Fuzzy Logic and Neural Network Controllers for 2 Links Manipulator

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Outline

1. Introduction to the Fuzzy Logic Control
2. Introduction to the RBF Neural Network Control
3. Comparison of the simulation result
4. Discussion and Conclusion
5. Reference

Technical contribution:

Fuzzy Logic Control	RBF Neural Network Control	Comparison of the result
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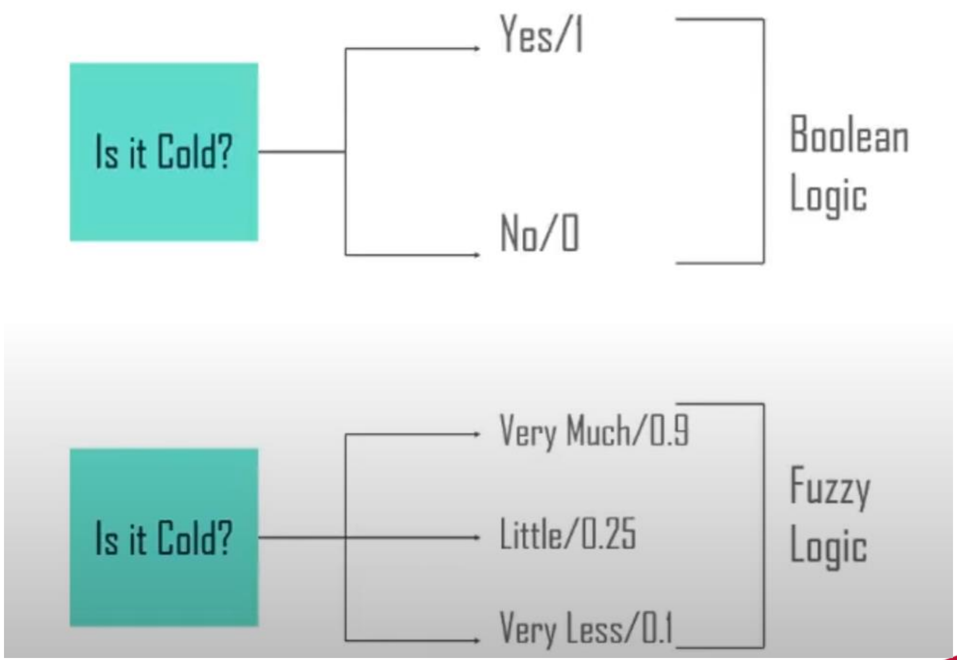
Motivation

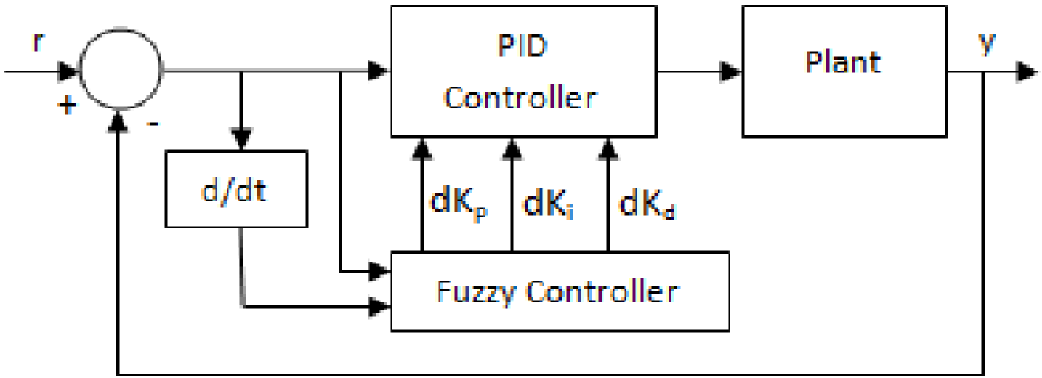
- Fuzzy logic is used in many applications:
  - Altitude control in aerospace engineering
  - Speed and traffic control for transportation
  - Assisted decision make system
  - Precise dosing control used in chemical engineering
- What problem can fuzzy logic solve?
  - Fuzzy logic helps to deal with uncertainty in models
  - Making the system more robust although the input signals are not very accurate
- Related work:
  - Sharma et al. proposed a fuzzy control system to achieve an ideal level for a ventilation systems [1]
  - Ali et al. used fuzzy logic controllers to promote suitable microclimates in agricultural greenhouse [2]
  - Farah et al. developed a simple self-tuning fuzzy logic controller for driving induction motor [3]
  - Kumar et al. designed a fuzzy PID control to address the uncertainty problem in a 2-link manipulator [4]

