

# 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  $\theta$ . For instance,  $\Psi$  is parameterized as  $\Psi = [r, \xi r, \xi^2 r]$  for a mass-damper-spring system with a differentiator  $\xi$ . Typically,  $n^{\text{th}}$  order backward difference is used as  $n^{\text{th}}$  order differentiator  $\xi_{BD}^n$  to design the feedforward parameterization [2] as

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

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

## 3 Approach

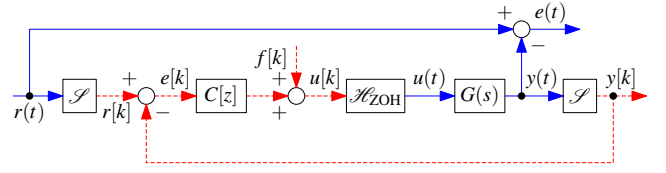
The aim is to develop flexible feedforward control with intersample consideration. The approach considers the feedforward parameterization with basis functions for flexibility that are designed with sampled-data characteristics such as zero-order-hold and multirate state tracking [3].

## 4 Results

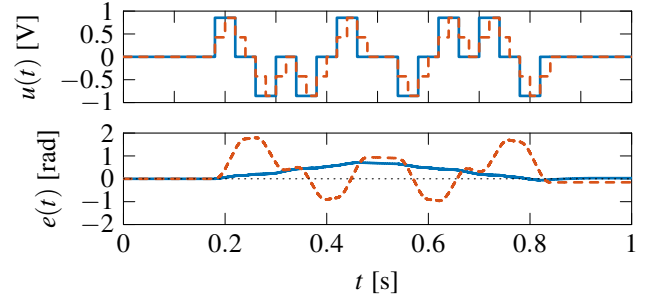
The stable inversion of the  $n^{\text{th}}$  order integrator discretized by zero-order-hold is used as  $n^{\text{th}}$  order differentiator  $\xi_{SI}^n$  to design the feedforward parameterization as

$$\xi_{SI}^n = \left\{ \mathcal{L} \left( \frac{1 - e^{-sT_s}}{s} \cdot \frac{1}{s^n} \right) z \right\}^{-1}. \quad (2)$$

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  $T_s = 20$  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  $\mathcal{H}_{ZOH}$  and sampler  $\mathcal{S}$ . 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

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### References

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