

Play-Back Buffers in Networked Control Systems

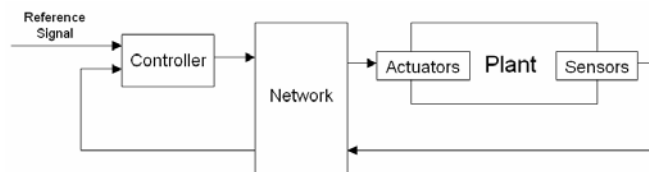
Evaluation and Design

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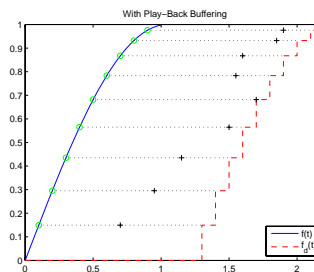
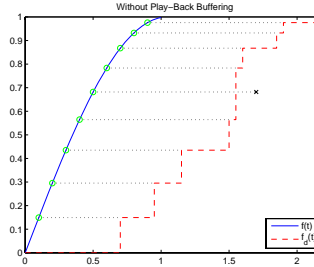
NCS Paradigm



- Feedback loop closed over a network
- A key challenge: time-varying, random loop delay
- Idea: Extend methods for dealing with constant loop delay to this setting

Play-Back Buffers

- MPC performs poorly with time-varying delays
- Play-back buffers hold samples until a specified play-back time is reached (Liberatore 2006)
- The loop delay becomes more deterministic, significantly improving MPC performance
- Drawback: an effective increase in loop delay



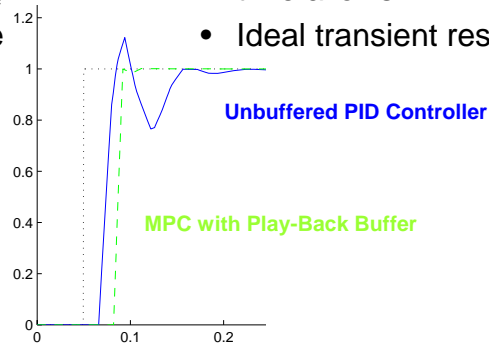
Evaluation: Two types of controllers

Unbuffered PID Controller

- Controller reacts immediately
- Design gains for the delay distribution
- More conservative transient response

MPC with Play-Back Buffer

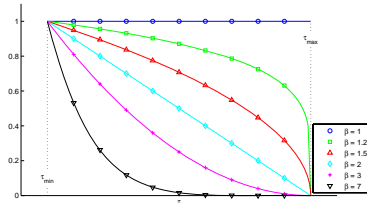
- Controller reacts after play-back delay, τ_{pb}
- Gains can be as aggressive as sampling time allows
- Ideal transient response



Evaluation: Setup

- First-order plant
- Delay distribution
 - Beta distribution (a bounded interval, so we can set $\tau_{pb} = \tau_{max}$)
 - Out-of-order drops are removed
- Obtain PID gains for each delay distribution via optimization of a tuning rule delay parameter, τ (O'Dwyer 2006)

$$G(s) = \frac{1}{0.1s + 1}$$



$$K_c = \frac{\left(0.7645 + \frac{0.6032}{\tau/T}\right)(T + 0.5\tau)}{K(T + \tau)}$$

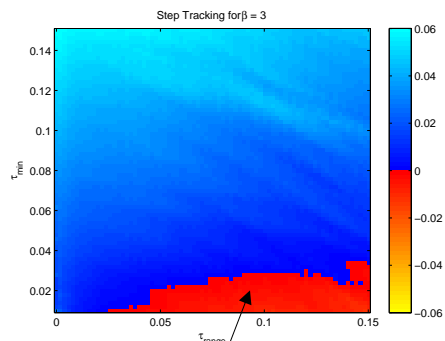
$$T_i = T + 0.5\tau$$

$$T_d = \frac{0.5T\tau}{T + 0.5\tau}$$

$$0.05 \leq \frac{\tau}{T} \leq 6$$

Performance Comparisons

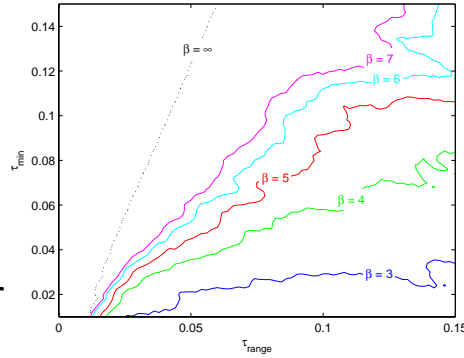
- Costs are compared by subtraction
- No randomness in cost for MPC with play-back buffer
- Randomness in cost for unbuffered PID controller is smoothed over several steps



