Advances in optimization-based feedforward tuning

Advances in Optimization-Based Feedforward Tuning

Frank Boeren[1], Dennis Bruijnen[2], Lennart Blanken[1], Maarten Steinbuch[1], Tom Oomen[1]
[1] Control Systems Technology, Dept. of Mechanical Engineering, Eindhoven University of Technology
[2] Philips Innovation Services
f.a.j.boeren@tue.nl

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. For example, the servo performance of systems with dominant rigid-body dynamics can be effectively enhanced by acceleration feedforward following the second law of Newton.

In view of stringent requirements on throughput and accuracy expected for next-generation motion systems, advances in feedforward control are needed. An increase in throughput results in more aggressive setpoints which directly influence positioning accuracy. The contribution of this research is to present two new aspects in feedforward control. First, more advanced feedforward controllers are proposed to enable an improved approximation of the inverse of the system. Second, an automated tuning approach is presented which enables accurate and fast tuning of more advanced feedforward controllers.

Regarding the first contribution, aggressive setpoints for next-generation motion system excite, in addition to rigid-body dynamics (intended), also the flexible dynamics of the system (not intended). Since acceleration feedforward is only effective at low frequencies, servo performance is limited by the low feedforward order. Hence, increasing the order of the feedforward controller improves servo performance since the inverse of a system containing performance-limiting flexible dynamics is approximated better. In this research, more advanced feedforward is proposed by establishing connections to input shaping [1] and rational feedforward design in ILC [2].

Regarding the second contribution, one of the key difficulties in feedforward control is tuning the parameters of a feedforward controller. On the one hand, manual tuning by means of trial-and-error is a widely successful approach in industrial practice. On the other hand, optimization-based methods, e.g., machine-in-the-loop optimization for feedforward control as depicted in Fig. 1, has significant advantages over manual tuning. In machine-in-the-loop optimization, the parameters of a feedforward controller are automatically tuned based on measured data from a previous task. In this research, a new approach is proposed to determine the feedforward controller by means of a machine-in-the-loop optimization [3]. The new theory relies on fundamental aspects in instrumental variable-based system identification [4]. The advantages are that the approach: i) has an increased accuracy in the presence of noise and disturbances and ii) closely resembles manual tuning.

Experimental results confirm the value of the new contributions to feedforward control, as verified on the NForcer setup depicted in Fig. 2.

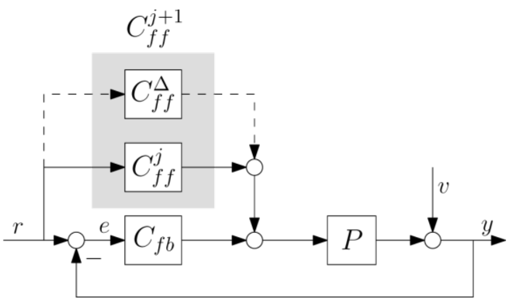

Figure 1: Two degree-of-freedom control configuration for machine-in-the-loop optimization

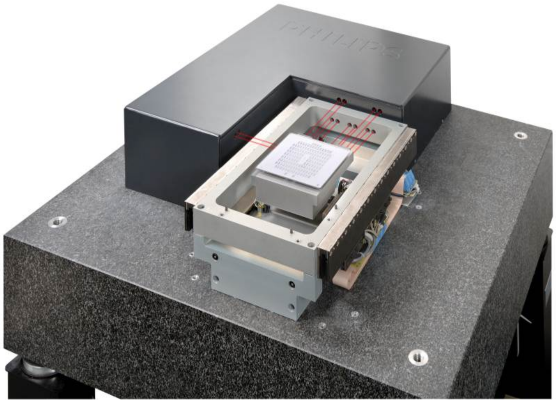

Figure 2: Nforcer experimental setup

References

[1] D. Bruijnen, N. van Dijk and J. Songtao, A practical comparison of feedforward control design techniques for high-precision motion systems, Proc. of the DSPE Conference on Precision Mechatronics, Deurne, The Netherlands, pp. 53-54, 2012.

[2] J. Bolder, T. Oomen and M. Steinbuch, Exploiting rational basis functions in iterative learning control, Proc. of the Conference on Decision and Control, Florence, Italy, pp. 7321-7326, 2013.

[3] F. Boeren and T. Oomen, Iterative feedforward control: a closed-loop identification problem and a solution, Proc. of the Conference on Decision and Control, Florence, Italy, pp. 6694-6699, 2013.

[4] T. Söderström and P. Stoica, Instrumental Variable Methods for System Identification, Springer-Verlag, Berlin, Germany, vol. 57 of Lecture Notes in Control and Information Sciences, 1983.