

Batch-to-batch rational feedforward tuning : from learning to identification approaches

Citation for published version (APA):

Blanken, L. L. G., Boeren, F. A. J., Bruijnen, D. J. H., & Oomen, T. A. E. (2016). Batch-to-batch rational feedforward tuning : from learning to identification approaches. In *35th Benelux Meeting on Systems and Control, March 22-24, 2016, Soesterberg, The Netherlands* (pp. 122)

Document status and date:

Published: 01/01/2016

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

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

Lennart Blanken¹, Frank Boeren¹, Dennis Bruijnen², Tom Oomen¹

¹Eindhoven University of Technology, Dept. of Mechanical Engineering, Control Systems Technology, The Netherlands

²Philips Innovation Services, Mechatronics Technologies, Eindhoven, The Netherlands

l.l.g.blanken@tue.nl

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.

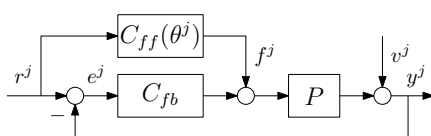


Figure 1: In batch-to-batch feedforward control with parameterized feedforward, parameters θ of $C_{ff}(\theta^j)$ are updated based on measured data after each task j .

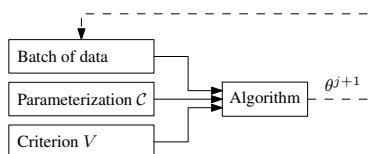


Figure 2: Batch-to-batch feedforward tuning from a system identification perspective. Based on a batch of data, parameterization C and criterion V , θ_{j+1} is determined and implemented to obtain a new batch of data.

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

$$\theta^{j+1} = Q\theta^j + Le^j, \quad (1)$$

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.

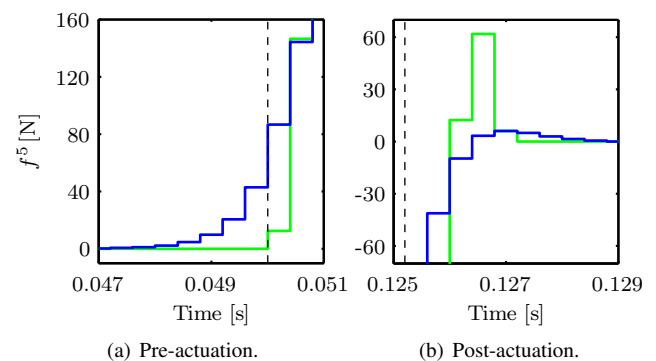


Figure 3: The rational parameterization (—) enables pre- and post-actuation of the system, in contrast to the polynomial parameterization (—). The start and end times of the motion task are indicated by black dashed lines.

References

- [1] F. Boeren, T. Oomen and M. Steinbuch, Iterative motion feedforward tuning: A data-driven approach based on instrumental variable identification, *Control Engineering Practice*, vol. 37, 11-19, 2015.
- [2] J. Bolder and T. Oomen, Rational basis functions in iterative learning control - With experimental verification on a motion system, *IEEE Transactions on Control Systems Technology*, 23(22):722-729, 2015.
- [3] D. Bristow, M. Tharayil, and A. Alleyne, A Survey of Iterative Learning Control, *IEEE Control Systems*, 26(3):96-114, 2006.
- [4] L. Ljung, *System identification - Theory for the User*, Upper Saddle River, New York, USA: Prentice Hall, 1999.
- [5] Q. Zou and S. Devasia, Preview-based stable-inversion for output tracking of linear systems, *ASME Journal of Dynamic Systems, Measurement and Control*, 121(1):625-630, 1999.