Flexible learning with prior knowledge: iterative learning control with sampled-data characterized basis functions

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1 Background

Performance and flexibility are typical trade-offs in mechatronic systems. Linearly parameterized feedforward control has both performance and flexibility [1]. The choice of parameterization should be determined by prior knowledge such as sampled-data characteristics.

2 Problem formulation

The controlled system is shown in Figure 1. The goal is to minimize the continuous-time tracking error $e(t)$ using the feedforward signal $f[k] = \Psi[k]\theta$ with parameter θ. For instance, Ψ is parameterized as $\Psi = [r, \xi r, \xi^2 r]$ for a mass-damper-spring system with a differentiator ξ. Typically, n^{th} order backward difference is used as n^{th} order differentiator ξ_{BD}^n to design the feedforward parameterization [2] as

$$\xi_{BD}^n = \left(\frac{1-z^{-1}}{T_s}\right)^n. \tag{1}$$

This does not explicitly address the zero-order-hold characteristic of the step-like input shape restriction.

3 Approach

The aim is to develop flexible feedforward control with intersample consideration. The approach considers the feedforward parameterization with basis functions for flexibility that are designed with sampled-data characteristics such as zero-order-hold and multirate state tracking [3].

4 Results

The stable inversion of the n^{th} order integrator discretized by zero-order-hold is used as n^{th} order differentiator ξ_{SI}^n to design the feedforward parameterization as

$$\xi_{SI}^n = \left\{\mathscr{Z}\left(\frac{1-e^{-sT_s}}{s}\cdot\frac{1}{s^n}\right)z\right\}^{-1}. \tag{2}$$

The experimental result in the single inertia system $G(s) = \frac{1}{Js^2}$ with the acceleration feedforward parameterization is shown in Figure 2. The sampling time is $T_s = 20\,\text{ms}$. It shows that the feedforward parameterization using stable inversion $\Psi_{SI}[k] = \xi_{SI}^2 r[k+1]$ outperforms that using backward difference $\Psi_{BD}[k] = \xi_{BD}^2 r[k+1]$.

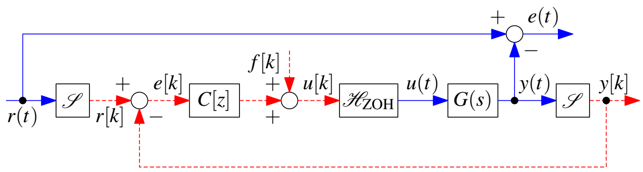

Figure 1: Controlled system discretized by zero-order-hold $\mathscr{H}_{\text{ZOH}}$ and sampler $\mathscr{S}$. The discrete-time signal (- - -) can be controlled and the continuous-time signal (——) is the performance variable.

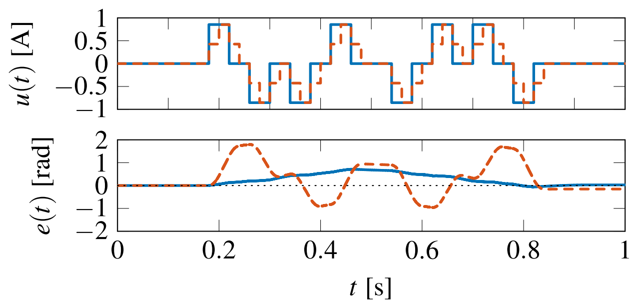

Figure 2: Experimental result of a reference tracking problem, with a parametric feedforward using stable inversion (——), that outperforms backward difference (- - -), reducing RMS and MAX errors by a factor of two.

5 Ongoing research

The ongoing research focuses on extending the feedforward parameterization that considers higher-order characteristics.

Acknowledgements

This research is granted from Tateishi Science and Technology Foundation.

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