When τ_{min} is low and τ_{range} is high, unbuffered PID control is superior

Performance Comparisons

- Isocurves of equal cost are particularly interesting features of these cost surfaces
- As β increases (i.e., distribution is closer to τ_{\min}), unbuffered PID control is superior over a larger parameter range



Design: Choosing τ_{pb}

- Analytical Approximation Method

- In practical situations, choosing $\tau_{pb} < \tau_{\max}$ often gives improved performance

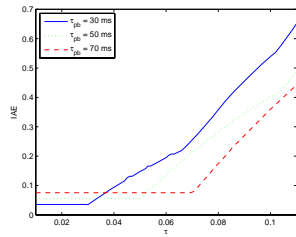
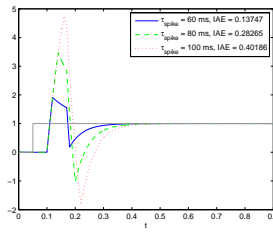
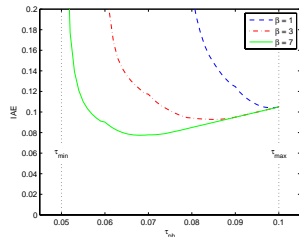
- Define a cost associated with a loop delay and a play-back delay using the worst-case delay spike

- Delay spike cost as a function of loop delay for different play-back delays

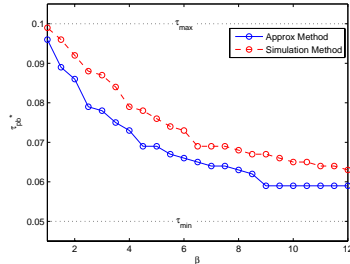
$$J_{spike}(\tau, \tau_{pb})$$

$$J_{pred}(\tau_{pb}) = \sum_{i=1}^N P(\tau_i) J_{spike}(\tau_i, \tau_{pb})$$

$$\tau_{pb}^* = \arg \min_{\tau_{pb}} J_{pred}(\tau_{pb})$$

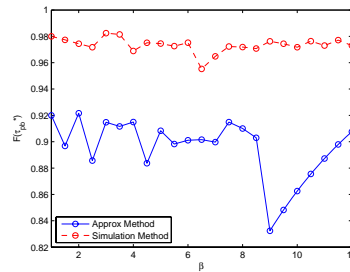


Design: Choosing τ_{pb}

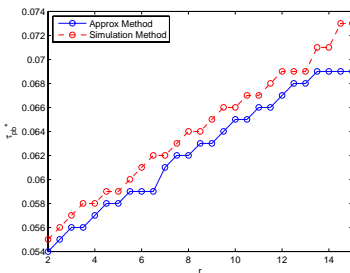


- Finding optimal τ_{pb} for the beta distribution

- Relating the optimal play-back delay to the CDF of the delay distribution

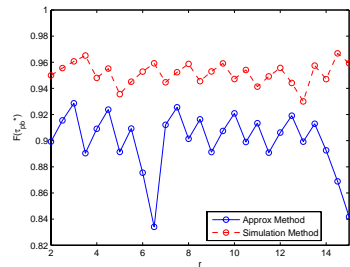


Design: Choosing τ_{pb}



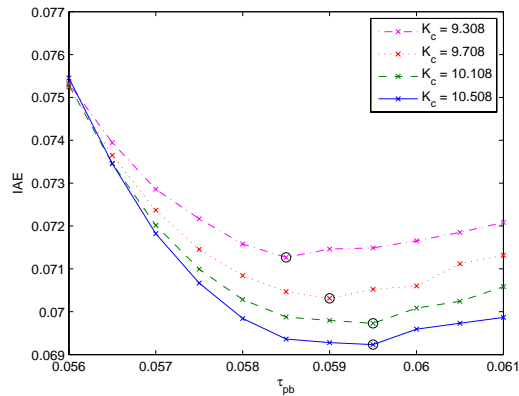
- Optimal τ_{pb} for a heavy-tailed distribution (gamma dist. for body, Pareto dist. for tail, see (Liberatore 2006))

- Relating the optimal play-back delay to the CDF of the delay distribution



Choosing PI Gains

Can performance be improved using more conservative gains and a more aggressive play-back delay? (Recall: Most IAE due to delay, not transient response)



$r = 5, \tau_{\min} = 50 \text{ ms}$

Recap

- Studied the value of removing uncertainty in the loop delay using a play-back buffer
- Explored design issues in the play-back buffer setup, including an approximation method for the choice of τ_{pb}

Future Work

- More advanced play-back implementations, including, e.g., variable sampling time
- Analytical results
- Robustness analysis

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References

- V. Liberatore. Integrated play-back, sensing, and networked control. In *IEEE Infocom*, 2006.
- A. O'Dwyer. Handbook of PI and PID Controller Tuning Rules. Imperial College Press, London, England, Second edition, 2006.