Batch-to-Batch Rational Feedforward Tuning: From Learning to Identification Approaches

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Introduction

Feedforward control enables high performance for industrial motion systems that perform non-repeating motion tasks. Recently, learning techniques have been proposed that improve both performance and flexibility to non-repeating tasks in a batch-to-batch fashion by using a rational parametrization in feedforward control. The aim here is to investigate the merits of these approaches. Experimental results on an industrial motion system confirm the theoretical findings and illustrate benefits of rational feedforward tuning in motion systems, including pre- and post-actuation.

Batch-to-Batch Feedforward from a System Identification Perspective

The goal in batch-to-batch feedforward control is to iteratively improve control performance by updating a feedforward controller C_{ff} from measured data in a batch-to-batch fashion, see Fig. 1. Here, the batch-to-batch feedforward techniques are interpreted in a system identification perspective [4], illustrated in Fig. 2. Essential for the achievable performance are i) the batches of measured data, ii) the feedforward controller parameterization, and iii) the optimization criterion.

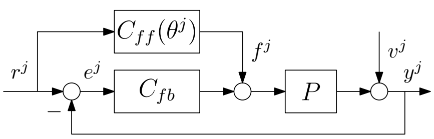


Figure 1: In batch-to-batch feedforward control with parameterized feedforward, parameters θ of $C_{ff}(\theta^j)$ are updated based on measured data after each task j.

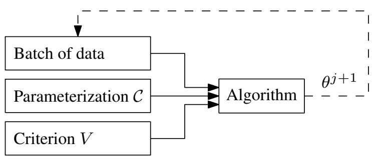


Figure 2: Batch-to-batch feedforward tuning from a system identification perspective. Based on a batch of data, parameterization $\mathcal{C}$ and criterion V, θ_{j+1} is determined and implemented to obtain a new batch of data.

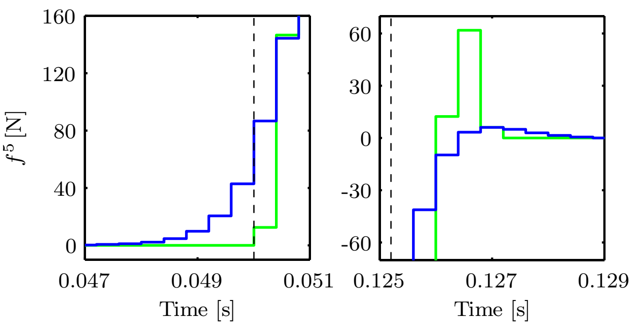
Two techniques to batch-to-batch feedforward are investigated: an instrumental variable-based technique [1], and an Iterative Learning Control (ILC) based technique [2]. In the framework of Fig. 2, these approaches turn out to be very similar. Their algorithms to compute θ^{j+1} can be interpreted in terms of a standard ILC update law, given by

$$\theta^{j+1} = Q\theta^j + Le^j, \tag{1}$$

with corresponding robustness and learning matrices Q, L.

Implementation & Experimental Results

Interestingly, rational feedforward controllers can also be used to generate pre-actuation by means of stable inversion procedures, see, e.g., [5]. The proposed approaches are implemented on a wafer stage. The results in Fig. 3 demonstrate preactuation, used to prevent transient errors at the start of the motion task, and postactuation, used to reduce residual vibrations in the system. This feature is key for the potential performance improvement of rational feedforward.



(a) Pre-actuation. (b) Post-actuation.

Figure 3: The rational parameterization (—) enables pre- and post-actuation of the system, in contrast to the polynomial parametrization (—). The start and end times of the motion task are indicated by black dashed lines.

References

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