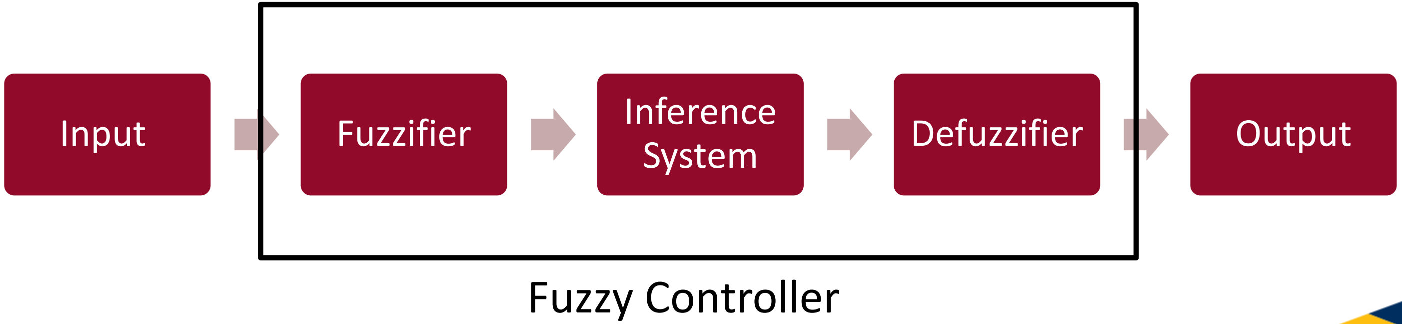
Introduction

- Fuzzy logic is a way of reasoning that mimic the human reasoning
- In Boolean logic, there is only
  - Truth(1) or False(0)
- In fuzzy logic, there could be
  - Absolute True (1)
  - Mostly True (0.75)
  - Hard to Tell (0.5)
  - Mostly False (0.25)
  - Absolute False (0)



