

FUZZY SWITCHING FOR MULTIPLE MODEL ADAPTIVE CONTROL IN MANIPULATOR ROBOT

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Abstract:

In this paper, fuzzy logic is used to perform switching controllers for Multiple Model Adaptive Control (MMAC) in manipulator robot. In the cases which uncertainty bounds of system's parameters are large, the performance and stability issue of system are considerable concerns. Multiple Model Adaptive Control approach can be useful method to stabilize these kinds of systems. In this control method, the uncertainty bound is divided into several smaller bounds. As a result, the process of stabilization would be streamlined. In this regard, one estimation is obtained for uncertain parameter in every minor bound, and based on estimation errors designed controller can alter. In order to avoid switching controllers and pertinent challenges a summation of controllers with coefficient tuned by fuzzy logic is considered. Simulation results substantiate the efficacy of this method.

Keywords: manipulator robot, fuzzy logic, multiple model adaptive control, switching

1. Introduction

In every system, uncertainty can have different origins like inaccuracy in measurement tools, changes in features of system and other factors related to the nature of system. If uncertainty bounds of system parameters are small, negative effects of uncertainty can be negligible. In contrast, if uncertainty bounds of parameters are large, instability and unacceptable performance can arise. Multiple Model Control approach is an efficacious control method to ameliorated unpleasant influences of uncertainty. In this control approach, the uncertainty bound is divided into multiple bounds and in every bound an estimation is obtained. Estimation errors are used to alter controller and appropriate controller is inserted in closed loop system. Kuipers and Ioannou [1] used conventional MMAC in two-cart most-spring damper system with uncertainty in spring parameter and delay in input signal. Jin and Li [2] utilized MMAC with weighted control signal which used a performance index based on errors of estimation. In this paper, fuzzy logic is used to tune coefficients and controllers. Fuzzy approach as an intelligent control approach has more flexibility and causes controllers' coefficients to be adjusted based on desires of designer in a way that controller which has low estimation error has more influence on total

control signal. In prior weighting method, like what is in [3], excessive gains for corresponding controllers result in having high gain for total control signal. This issue can eventuate in probability of instability. In fuzzy weighing method, membership function of coefficients can be designed so that coefficient of inappropriate controller have less overlap; therefore, appropriate controller has noteworthy effect.

This paper is organized as follows: section 2 describes the dynamic model of manipulator robot. In section 4, fuzzy weighting method is explained. Section 5 includes simulation results. In final, conclusions are rendered in section 6.

2. System Dynamic

In this paper, a two DOF manipulator is considered as system. The first joint is Revolute and the second joint is Prismatic. Figure 1 shows this manipulator. In order to obtain dynamic model of system Lagrangian equation is used.

$$\begin{aligned} \frac{d}{dt} \frac{\partial \mathcal{E}_1}{\partial \dot{\theta}_1} - \frac{\partial \mathcal{E}_1}{\partial \theta_1} &= \tau_1 \\ \frac{d}{dt} \frac{\partial \mathcal{E}_2}{\partial \dot{d}_2} - \frac{\partial \mathcal{E}_2}{\partial d_2} &= \tau_2 \end{aligned} \quad (1)$$

where (θ_1, d_2) and $(\dot{\theta}_1, \dot{d}_2)$ are displacement and derivative of displacement in joints. \mathcal{E} is Lagrangian of system. τ is exerted torque on joints. Therefore, dynamic equation of system is modeled as:

$$M(\theta_1, d_2) + C(\theta_1, d_2, \dot{\theta}_1, \dot{d}_2) = \tau \quad (2)$$

$$M(\theta_1, d_2) = \begin{bmatrix} m_1 l_1^2 + I_1 + I_2 + m_2 d_2^2 & 0 \\ 0 & m_2 \end{bmatrix}$$

$$C(\theta_1, d_2, \dot{\theta}_1, \dot{d}_2) = \begin{bmatrix} 2m_2 d_2 \dot{\theta}_1 \dot{d}_2 \\ -m_2 d_2 \dot{\theta}_1^2 \end{bmatrix}$$

