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Advances in Optimization-Based Feedforward Tuning

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Introduction

Feedforward control is the key method to improve the servo performance of high-precision motion systems. In typical applications of motion control, a low-order feedforward controller is designed that approximates the inverse of the system. The contribution of this research is twofold:

1. Advanced feedforward controllers are proposed to enable an improved approximation of the inverse of the system,
2. A novel approach is proposed to achieve accurate and fast tuning of feedforward controllers.

Advanced Feedforward

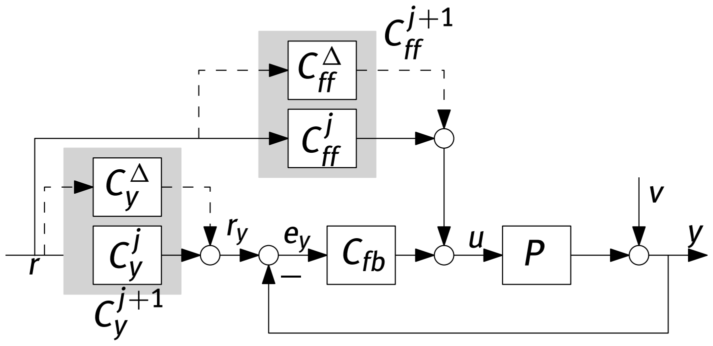
Aggressive setpoints for next-generation system excite, in addition to rigid-body dynamics (intended), also the flexible dynamics (not intended). These flexible dynamics should be explicitly adressed in feedforward control to attain high servo performance. This implies that a rational $P = \frac{A(z,\theta)}{B(z,\theta)}$ should be inverted.

Considered advanced feedforward structures:

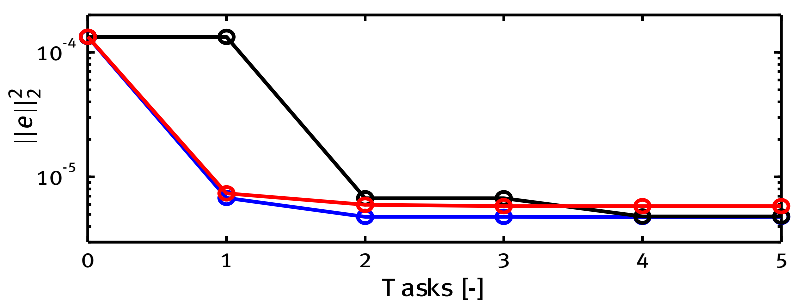
1. Feedforward and input shaping [2]
   $C_{ff} = B(z,\theta), \quad C_y = A(z,\theta).$
2. Rational Feedforward (as in [3]): $C_{ff} = \frac{B(z,\theta)}{A(z,\theta)}, \quad C_y = I.$

Improved Feedforward Tuning

Optimization-based methods for feedforward control have significant advantages over manual tuning. In this research, a new approach is proposed to determine the feedforward controller by means of a machine-in-the-loop optimization. The new theory relies on fundamental aspects in instrumental variable-based system identification [1].

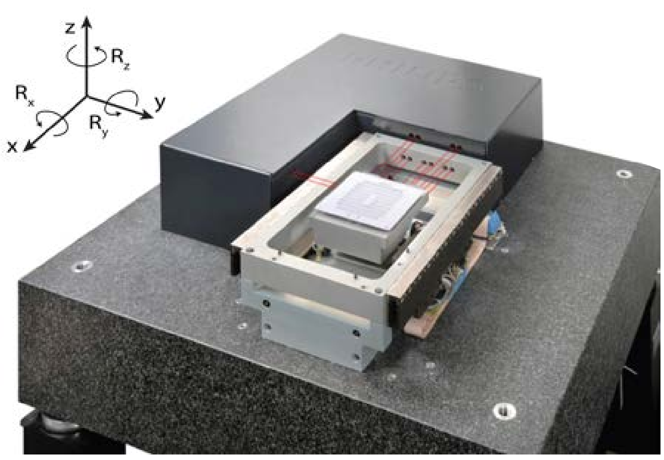


Control Configuration for optimization-based feedforward

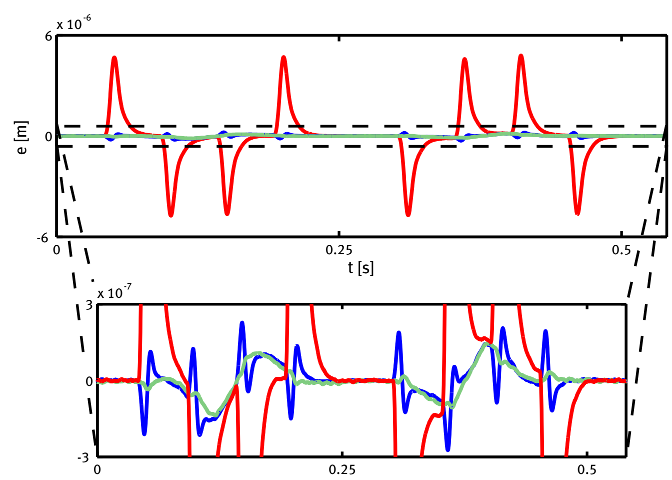


Proposed approach (blue) shows improved convergence and accuracy compared to pre-existing approaches (red/black)

Experimental Results



Nforcer experimental setup



Servo error as function of tasks - 1^{th} (red), 2^{nd} (blue) and 3^{th} (green) task

Ongoing research

1. MIMO extension
2. Integrated trajectory and feedforward design
3. Loop-shaping based approach in ILC

References

[1] F. Boeren and T. Oomen, Iterative feedforward control: a closed-loop identification problem and a solution, Proc. of the CDC, pp. 6694-6699, 2013.

[2] F. Boeren, D. Bruijnen, N. van Dijk and T. Oomen, Joint Input Shaping and Feedforward for Point-to-Point Motion: Automated Tuning for an Industrial Nanopositioning System, IFAC Mechatronics, To appear.

[3] J. Bolder, T. Oomen and M. Steinbuch, Rational Basis Functions in Iterative Learning Control - With Experimental Verification on a Motion System, IEEE Transactions on Control Systems Technology, To appear.