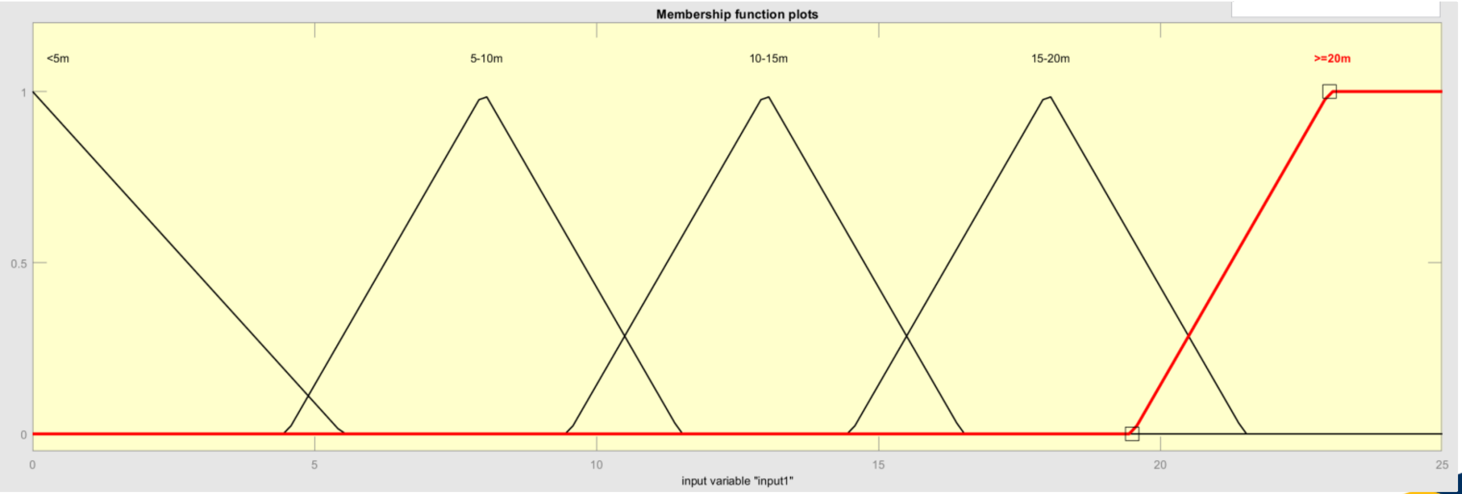
Fuzzy Logic Controller





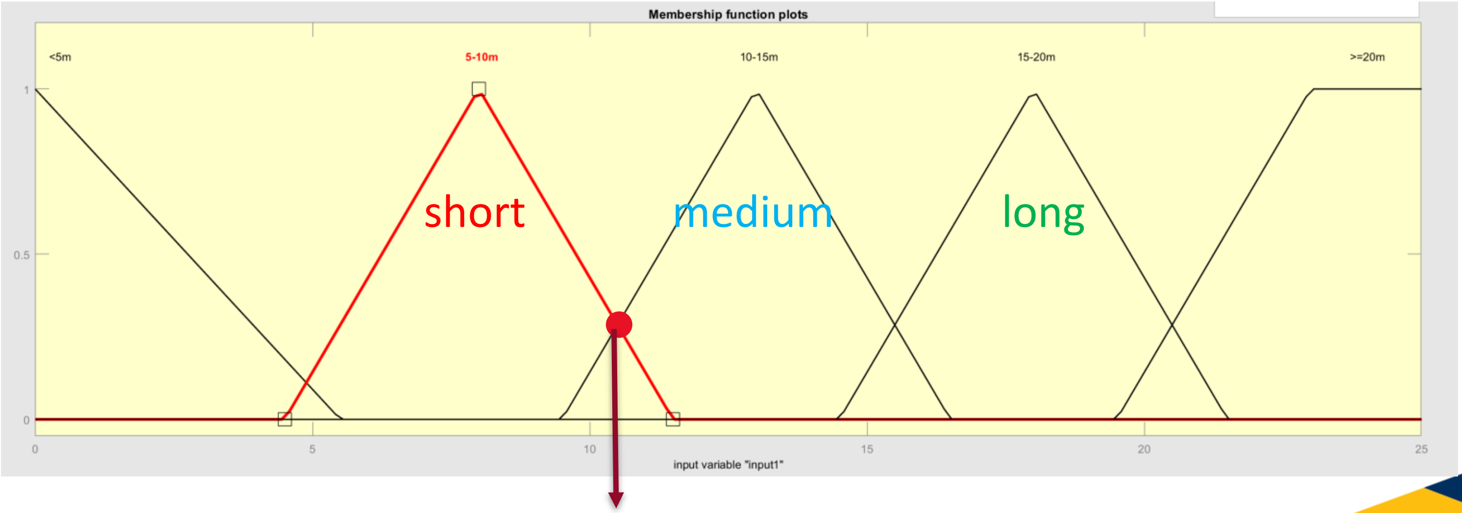
Fuzzifier and Membership Functions

< 5 m	5 m – 10 m	10 m – 15 m	15 m – 20 m	>= 20 m
Brake 100%	Brake 75%	Brake 50%	Brake 25%	Don’t brake



Fuzzification

< 5 m	5 m – 10 m	10 m – 15 m	15 m – 20 m	>= 20 m
Brake 100%	Brake 75%	Brake 50%	Brake 25%	Don't brake



