Fuzzy Model Reference Learning Control

ME 697Y

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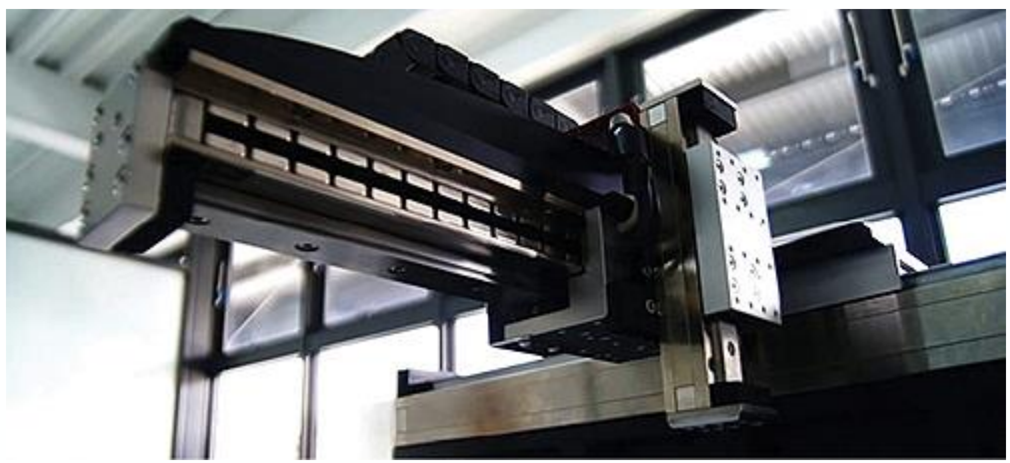
4/2/24

PURDUE UNIVERSITY | School of Mechanical Engineering

Linear Motion Control

- High-speed and high-accuracy required for modern mechanical systems like machine tools
- Can be realized using direct drive linear motors
- <u>Challenge</u>: uncertainties and nonlinearities have a significant effect on the load, making control difficult
- In literature, advanced control techniques like MRAC, H_∞, disturbance observer have been applied



Linear motor - linearmotiontips.com

Modeling

Simplified model of iron-core linear motor:

$$M_e\,\ddot{y} = u - B\,\dot{y} - F_{sc}(\dot{y}) - F_{cog}(y) + d(t)$$

where

y - position of the linear motor,

M_e - equivalent inertia of linear motor plus load

u – control voltage applied to the driver

B – lumped viscous damping friction force

$F_{sc}(\dot{y})$ – Coulomb friction

$$F_{sc}(\dot{y}) = A_{sc}\mathrm{sat}(k_f\dot{y})$$

$F_{cog}(y)$ – magnetic cogging force

$$F_{cog}(y) = A_{cog1}\sin\left(\frac{2\pi}{P}y\right) + A_{cog3}\sin\left(\frac{6\pi}{P}y\right)$$

$d(t)$ - external disturbance forces

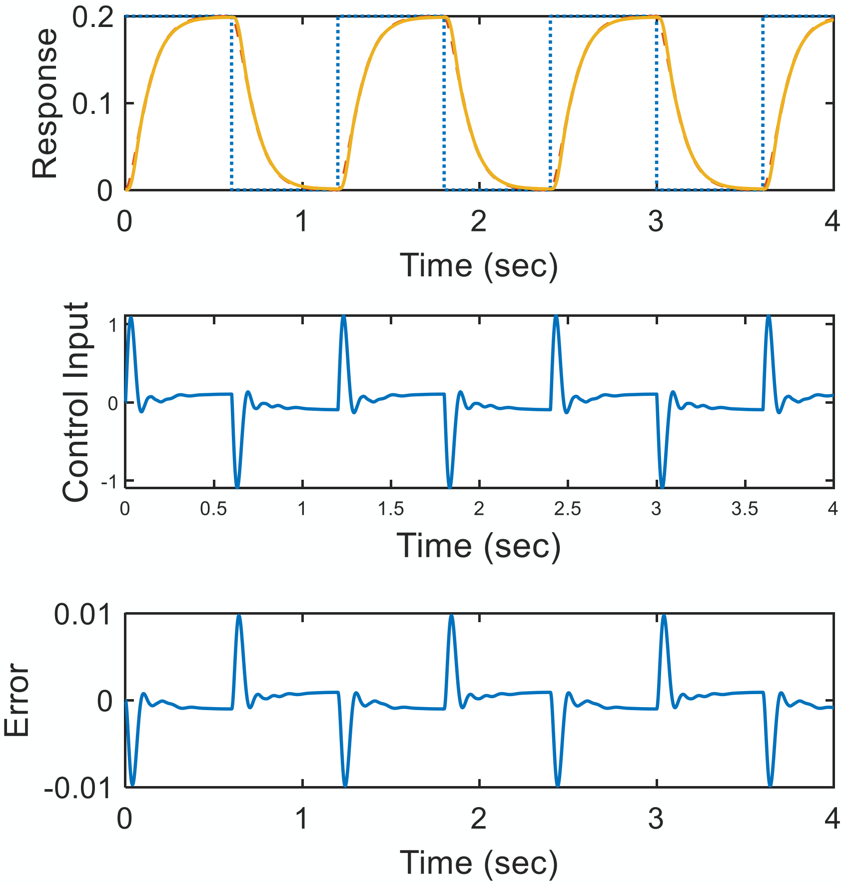
Parameter uncertainty:

