Gaussian Process Repetitive Control for Suppressing Spatial Disturbances

Gaussian Process Repetitive Control for Suppressing Spatial Disturbances: With Application to a Substrate Carrier System

Noud Mooren [1,*], Gert Witvoet [1,2], Tom Oomen [1]

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

[2] TNO Technical Sciences, Optomechatronics Departments, Delft, The Netherlands. *Email: n.f.m.mooren@tue.nl

1 Background

Motion systems are often subject to disturbances such as, cogging, commutation errors, gearings and imbalances, which are position-dependent disturbances, i.e., induced by an underlying cause in the spatial domain, see [1]. In the case that a rotary system operates with a constant operating velocity, or a linear system performs a repetitive motion task, these disturbances appear periodic in the time domain. However, if the operating conditions deviate, the disturbances appears a-periodic in the time domain while being periodic in the spatial domain [2].

2 Problem formulation

Classical repetitive control (RC) is not effective for disturbances that appear with varying period or a-periodic in the time domain [3]. This implies that classical RC with a memory loop in the time domain is not applicable to the aforementioned motion systems. The aim of this paper is to develop an RC approach for position-dependent disturbances.

3 Spatial Repetitive Control

The key idea is to construct a memory loop in the spatial domain. This is done by means of a Gaussian Process (GP) [4]. The time-domain signals are transformed to the spatial domain and stored in the GP, see Fig. 1. Furthermore, a suitable periodic kernel is developed to include periodicity and enforce smoothness in the GP. In addition, RC is developed using the traditional design philosophy [3].

4 Simulation case study

A simulation study is performed to show that classical RC fails if the disturbance period varies, whereas, the spatial RC approach is able to deal with these varying disturbances successfully as shown in Fig. 2.

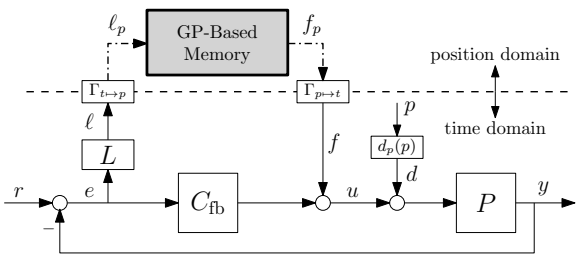

Figure 1: Spatial RC framework, with learning filter L.

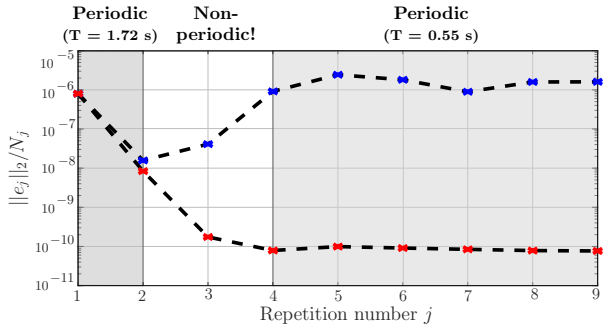

Figure 2: The 2-norm of the error with classical RC (×) and spatial RC (×). The disturbance is periodic at first, then non-periodic (after $j = 2$) and becomes periodic again (after $j = 4$) with a different period time.

5 Conclusions & Ongoing research

A new spatial RC approach is presented for rejection of disturbances that are periodic in a spatial domain and may appear a-periodic in the time domain. Furthermore, it deals efficiently with the non-equidistant observations through a GP-based memory loop. The potential of this methods is shown and ongoing work aims at the implementation on a substrate carrier system.

6 Acknowledgments

The research leading to these results has received funding from the European Union H2020 program under grant agreement n. 637095 (Four-By-Three) and ECSEL-2016-1 under grant n. 737453 (I-MECH).

References

[1] Ahn, H.S., Chen, Y., and Dou, H. (2005). State-periodic adaptive compensation of cogging and coulomb friction in permanent magnet linear motors, In Proceedings of the American Control Conference, 3036-3041

[2] Chen, C.L. and Chiu, G.T.C. (2008). Spatially periodic disturbance rejection with spatially sampled robust repetitive control. Journal of Dynamic Systems, Measurement, and Control, 130(2), 021002.

[3] Longman, R.W. (2010). On the theory and design of linear repetitive control systems. European Journal of Control, 16(5), 447-496.

[4] Williams, C.K. and Rasmussen, C.E. (2006). Gaussian processes for machine learning. MIT press Cambridge, MA, 2