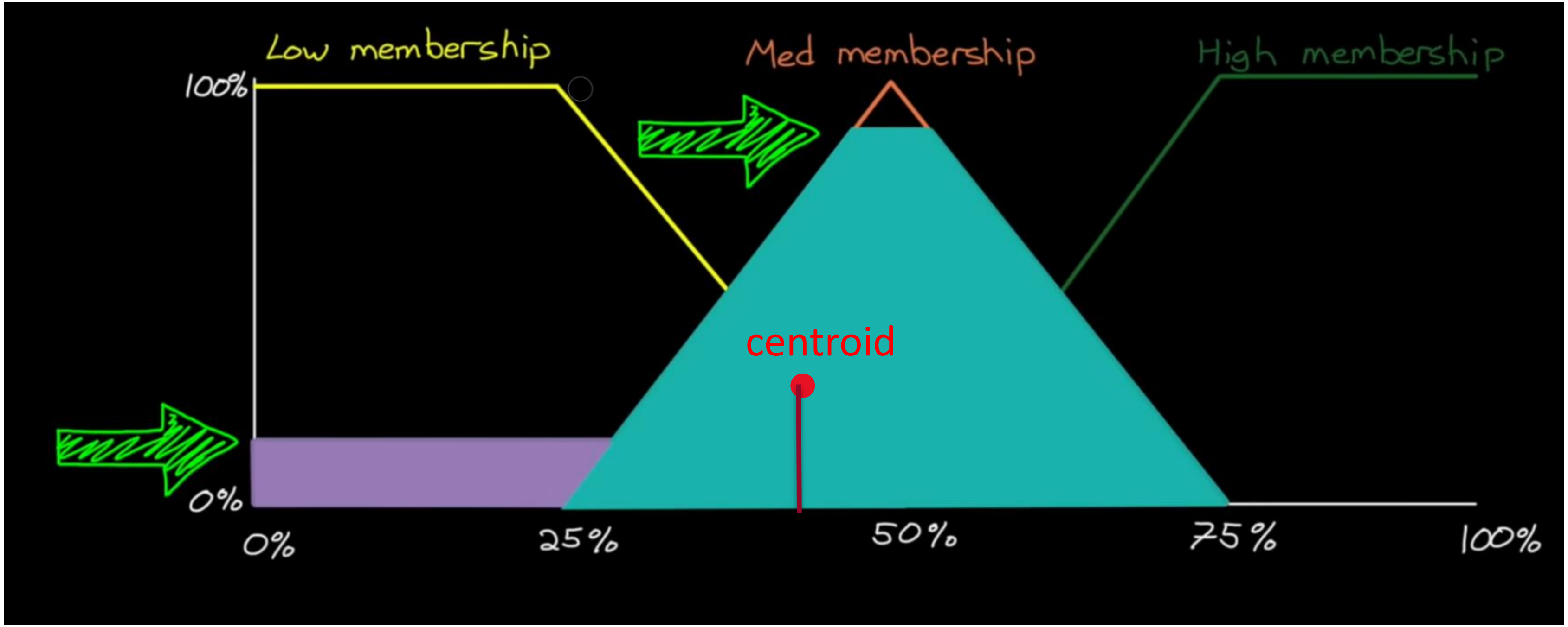
Input of 11m -> [0 0.3 0.3 0 0]

Inference System

< 5 m	5 m – 10 m	10 m – 15 m	15 m – 20 m	>= 20 m
Brake 100%	Brake 75%	Brake 50%	Brake 25%	Don't brake