$$M_e \in (0.025, 0.085),$$
$$B \in (0.1, 0.35),$$
$$A_{sc} \in (0.1, 0.15),$$
$$A_{cog1} \in (0.01, 0.05),$$
$$A_{cog3} \in (0.01, 0.05)$$

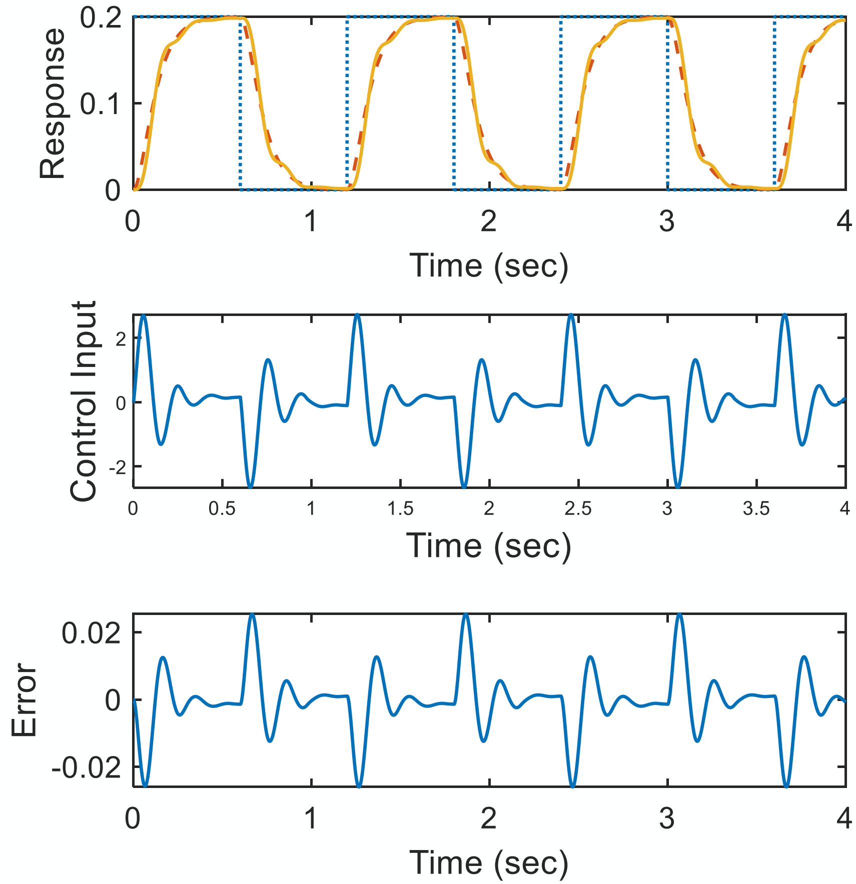
PID control of linear motor, $d(t) = 0$

$K_p = 100, K_i = 10, K_d = 1$

PID, parameter set 1