$$\tau = \begin{bmatrix} (m_1 l_1^2 + I_1 + I_2 + m_2 d_2^2) \ddot{\theta}_1 + 2m_2 d_2 \dot{\theta}_1 \dot{d}_2 \\ m_2 \ddot{d}_2 - m_2 d_2 \dot{\theta}_1^2 \end{bmatrix}$$

where $M(\theta_1, d_2)$ is inertia matrix. $C(\theta_1, d_2, \dot{\theta}_1, \dot{d}_2)$ is vector of the coriolis and centrifugal force. m_i is mass of i th link. I_i is inertia tensor of i th link. θ_1 is rotation of first joint. d_2 is displacement of second joint with respect to first joint. l_1 is distance of mass center of first link from first joint. In this system, uncertainty is presumed to be in l_1 .

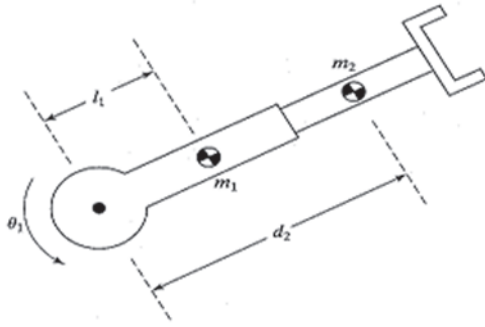


Fig 1. Schematic of manipulator robot

3. Multiple Model Adaptive Control

Multiple Model Adaptive Control is a versatile approach to stabilize system with large uncertainty bound. In systems which uncertainty bounds are large, dynamic characteristic of system alters drastically. As a consequence, system is prone to be unstable. In MMAC method uncertainty bounds are divided and in smaller bounds more accurate estimations are obtained. Estimation errors are used to select the controller block related to smallest estimation error and appropriate controller is inserted in closed loop system. Figure 2 depicts the configuration of MMAC.

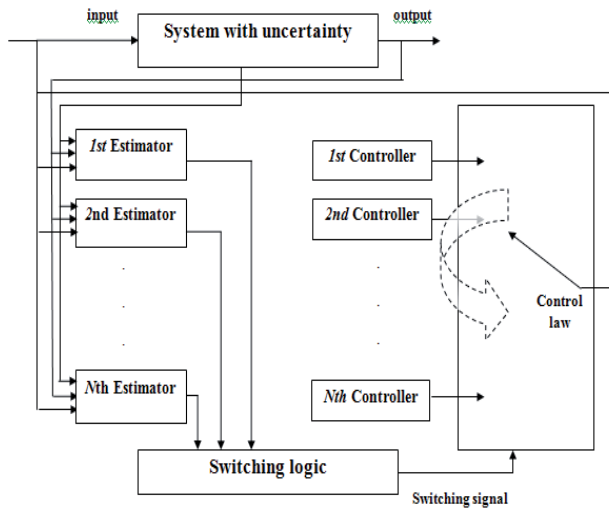


Fig 2. Configuration of MMAC

Sliding mode control is considered as control method. Hence, exerted torque is presented as:

$$\tau_i = s - k_i \text{sat}(s) \quad (3)$$

where k_i is positive constant which is obtained as

$$k_i(j, j) \geq |\Delta U_i|, \quad \Delta U = (\hat{M} - M) \left(\gamma_1 \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{d}_2 \end{bmatrix} + \gamma_2 \begin{bmatrix} \dot{e}_{\theta_1} \\ \dot{e}_{d_2} \end{bmatrix} \right) + (\hat{C} - C) \gamma_1 \begin{bmatrix} \dot{\theta}_1 \\ \dot{d}_2 \end{bmatrix} + \gamma_2 \begin{bmatrix} e_{\theta_1} \\ e_{d_2} \end{bmatrix} \quad (4)$$

and s is sliding surface.

$$s = c_1 \dot{e} + c_2 e \quad (5)$$

$$\begin{bmatrix} e_{\theta_1} \\ e_{d_2} \end{bmatrix} = \begin{bmatrix} \theta_{1desired} - \theta_1 \\ d_{2desired} - d_2 \end{bmatrix}$$

where c_1 and c_2 are positive constants. In this control method, switching process causes instability probability. Hence, appropriate measures is needed to reduce the possibility of unstable behavior.

