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Enhancing Performance and Cost-Effectiveness in Motion Control Via Multi-Rate Sampling

Jurgen van Zundert[1], Tom Oomen[1], Wouter Aangenent[2], W.P.M.H. (Maurice) Heemels[1]
[1]Eindhoven University of Technology, Department of Mechanical Engineering, Control Systems Technology group, The Netherlands
[2]ASML Research Mechatronics, Veldhoven, The Netherlands

1 Motivation

In traditional feedback control, a single sampling frequency is used for all control loops and increasing performance requirements typically lead to an increase of the sampling frequency. This is often very costly in terms of required hardware and hence there exists a trade-off between performance and cost-effectiveness, see Figure 1. Usually, this high sampling frequency is only required for some of the control loops, and not necessary in the other loops. Therefore, the trade-off can be ameliorated by use of multi-rate control: using different sampling frequencies in the different control loops.

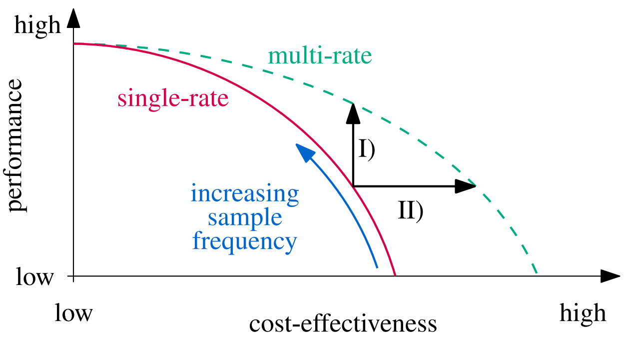

Figure 1: The performance/cost-effectiveness trade-off observed in classical control can be enhanced by use of multi-rate control: I) higher performance for equal cost; or II) same level of performance for lower cost.

Multi-rate control has a strong potential in many motion control problems, including dual stages, sampled-data control [1], master/slave configurations [2], thermo-mechanical applications, and non-equidistant sampling [3].

Although a large number of theoretical issues have been solved, the design of multi-rate controllers is by no means straightforward. Indeed, multi-rate systems are LPTV (linear, periodically time-varying), so common design techniques for LTI systems are not directly applicable. The aim of this research is to develop a systematic design framework for multi-rate control. The framework is demonstrated in the context of wafer scanner systems.

2 Case study: dual stage in wafer scanner systems

Wafer scanner systems perform a key role in the automated production of integrated circuits (ICs). An important aspect is the positioning of the wafer stage containing the wafer with ICs. The wafer stage covers a stroke of a meter, while at the same time it achieves a position accuracy in the order of nanometers. The large ratio between stroke and accuracy is often addressed using a dual stage approach: a coarse stage (long stroke) used for micrometer accuracy, with on top a fine stage (short stroke) used for nanometer position accuracy. Since the long stroke requires a much lower accuracy than the short stroke, its sampling frequency can be much smaller. This opens up the possibility of an improved accuracy-cost trade-off by using a multi-rate approach.

3 Approach

The research in this paper focuses at multi-rate feedfoward controller design, since for motion applications feedforward constitutes the largest part of the system's control input. For multi-rate feedback controller design see, for example, [4]. In the developed framework, multi-rate systems are described using the finite-time/lifting framework [1]. The framework is used for norm-based feedforward controller optimization along the lines of [5]. Initial results, including simulations of the dual stage case study, are reported in [6].

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References

[1] Tongwen Chen and Bruce A. Francis. "Optimal Sampled-Data Control Systems", *Springer*, London, Great Britain, 1995.

[2] Cees J.H. Lambregts, Marcel F. Heertjes, and Bartel J. van de Veek, "Multivariable Feedback Control in Stage Synchronization", *in 2015 American Control Conference*, pages 4149-4154, Chicago, Illinois, 2015.

[3] Jurgen van Zundert, Tom Oomen, Dip Goswami, and W.P.M.H. (Maurice) Heemels, "On the Potential of Lifted Domain Feedforward Controllers with a Periodic Sampling Sequence", [in preparation].

[4] Tom Oomen, Marc van de Wal, and Okko Bosgra, "Design framework for high-performance optimal sampled-data control with application to a wafer stage", *International Journal of Control*, 80(6):919-934, 2007.

[5] Stan H. van der Meulen, Rob L. Tousain, and Okko H. 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):051006:1-16, 2008.

[6] J.C.D. van Zundert, J.L.C. Verhaegh, W.H.T.M. Aangenent, T. Oomen, D. Antunes, and W.P.M.H. Heemels. "Feedforward for Multi-Rate Motion Control: Enhanced Performance and Cost-Effectiveness", *in 2015 American Control Conference*, pages 2831-2836, Chicago, Illinois, 2015.