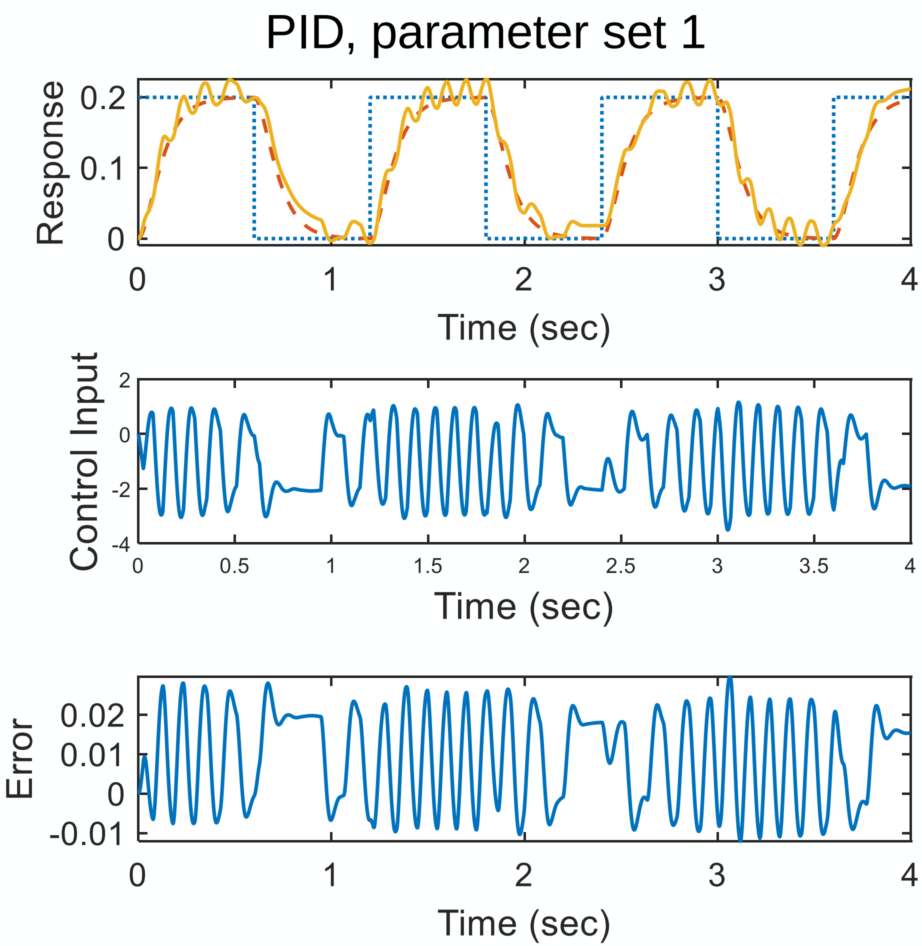


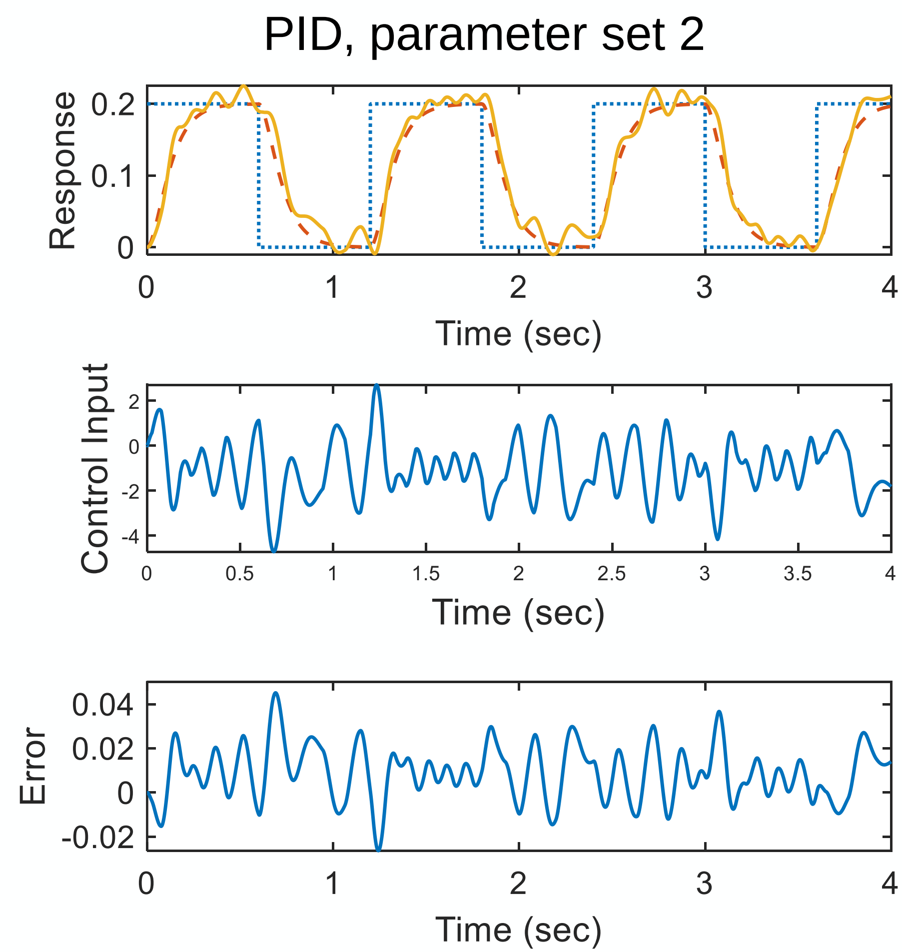
PID, parameter set 2



PID control of linear motor, $d(t) = 1 + (-1)^{round(10sin(2t))}$

$K_p = 100, K_i = 10, K_d = 1$

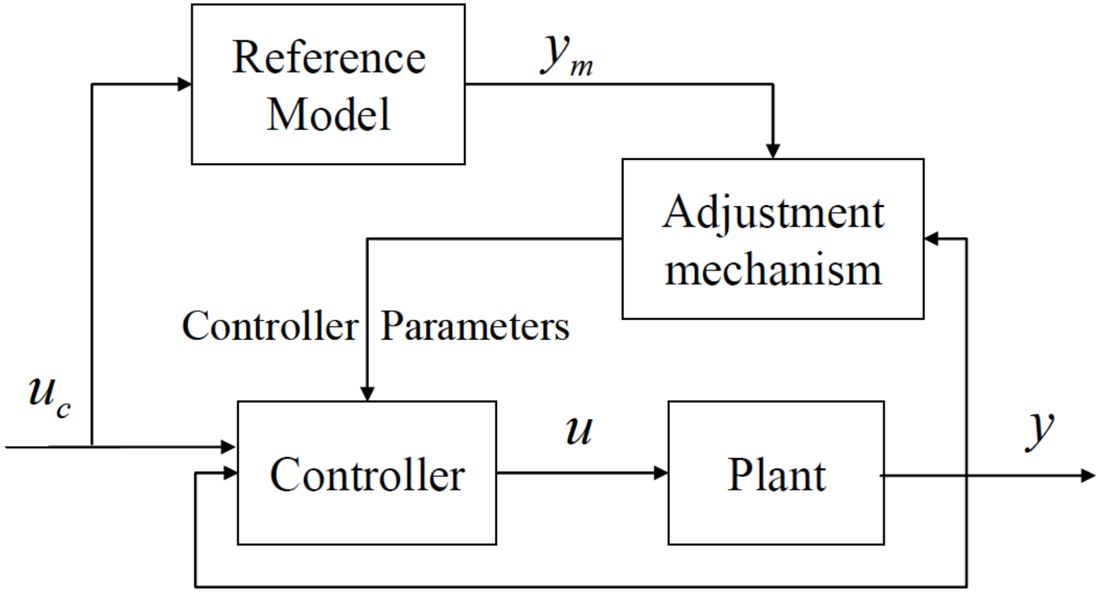




Model reference adaptive control (MRAC)

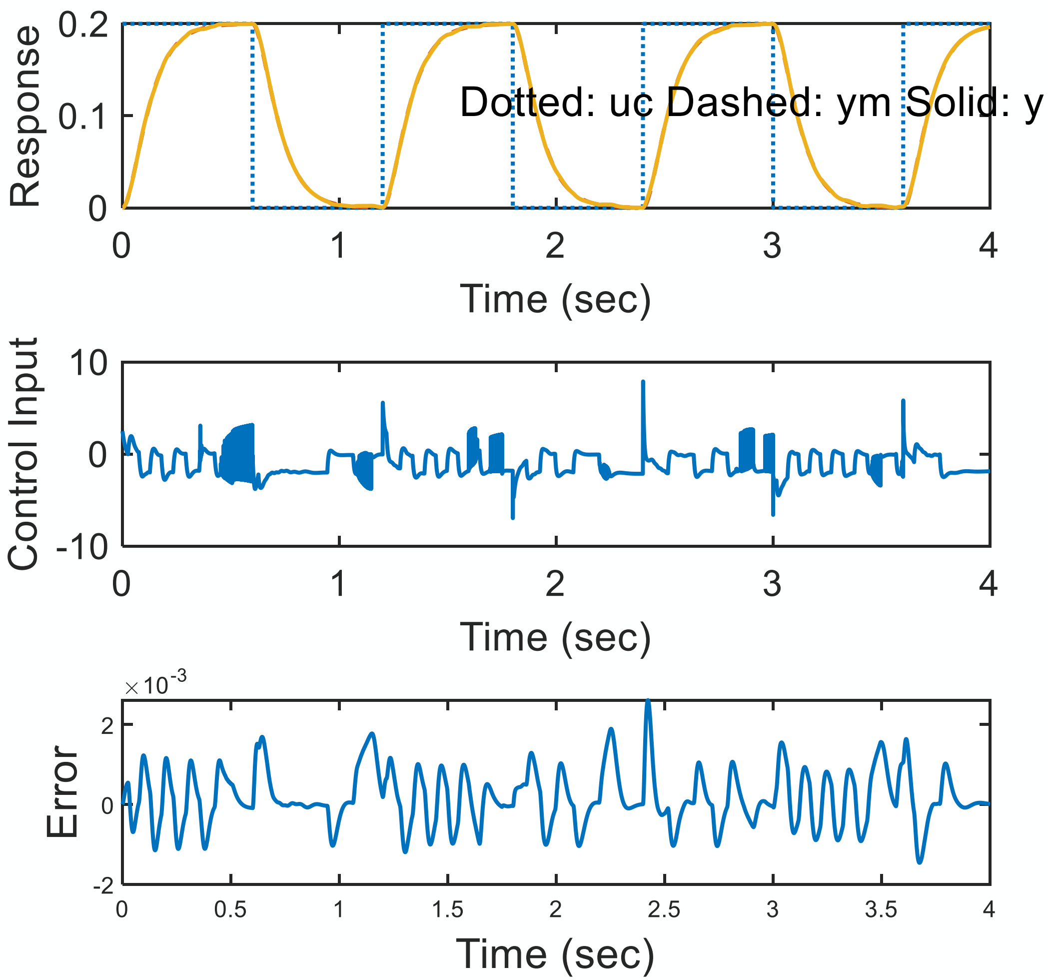
- MIT Rule
  - Adjust parameters such that the loss function $J(\theta) = \frac{1}{2}e^2, e = y - y_m$ is reduced.
- Requires parameter estimation (indirect)
  - $\dot{\theta} = -\Gamma \varphi e$
- $u = u_a + u_s$
  - u_a is model compensation
  - u_s is stabilizing feedback