4. Fuzzy Weighting Method in MMAC

In order to avoid encountering outcomes of switching in MMAC, a summation of weighted controllers is used as pertinent controller instead of switching among several controllers. In this approach, coefficients of controllers are tuned based on estimation errors by means of fuzzy logic. Consequently, total control signal is presented as:

$$\tau_t = \sum_{i=1}^N \alpha_i \tau_i \quad (6)$$

where α_i is coefficient of i th controller. The configuration of fuzzy weighting approach is shown in Figure 3.

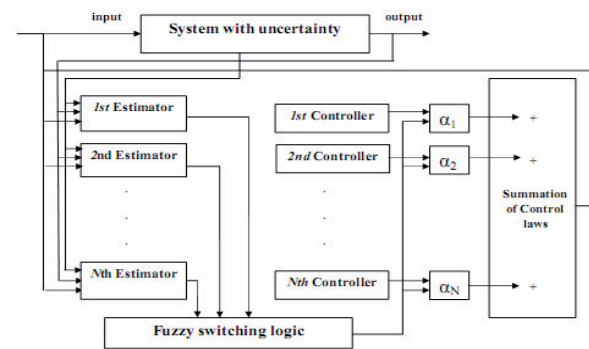


Fig 3. Configuration of MMAC with fuzzy weighting approach

Membership functions for estimation errors is shown in Figure 4. Membership functions of controllers' coefficients are shown in Figure 5. Fuzzy rule is considered as below to tune coefficients of controllers.

- If $e_{j=i}$ is small and $e_{j \neq i}$ are medium or big, Then $\alpha_{j=i}$ is big and $\alpha_{i \neq j}$ are small.

In this rule, $e_{j=i}$ is the smallest estimation error, $e_{j \neq i}$ are other estimation errors, $\alpha_{j=i}$ is the coefficient of controller designed based on uncertain system which is in uncertainty bound with smallest estimation error, and $\alpha_{i \neq j}$ are other coefficients.

In order to analyze the stability of system by use of this control method energy function is considered as:

$$v(\dot{\theta}_1(t), \dot{d}_2(t)) = \frac{1}{2} \begin{bmatrix} \dot{\theta}_1(t) \\ \dot{d}_2(t) \end{bmatrix}^T M(\theta_1(t), d_2(t)) \quad (7)$$

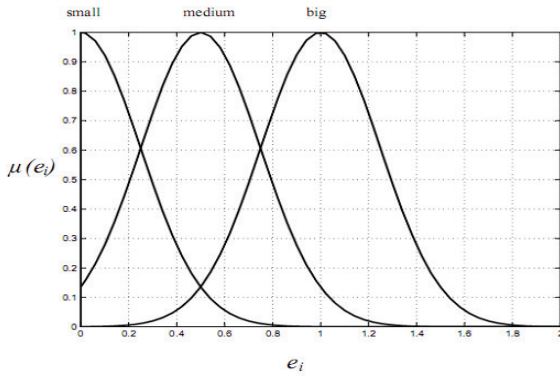


Fig 4. Membership function of estimation errors

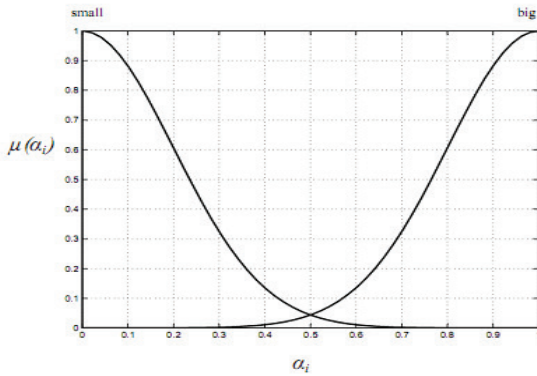


Fig 5. Membership function of coefficients of controllers

Based on passivity theory for stability proof of the system the following inequality should be vindicated.