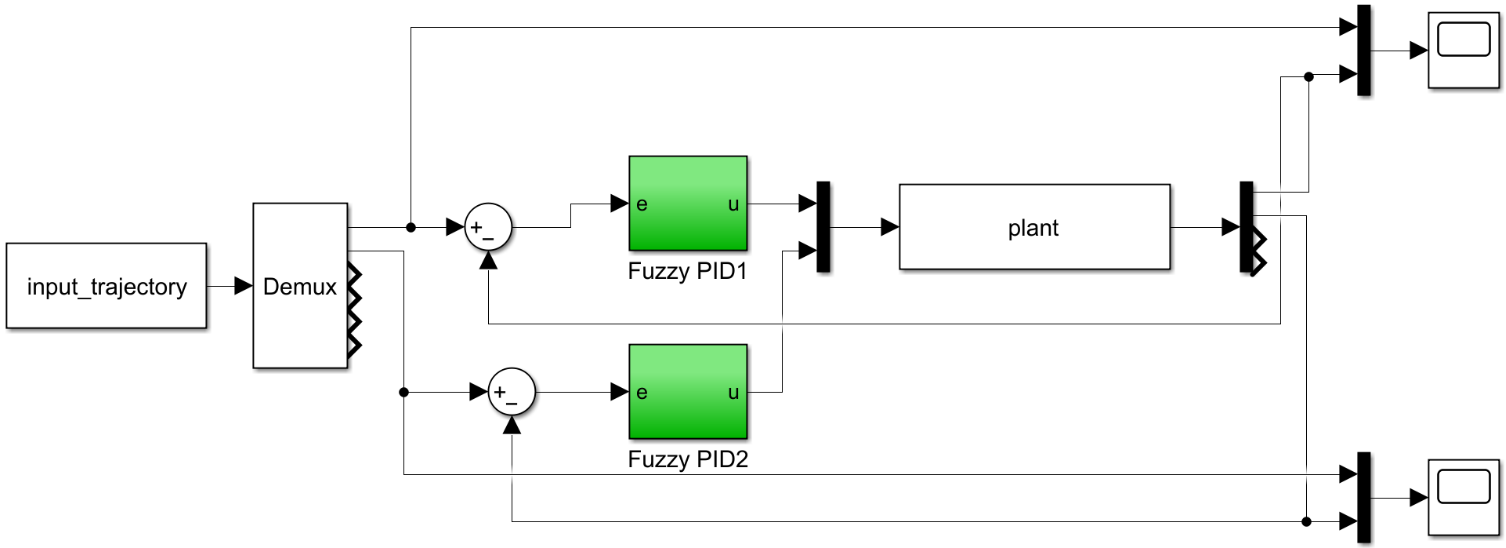
- Inference system draw connections between the received fuzzy input (nx1 matrix) and the rules. When conditions met, the rules will be fired.
  - If distance < 5m, then brake 100%
  - If 5m < distance < 10, then brake 75%
  - If 10m < distance < 15, then brake 50%
  - If 15m < distance < 20, then brake 25%
  - If distance > 20, then brake 0%

Defuzzification



- Defuzzify the input received give the x-coordinate of the centroid [3]
- Defuzzify [0.1 0.9 0] = 46%

Simulink Model

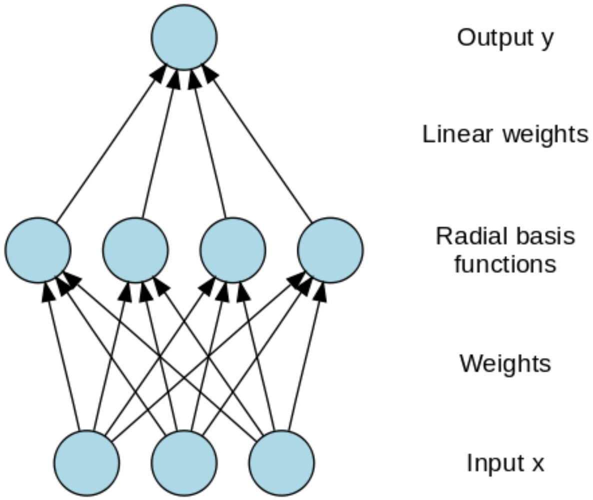


Introduction to Radial Basis Functions Neural Network Controllers

- Introduction:
  - Related work:
    - M. Moradi proposed a feedback linearization neural network to overcome the uncertainty and nonlinear characteristic in the plant [8]
    - Wei He applies a adaptive neural network control on a manipulator with time-varying output constraints [9]
    - Changyin Sun proposed a fuzzy neural network control for flexible manipulator [10]
  - Dynamic of manipulator:
    - $D(q)\ddot{q} + C(q,\dot{q}) + G(q) = \tau + d$