Reference model:
2^{nd} order system with $\omega_n = 15$ and $\zeta = 1$

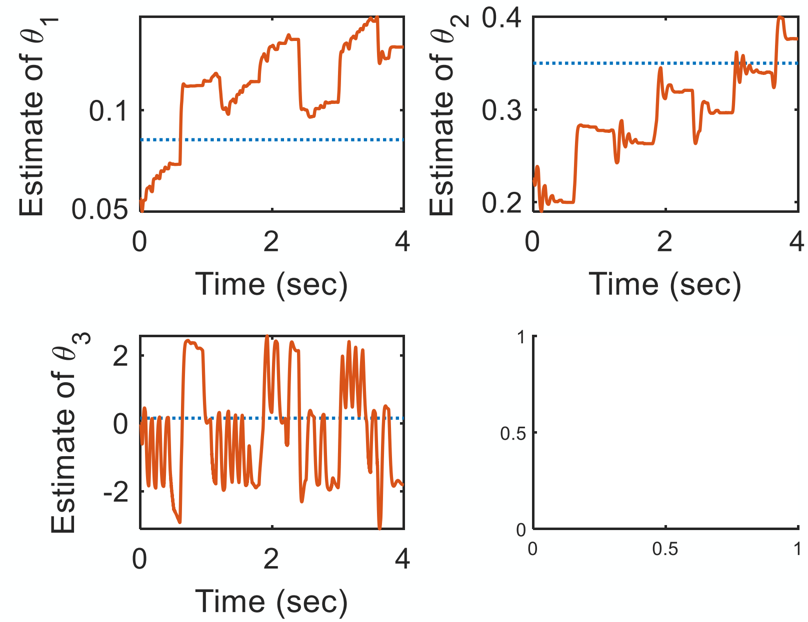


MRAC, linear motor

MRAC, parameter set 2, $d(t) = 1 + (-1)^{round(10sin(2t))}$

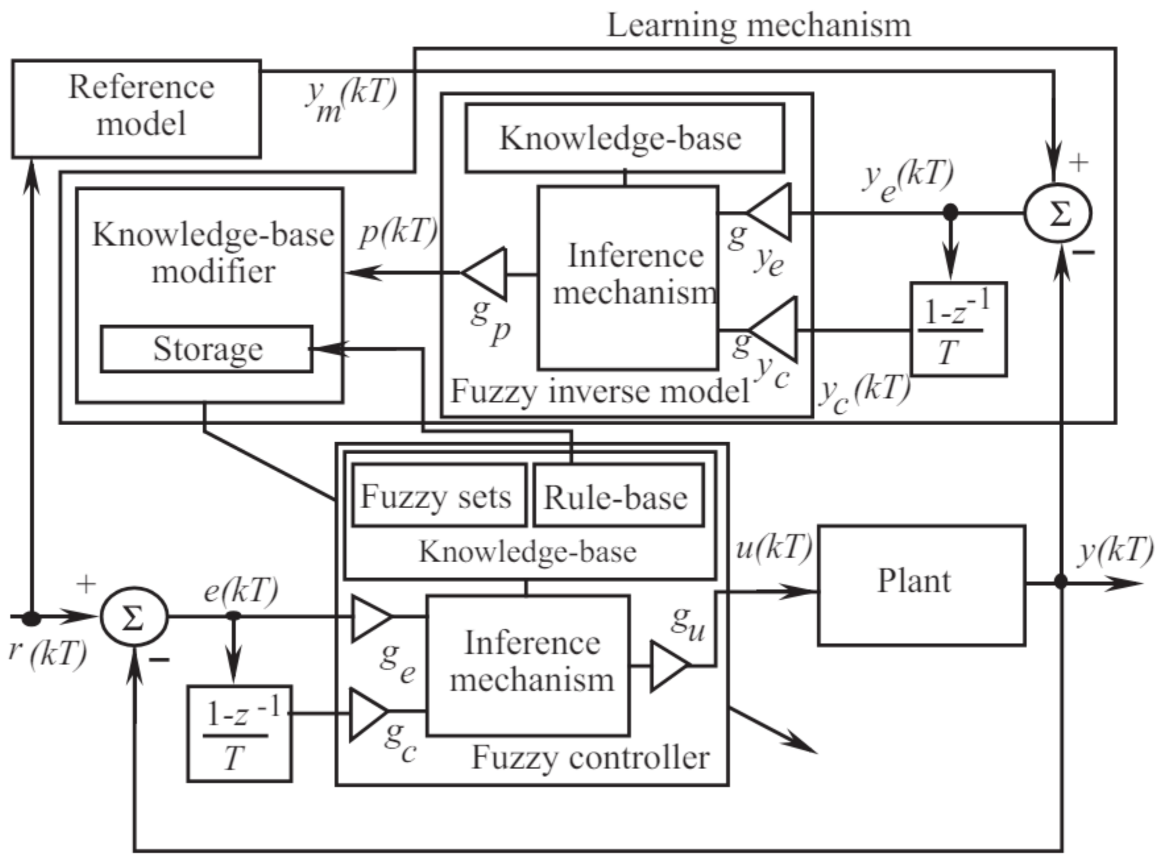


Parameter estimation:



Fuzzy model reference learning control (FMRLC)

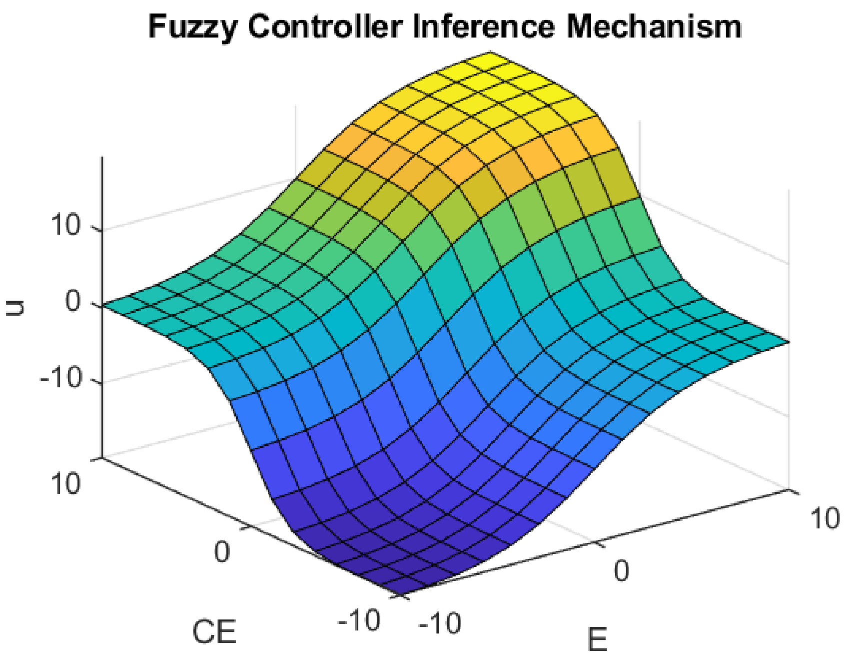
- Fuzzy controller
- Fuzzy inverse model
  - Characterizes how to change the plant inputs to force the plant output to be as close as possible to reference model