$$\int \begin{bmatrix} \dot{\theta}_1 \\ \dot{d}_2 \end{bmatrix}^T \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} dt \geq v(\dot{\theta}_1(t), \dot{d}_2(t)) \quad (8)$$

5. Simulation Results

In this paper, manipulator robot is considered whose first joint is Revolute and the second joint is Prismatic. Uncertain parameter of system is length of vector between first joint and center of mass of first link. Dynamic parameters of manipulator robot are presented in Table 1.

Table 1. Dynamic parameters of system

m_1	m_2	I_1	I_2	l_1	l_2
1.2	1.2	0.1	0.1	0.6	0.6

c_1 , c_2 , γ_1 and γ_2 are considered as the following matrices and k according to Equation (4) is obtained.

$$c_{1,2}, \gamma_{1,2} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \quad k = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

The uncertain parameter alters in the following interval.

$$l_{1nominal} - 0.5l_{1nominal} \leq l_1 \leq l_{1nominal} + 0.5l_{1nominal} \quad (9)$$

Based on designed controller, inequality (8) is vindicated to confirm the stability situation of system as is shown in Figure 6.

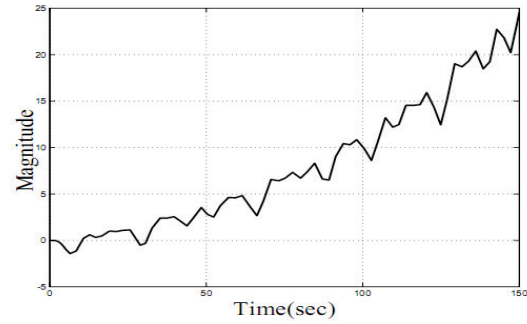


Fig 6. Vindication of stability based on the passivity method

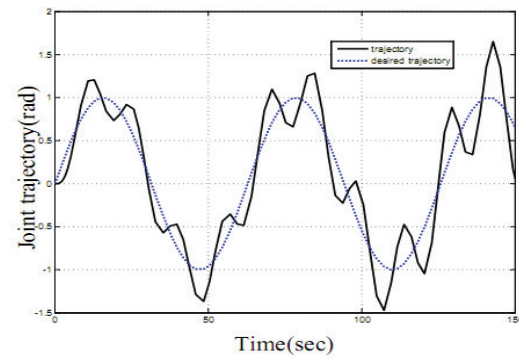


Fig7. Quality of tracking the desired trajectory in Revolute joint

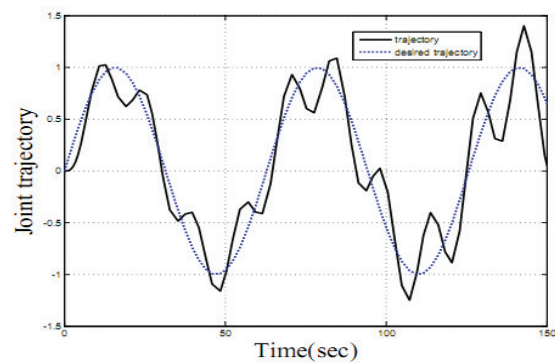


Fig 8. Quality of tracking the desired trajectory in Prismatic joint

Exerted torque as control law causes manipulator robot joints to track the desired trajectories. Figures 7 and 8 show the quality of tracking.

6. Conclusions

In this paper, fuzzy weighting method was used to substitute for switching method in Multiple Model

Adaptive Control. This method provides assurance regarding stable behavior of system with the presence of uncertain parameter with large bound. Fuzzy logic tunes coefficients of designed controllers forming total controller. Consequently, control system eliminates sharp jumps. Simulation results display appropriate outcomes obtained by proposed approach.

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