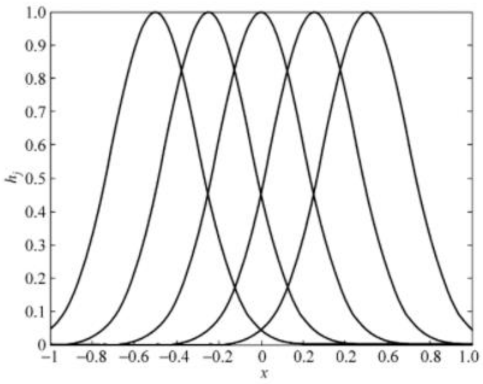
    Control Command:
    - Ideal:$\tau = D(q)\left(\ddot{q}_d - k_v\dot{e} - k_p e\right) + C(q,\dot{q}) + G(q)$
    - Actual:$\tau = D_0(q)\left(\ddot{q}_d - k_v\dot{e} - k_p e\right) + C_0(q,\dot{q}) + G_0(q)$
    - $\ddot{e}$+ $k_v\dot{e} + k_p e = D_0^{-1}(\Delta D\ddot{q} + \Delta C(\dot{q}) + \Delta G + d)$
    - Uncertainty : f = $D_0^{-1}(\Delta D\ddot{q} + \Delta C(\dot{q}) + \Delta G + d)$
    - Fixed control command:$\tau = D_0(q)\left(\ddot{q}_d - k_v\dot{e} - k_p e\right) + C_0(q,\dot{q}) + G_0(q)$ - $D_0(q)$f

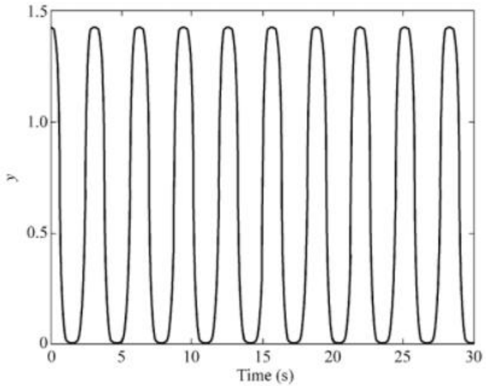
RBF Neural Network



$$f(\mathrm{x}) = \sum_{j=1}^{m} w_j h_j(\mathrm{x})$$

$$h(x) = \exp\left(-\frac{(x-c)^2}{r^2} \right)$$





RBF Neural Network Approximation Based on Gradient Descent Method

$$h_j = \exp\left(-\frac{\|\mathbf{x}-\mathbf{c}_j\|^2}{2b_j^2}\right), \quad j = 1, 2, \ldots, m.$$

$$\boldsymbol{b} = [b_1, \ldots, b_m]^{\mathrm{T}}$$

$$\boldsymbol{w} = [w_1, \ldots, w_m]^{\mathrm{T}}$$

$$y_m(t) = w_1 h_1 + w_2 h_2 + \cdots + w_m h_m.$$

$$E(t) = \frac{1}{2}(y(t) - y_m(t))^2.$$

$$\Delta w_j(t) = -\eta \frac{\partial E}{\partial w_j} = \eta(y(t) - y_m(t))h_j$$

$$w_j(t) = w_j(t-1) + \Delta w_j(t) + \alpha\big(w_j(t-1) - w_j(t-2)\big)$$

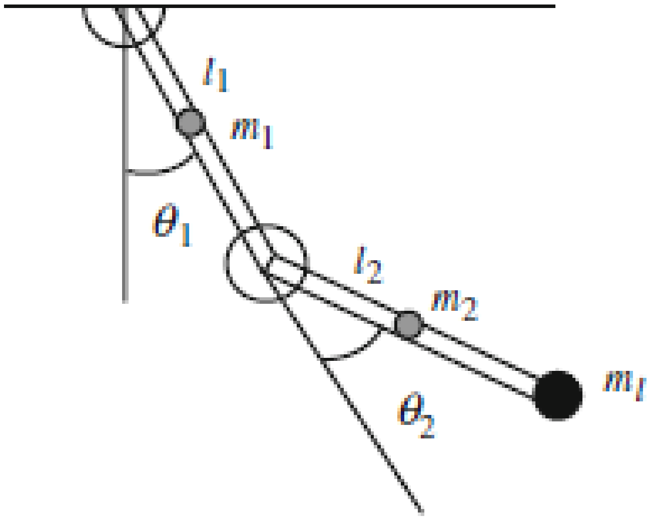
$$\Delta b_j = -\eta \frac{\partial E}{\partial b_j} = \eta(y(t) - y_m(t))w_j h_j \frac{\|\boldsymbol{x}-\boldsymbol{c}_j\|^2}{b_j^3}$$

$$b_j(t) = b_j(t-1) + \Delta b_j + \alpha\big(b_j(t-1) - b_j(t-2)\big)$$

$$\Delta c_{ji} = -\eta \frac{\partial E}{\partial c_{ji}} = \eta(y(t) - y_m(t))w_j \frac{x_j - c_{ji}}{b_j^2}$$

$$c_{ji}(t) = c_{ji}(t-1) + \Delta c_{ji} + \alpha\big(c_{ji}(t-1) - c_{ji}(t-2)\big)$$