  - Inputs are $y_e(kT)$ and $y_c(kT)$
  - Normalizing scaling factors: g_{y_e}, g_{y_c}, g_p
- $u(kT) = \underline{u}(kT) + p(kT)$
  - $p(kT)$ from fuzzy inverse model shifts control action $\underline{u}(kT)$from fuzzy controller alone

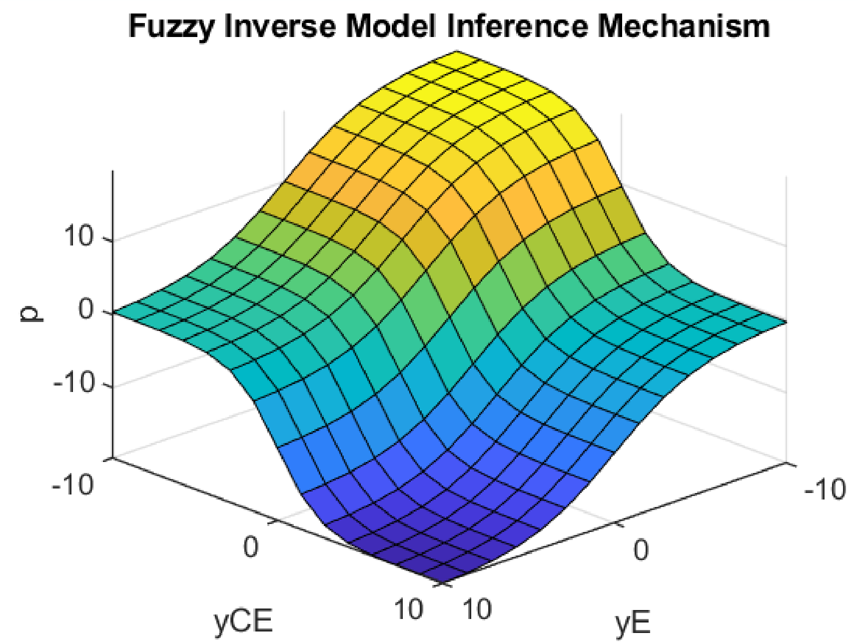


FMRLC architecture,
Layne, Jeffery R. and Passino, Kevin M. ‘Fuzzy Model Reference Learning Control’. 1 Jan. 1996 : 33 – 47.

