Multi-Period Repetitive Control: Sequential Design Approach Applied to a Roll-to-Roll Industrial Printer

Lennart Blanken[1], Sjirk Koekebakker[2], Tom Oomen[1]
[1]Eindhoven University of Technology, Dept. of Mechanical Engineering, Control Systems Technology, The Netherlands
[2]Océ Technologies B.V., Venlo, The Netherlands. Email: l.l.g.blanken@tue.nl

Background

Many disturbances in mechatronic applications involve the sum of multiple periodic signals. Their summation is not necessarily periodic, e.g., consider two signals with period times 1 and π, or may have a large common period. A relevant example is roll-to-roll printers, where multiple rotating components in the paper handling cause disturbances in the paper positioning, see Figure 1 for a measurement.

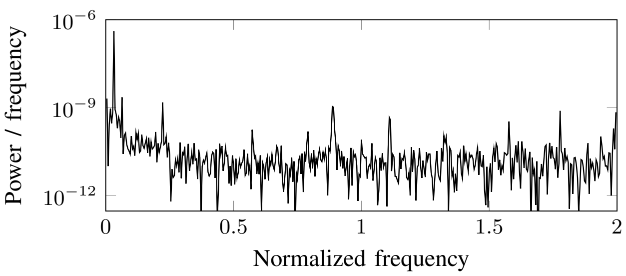

Figure 1: Power spectral density of disturbances in industrial roll-to-roll printer, indicating multiple dominant periodic contributions.

Problem Formulation

Repetitive control (RC) enables high performance for systems that are subject to periodic disturbances. However, standard RC typically i) amplifies disturbances that are non-periodic [1], and ii) may yield unacceptably slow convergence when implemented for the least common multiple (lcm) of multiple periodic disturbance. In addition, joint implementation of multiple RCs, each aiming to reject one periodic contribution, may lead to stability and performance issues due to interaction between controllers.

Approach

To enable high performance with fast convergence, a multi-period RC framework with a cascaded interconnection of multiple RCs is proposed, see Figure 2. A sequential design approach with closed-loop stability guarantee is presented. The approach builds upon results in [2], and consists of the following steps:

1. Initialize index $i = 1$.
2. Construct $u_i \mapsto e_i : G_i^{\text{eq}} = \begin{cases} G & \text{if } i = 1, \\ \frac{1+\widehat{G}R_{i-1}}{1+G_{i-1}^{\text{eq}}R_{i-1}} G_{i-1}^{\text{eq}} & \text{if } i > 1. \end{cases}$
3. Design R_i based on G_i^{eq}, and implement.
4. Until $i = n$, set index $i \to i + 1$ and return to step 2.

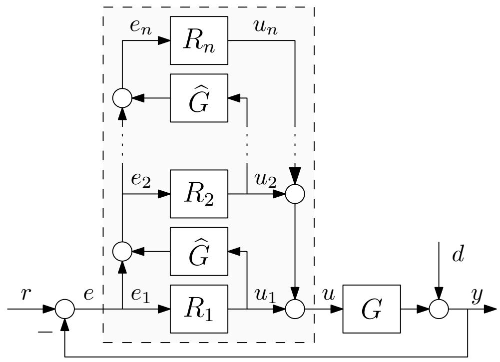

Figure 2: Multiple repetitive controllers R_i in a cascaded structure, and approximate model $\widehat{G}$ of plant G to reduce interaction.

Experimental Results

The proposed approach is compared to traditional methods by application to an industrial roll-to-roll printer. A disturbance $r = r_1 + r_2$ is applied, with respective period-times N_1 and $N_2 = \frac{8}{3}N_1$ such that $\text{lcm}(N_1, N_2) = 8N_1 = 3N_2$. The results in Figure 3 show the achieved improvements.

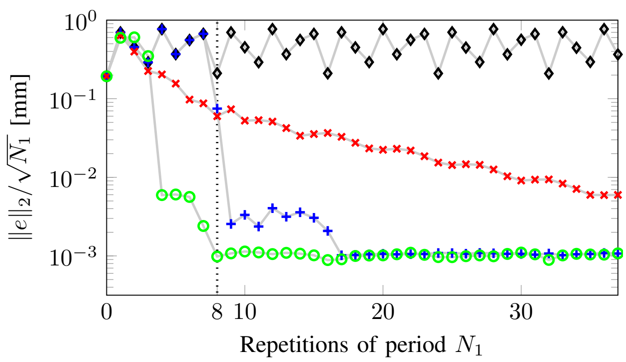

Figure 3: Results: the developed cascaded multi-period RC (○) results in fast convergence, whereas parallel multi-period RC (×) leads to extremely slow convergence, and single-period RC (+) updates only every $\text{lcm}(N_1, N_2) = 8N_1$ samples, indicated by the dotted line. The error obtained without RC is shown as (◇).

References

[1] G. Pipeleers, B. Demeulenaere, J. De Schutter, and Jan Swevers, "Robust high-order repetitive control: Optimal performance trade-offs," Automatica, 44(10):2628-2634, 2008.

[2] M. Hovd and S. Skogestad, "Sequential design of decentralized controllers," Automatica, 30(10):1601-1607, 1994.