Dynamic of the Testing Plant



$$\boldsymbol{M}(\boldsymbol{q})\,\ddot{\boldsymbol{q}} + \boldsymbol{V}_{\mathrm{m}}(\boldsymbol{q},\dot{\boldsymbol{q}})\,\dot{\boldsymbol{q}} + \boldsymbol{G}(\boldsymbol{q}) = \boldsymbol{\tau}$$

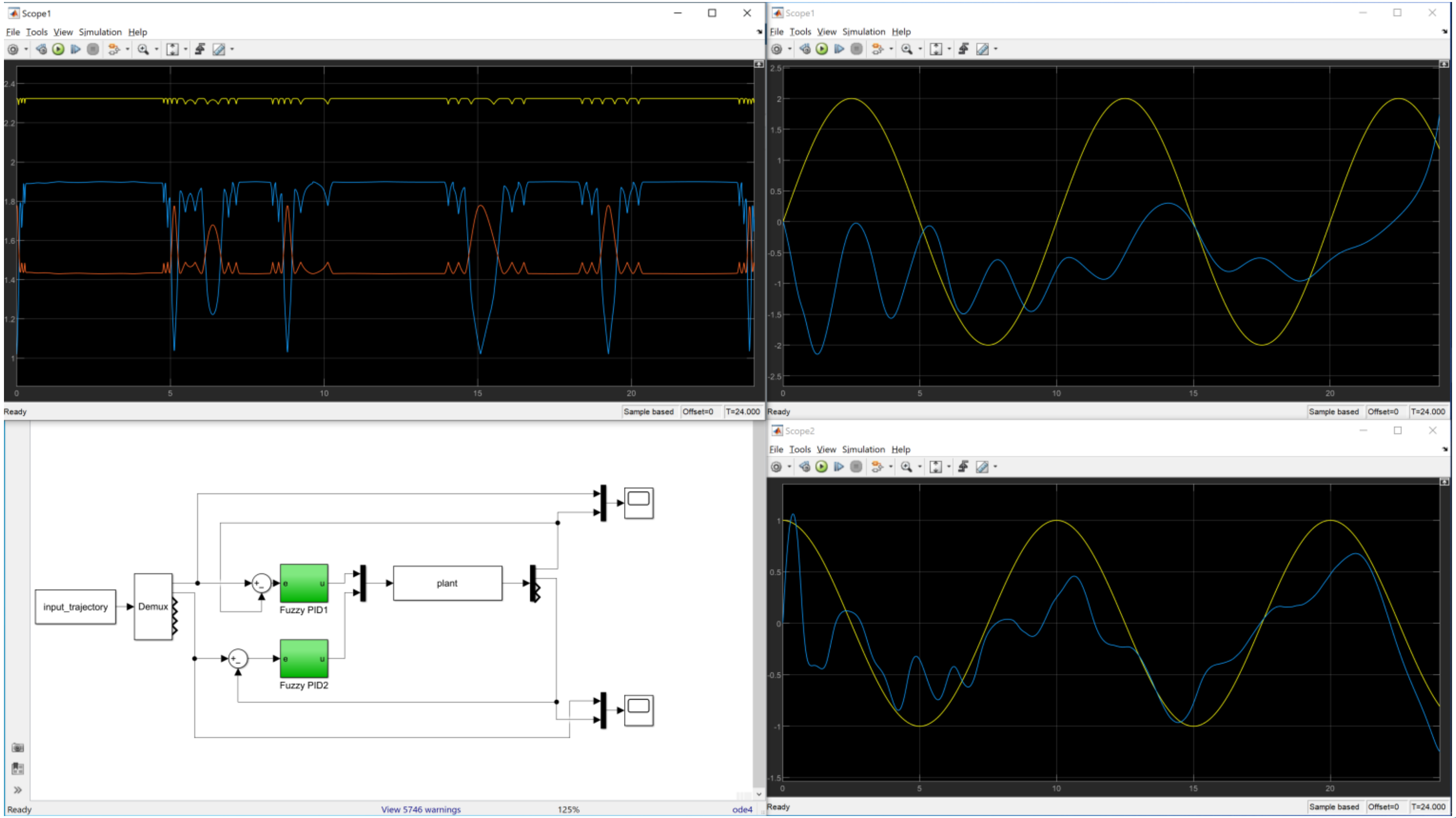
$$\boldsymbol{D}(\boldsymbol{q}) = \begin{bmatrix} p_1 + p_2 + 2p_3\cos q_2 & p_2 + p_3\cos q_2 \\ p_2 + p_3\cos q_2 & p_2 \end{bmatrix}$$