Fuzzy controller and inverse model

- Gaussian membership function, 4 rules each



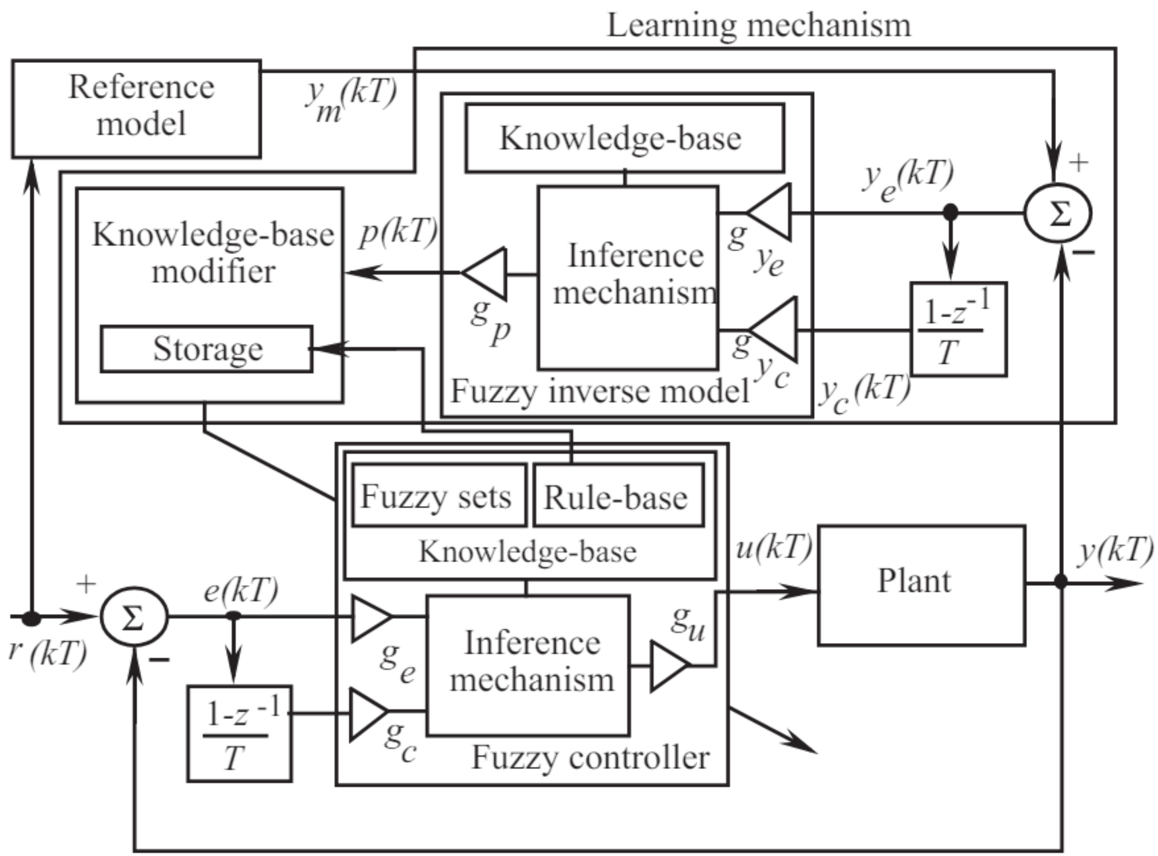


Change in error

Error

Normalizing Scaling Factor Tuning

- Select g_e, g_c, g_u, g_{y_e} so that each universe of discourse is mapped to $[-1,1]$
- Choose $g_p = \mathrm{g_u}$
- Assign numerical value 0 to g_{y_c}
- Apply and step input and observe response
  - If unacceptable oscillations exist, increase g_{y_c}
  - If output response is unable to “keep up” with reference model, decrease g_{y_c}
  - If acceptable, design is completed



