory applied to a motion system. In *Proc. American Control Conference (ACC)*, pages 5484–5489, New York, USA, 9-13 July 2007.