$$\boldsymbol{C}(\boldsymbol{q},\dot{\boldsymbol{q}}) = \begin{bmatrix} -p_3\,\dot{q}_2\sin q_2 & -p_3(\dot{q}_1 + \dot{q}_2)\sin q_2 \\ p_3\,\dot{q}_1\sin q_2 & 0 \end{bmatrix}$$

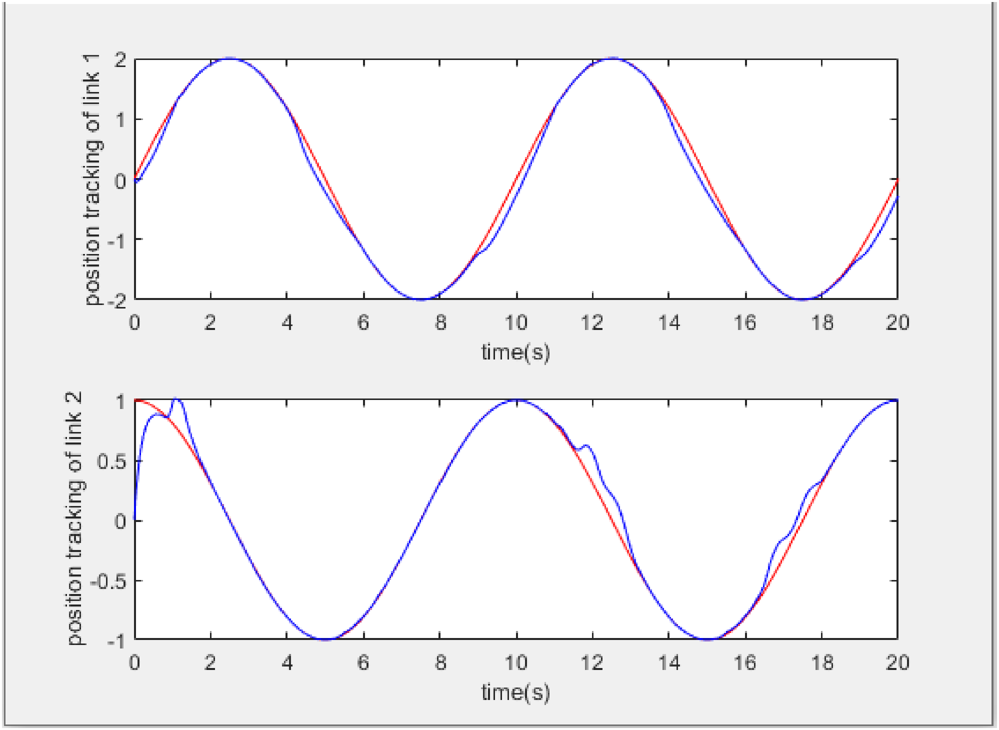
$$\boldsymbol{G}(\boldsymbol{q}) = \begin{bmatrix} p_4\cos q_1 + p_5\cos(q_1 + q_2) \\ p_5\cos(q_1 + q_2) \end{bmatrix}$$

- m_1 =3.5 kg
- m_2 = 2.2 kg
- m_l=1m
- l_1 = 0.5
- l_2 = 0.5

Fuzzy Logic Controller Simulation Results



Result of RBF Neural Network Control



Discussion and Conclusion

- In this testing plant, RBF neural network controller has a better performance

- The Fuzzy Logic Control is not fully toned based on the testing plant

- Neural network Control has a strong adaptability

Reference

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