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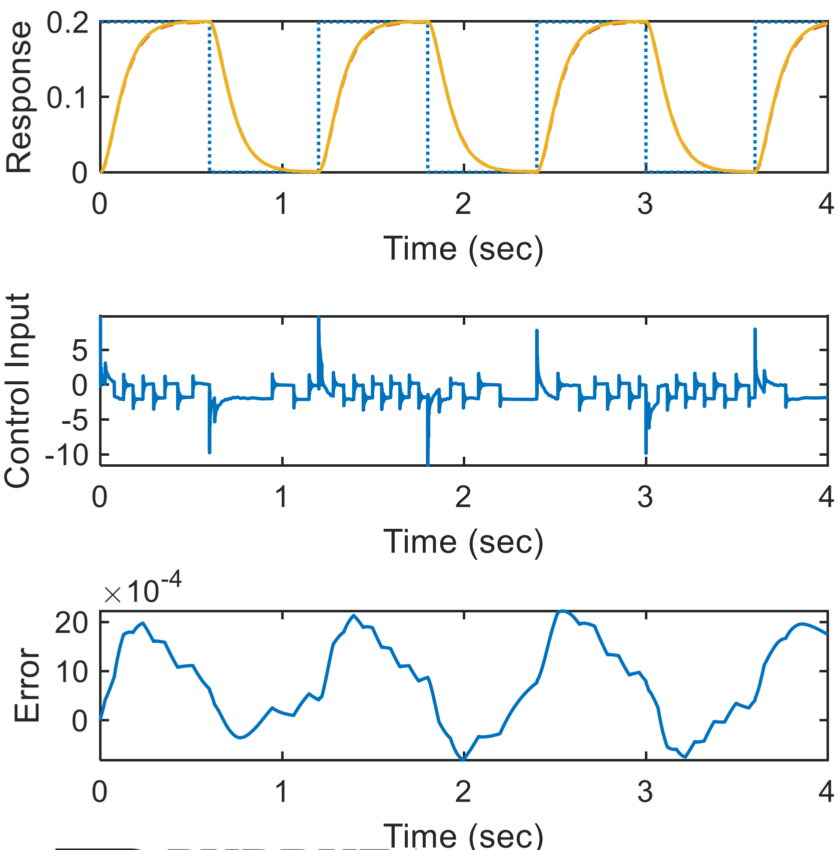
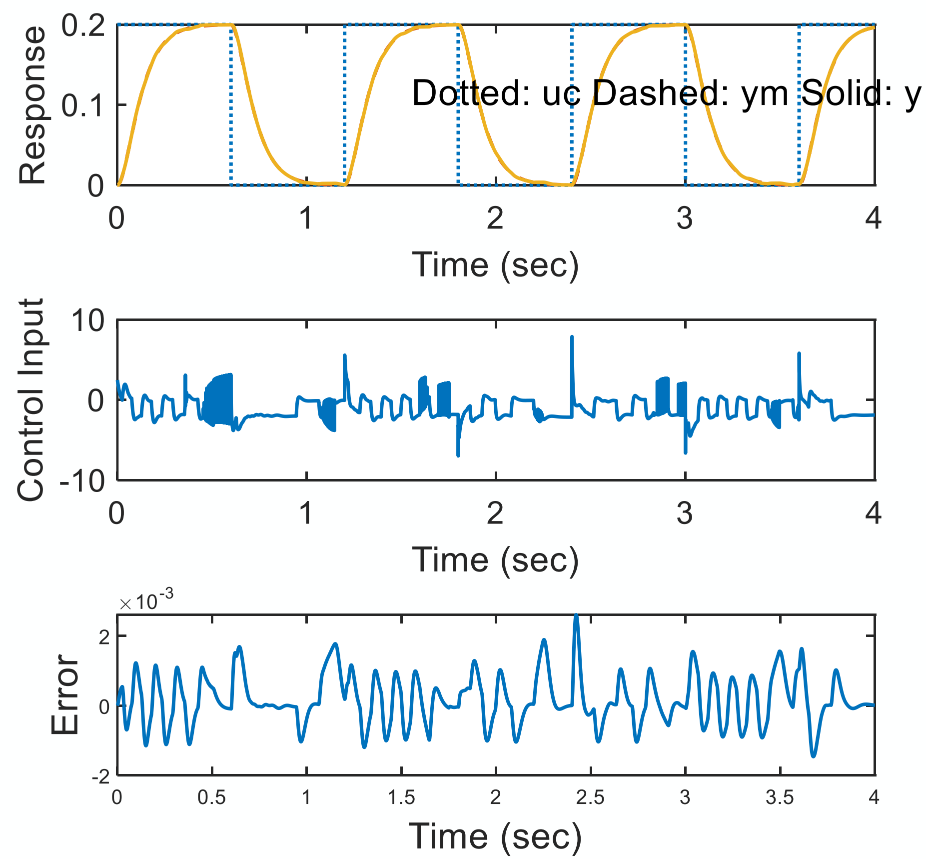
FMRLC results vs. MRAC

FMRLC vs. MRAC for parameter set 2, $d(t) = 1 + (-1)^{round(10sin(2t))}$

FMRLC



MRAC



Thank You

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