Control System Design

Lecture 6

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Elective Course in Mechatronics Engineering
Credits (2/2/3)

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Internal Model Control (IMC): Youla Parametrization

Prerequisites for Youla Parametrization

- Stable plant: $G(s)$, positive relative degree

Goal

- Design $T(s) = Q(s)G(s)$
- Determine $Q(s)$ stable and with non-negative relative degree
- Compute controller $C(s) = \frac{Q(s)}{1-T(s)}$

Block Diagram Representation of Youla Parametrization

Gap 1

Internal Model Control (IMC): Equivalent Representation

IMC-Control Loop

Gap 2

$\Rightarrow$ No feedback if the plant model is exact and there is no disturbance

Behavior for exact Plant Model

- $T = QG$
- $S = 1 - QG$

Internal Model Control (IMC): Non-exact Plant Model

Behavior for non-exact Plant Model

$$T = \frac{C\hat{G}}{1 + C\hat{G}} = \frac{\frac{Q}{1-QG}\hat{G}}{1 + \frac{Q}{1-QG}\hat{G}} = \frac{Q\hat{G}}{1 + Q(\hat{G} - G)}$$

$$S = \frac{1}{1 + \frac{Q}{1-QG}\hat{G}} = \frac{1 - QG}{1 + Q(\hat{G} - G)}$$

Robustness of IMC

- Assume $\hat{G} = G(1 + \delta G)$
- Assume upper bound estimate for uncertainty $|\delta G(s)| < B(s)$
- Stability of the IMC-loop requires $|Q(j\omega)G(j\omega)B(j\omega)| < 1$ for all ω

Smith Predictor: Time-Delay Plant

Transfer function

$$G(s) = \tilde{G}(s)e^{-s\tau}$$

- Time-delay: τ

Example

Gap 3

Smith Predictor: Basics

Prerequisites

- Delay plant: $G(s) = \tilde{G}(s)e^{-s\tau}$, $\tilde{G}(s)$ rational in s

Goal

- Design of preliminary controller $\hat{C}(s)$ without delay component $e^{-s\tau}$
- Consideration of delay in particular controller structure

Gap 4

Smith Predictor: Properties

Controller Structure

- Compensate delayed plant reaction by parallel model $\hat{G}(s)e^{-s\tau}$ (ideally $\tilde{G}(s) = \hat{G}(s)$ and $y = \hat{y}$)
- Ideally, control loop is formed by $\hat{C}(s)$ and $\hat{G}(s)$ (predicts reaction of plant without delay)
  $\Rightarrow$ Controller design for $\hat{G}(s)$
- Plant output y follows internal output $\tilde{y}$ with delay τ

Equivalent Loop

Gap 5

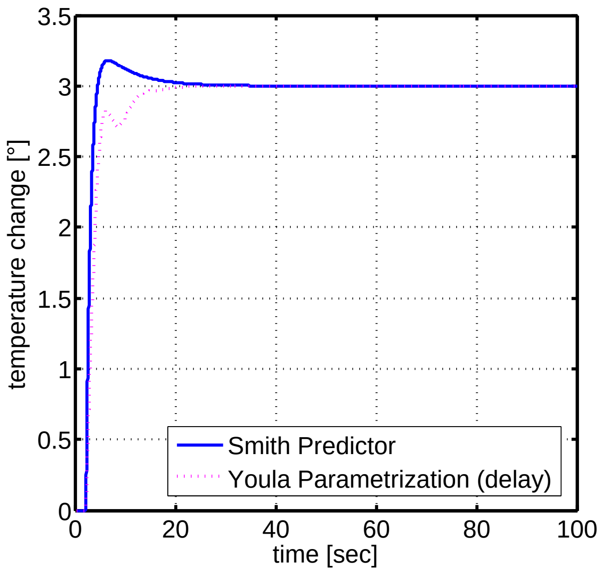
Smith Predictor: Example

Temperature control

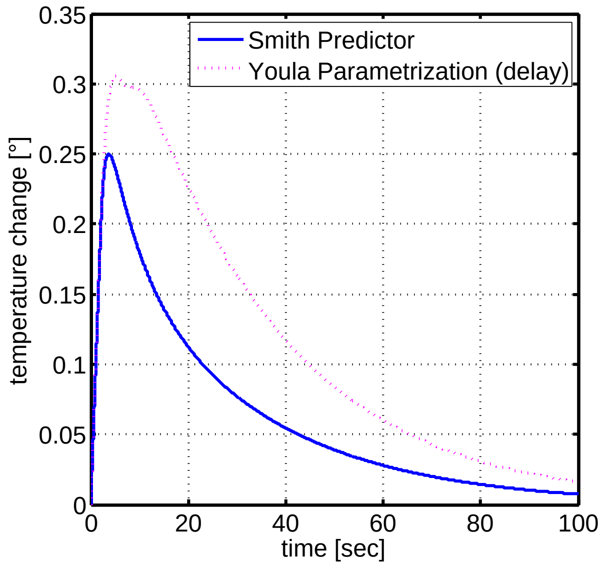
Gap 6

Youla Parametrization: Output Trajectories

Plant Input Step



Plant Disturbance Step



$\Rightarrow$ Reference tracking follows designed closed loop with delay 2

$\Rightarrow$ Disturbance rejection depends on design of $\hat{C}$

Smith Predictor: Concluding Remarks

Usage

- Stable delay plants
- Standard design for delay-free part of the plant
- "Delay outside the loop"

Limitations

- Not applicable to instable plants
- Possible degradation of disturbance rejection due to controller structure