Design Framework for Multivariable ILC: (De)centralized Design & Modeling Considerations

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Background

Iterative Learning Control (ILC) [1] can significantly improve the performance of systems that perform repeating tasks, e.g., additive manufacturing machines, industrial robots, printing systems and wafer stages. Although many of these systems are multivariable, ILC design procedures often involve multi-loop SISO filters and tacitly ignore interaction, which can lead to non-convergent algorithms. The aim of this work is to develop a design framework for multivariable ILC, covering a spectrum of systematic decentralized designs to centralized designs. The framework provides a coherent overview of available approaches, such that a well-motivated choice can be made for the particular problem at hand.

Multivariable Iterative Learning Control

Iterative learning control learns a feedforward signal f_{j+1} by using measured data from the previous iteration j, see Figure 1. The feedforward update law is given by

$$f_{j+1} = Q(f_j + Le_j), \tag{1}$$

where L and Q are the to-be-designed learning filters.

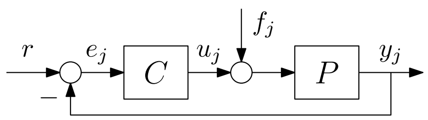

Figure 1: The aim of ILC is to minimize e_j by iteratively improving the feedforward signal f_j.

In ILC for multivariable systems, it is tempting to exploit well-known SISO design techniques for L and Q. However, when interaction is ignored this approach can lead to non-convergent algorithms, see Figure 3. This calls for systematic design techniques that explicitly account for interaction.

Design Framework for Multivariable ILC

The aim of this work is to develop a systematic design framework for analysis and synthesis of multivariable ILC, while addressing modeling and robustness aspects in typical ILC applications [2]. The framework ranges from decentralized designs to centralized designs, with various levels of sophistication. Crucial aspects herein are the trade-off between modeling requirements and required robustness, its implication on performance, and (non)causality [3].

Results

The developed design framework is applied to a model of the multivariable flatbed printer shown in Figure 2. The results in Figure 3 point out key aspects in multivariable design.

- Ignoring interaction can lead to non-convergent schemes.
- Accounting for interaction is crucial in decentralized design: a new approach based on independent SISO designs [2] improves performance compared to a conservative design which accounts for the worst-case interaction.
- A centralized design yields the highest performance, at the expense of the requirement for a multivariable model.

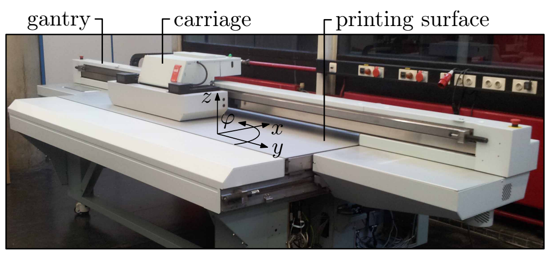

Figure 2: Océ Arizona 550 GT at the TU/e CST Motion Lab.

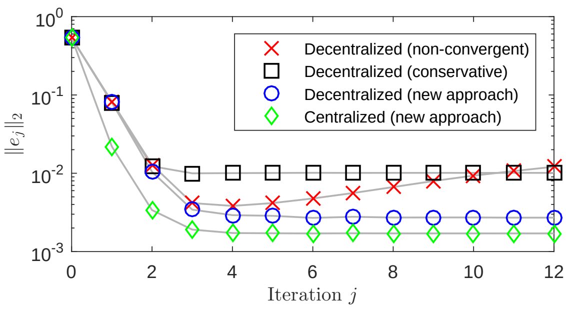

Figure 3: The importance of multivariable ILC design: i) ignoring interaction can lead to non-convergent schemes (×); ii) appropriately accounting for interaction can improve performance (○ vs. □); and iii) centralized ILC (◇) yields the highest performance at the cost of increased modeling requirements.

References

[1] D. Bristow, M. Tharayil and A. Alleyne, "A survey of iterative learning control," *IEEE Control Systems Magazine*, 26(3):96-114, 2006.

[2] L. Blanken, S. Koekebakker, and T. Oomen, "Design and modeling aspects in multivariable iterative learning control,", in *55th IEEE Conference on Decision and Control*, 5502-5507, Las Vegas, Nevada, USA, 2016.

[3] J. van Zundert, J. Bolder, S. Koekebakker, and T. Oomen, "Resource-efficient ILC for LTI/LTV systems through LQ tracking and stable inversion: Enabling large feedforward tasks on a position-dependent printer," *Mechatronics*, 38:76-90, 2016.