

Iterative feedforward control with application to a wafer stage

Citation for published version (APA):

Blanken, L. L. G., Boeren, F. A. J., Bruijnen, D. J. H., & Oomen, T. A. E. (2015). Iterative feedforward control with application to a wafer stage. In *34th Benelux Meeting on Systems and Control, March 24-26, 2015, Lommel, Belgium* (pp. 112)

Document status and date:

Published: 01/01/2015

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.

Iterative Feedforward Control with Application to a Wafer Stage

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@student.tue.nl

Introduction

Feedforward control enables high performance in industrial motion systems. The key performance enhancement is in general obtained by using feedforward with respect to the reference trajectory. In existing methods, typically a trade-off exists between the attainable performance and the required robustness to changes in the reference. Through new developments in feedforward control it is aimed to attain high performance for a class of reference signals.

Iterative feedforward control with a rational basis

Iterative feedforward control can attain high performance for a class of reference signals [1]. To achieve this, measured data from previous tasks is exploited in conjunction with a suitable parametrization for the feedforward controller $C_{ff}(\theta)$. The need for an approximate model of the system, as is common in ILC [2], is eliminated by formulating the approach as an instrumental variable-based estimation problem as in [3]. The corresponding control configuration is depicted in Fig. 1. The parameters θ^{j+1} in the $(j+1)^{\text{th}}$ task result from an optimization problem based on measured data from the j^{th} task.

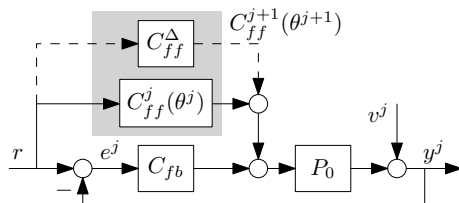


Figure 1: Control configuration for iterative feedforward control.

Existing approaches focus on a polynomial parametrization of C_{ff} , see e.g. [1], [4]. However, in [2] it is shown that for a rational system P_0 , a rational parametrization is required for C_{ff} to attain high performance for a class of reference signals. The present research aims to introduce such a parametrization in iterative feedforward control using system identification techniques.

A system identification approach to iterative feedforward control

The present research consists of three main aspects. First, a framework is presented for iterative feedforward control with a rational parametrization. This approach is based on instrumental variables, as in [3], [5]. Second, the limits of accuracy are investigated and an iterative algorithm is proposed that obtains parameter estimates θ^{j+1} with optimal accuracy in terms of variance. Third, an experimental validation of the proposed methodology is presented.

Experimental results

The proposed approach is implemented on a wafer stage. The experimental results in Fig. 2 and 3 illustrate that superior servo performance is achieved with the proposed rational parametrization for C_{ff} .

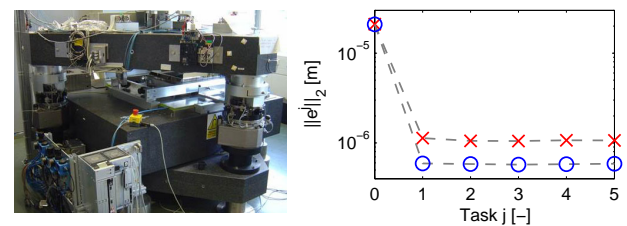


Figure 2: Wafer stage (left) and experimental results (right): superior performance is achieved with a rational parametrization (○) compared to a polynomial parametrization (×).

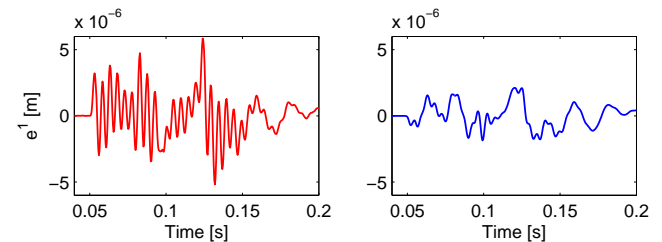


Figure 3: Time domain plot of measured error signal e^1 in the first task. Left: polynomial parametrization, right: rational parametrization.

Ongoing research

Current work is aimed at generalizing the proposed approach to multivariable systems, extensions to position-dependent behavior, and trajectory design.

References

- [1] S. van der Meulen and R. Tousain and O. Bosgra, Fixed Structure Feedforward Controller Design exploiting Iterative Trials: Application to a Wafer Stage and a Desktop Printer, *Journal of Dynamic Systems, Measurement, and Control*, 130(5):0510061-05100616, 2008.
- [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] T. Söderström and P. Stoica, Instrumental Variable Methods for System Identification, ser. LNCIS, vol. 57, Springer-Verlag, Germany, Berlin, 1983.
- [4] F. Boeren, and 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.
- [5] M. Gilson, H. Garnier, P. Young and P. Van den Hof, Optimal instrumental variable method for closed-loop identification. *IET Control Theory & Applications*, 5(10):1147-1154, 2011.

This research is supported by Philips Innovation Services.