Determination Of Adaptive Control Parameter Using Fuzzy Logic Controller

Omur Can Ozguney, Recep Burkan

Abstract: The robot industry has developed along with the increasing the use of robots in industry. This has led to increase the studies on robots. The most important part of these studies is that the robots must be work with minimum tracking trajectory error. But it is not easy for robots to track the desired trajectory because of the external disturbances and parametric uncertainty. Therefore, adaptive and robust controllers are used to decrease tracking error. The aim of this study is to increase the tracking performance of the robot and minimize the trajectory tracking error. For this purpose, adaptive control law for robot manipulator is identified and fuzzy logic controller is applied to find the accurate values for adaptive control parameter. Based on the Lyapunov theory, stability of the uncertain system is guaranteed. In this study, robot parameters are assumed to be unknown. This controller is applied to a robot model and the results of simulations are given. Controller with fuzzy logic and without fuzzy logic are compared with each other. Simulation results show that the fuzzy logic controller has improved the results.

Keywords: Fuzzy Logic Control, Lyapunov Stability, Adaptive Control, Robotics.

1 Introduction

Spong [1], derived a simple adaptive nonlinear control law for n-link robot manipulators. Passivity-based approach is used and the stability of the uncertain system is guaranteed based on the Lyapunov theory. This methodology has some advantages about both robustness and design. Er and Gao [2] designed a robust adaptive fuzzy neural controller for multilink manipulators. Asymptotic stability of the control system is established using the Lyapunov theory. This study shows that tracking errors and handled external disturbances are compensated by this new controller. Tayebi [3] represents adaptive iterative learning control for rigid robot manipulators. This model includes unknown parameters. This control was designed based on a proportional-derrivative feedback control. The simulation results show the effectiveness of the proposed controller. An integration of kinematic controller and a torque controller was presented by Fukao, Nakagawa and Adachi [4]. First a new adaptive control law was introduced than a torque adaptive controller derived by using this new adaptive kinematic controller. The controller was applied to a nonholonomic mobile robot. The results show that for proposed controller was effective at values of angular velocity approaching zero. Fateh and Farhangfard [5] discussed the uncertainties of the Jacobian matrix in the control system. The trajectory tracking error in the task space was improved by using the new controller. Feedback linearization is the main part of this control method. Massoud, Elmaraghy and Lahdhiri [6] used a feedback linearization, a sliding mode technique, and a LQE methodology together. The controller takes advantages of these control methods and the new control method was applied to flexible joint manipulator. The results showed that the developed controller was successful in end-point position control.

- *Omur Can Ozguney is currently pursuing phd program in mechanical engineering in Istanbul University, Turkey, E-mail: omur.ozguney@istanbul.edu.tr*
- *Dr. Recep Burkan is currently professor in mechanical engineering in Istanbul University, Turkey, E-mail: burkanr@istanbul.edu.tr*

Fateh [7] improves his previous study [8] and applied to a three-joint articulated flexible-joint robot. This study based on torque control strategy. Stability of the system was guaranteed and performance of the control system is evaluated. In this paper, a new fuzzy-adaptive control law is developed based on the Lyapunov function, thus stability of the system is guaranteed. First, adaptive control law is identified then, control parameter is defined by fuzzy logic controller. After simulation results, it has been seen that fuzzy logic controller improve the performance of the adaptive control law.

2 STABILITY ANALYSIS AND DEFINITION OF THE ADAPTIVE CONTROL LAW

In the absence of friction or other disturbances, the dynamic model of an n-link manipulator can be written as [1];

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)=\tau \qquad (1)$$

where q denotes generalized coordinates, τ is the n-dimensional vector of applied torques (or forces), M(q) is the nxn symmetric positive definite inertia matrix, $C(q,\dot{q},\ddot{q})$ is the n-dimensional vector of centripetal and Coriolis terms and G(q) is the n-dimensional vector of gravitational terms. With $q\in R^{\rho}, \tau\in R^{n}$ which has both the skew-symmetry property that the matrix [9];

$$N(q,\dot{q})=\dot{M}(q)-2C(q,\dot{q}) \qquad (2)$$

is skew-symmetric. Equation (1) can be also written in the following form.

$$M(q)\ddot{q}+C(q,\dot{q})\dot{q}+G(q)=Y(q,\dot{q},\ddot{q})\theta=\tau \qquad (3)$$

Where θ is a constant p-dimensional vector of robot parameters and Y is an nxp matrix of known functions of joint position, velocity and acceleration. We can say that θ is uncertain if there exists $\theta_0\in R^{\rho}, \rho\in R_+$ both known, such that [1]

$$\left\|\tilde{\theta}\right\|=\left\|\theta-\theta_0\right\|\le\rho \qquad (4)$$

As distinct to similar study [10], θ and ρ are unknown. The nominal control vector τ_0 is described as [1];

$$\begin{aligned}\tau_0 &= M_0(q)a + C_0(q,\dot{q})v + G_0(q) - K_D r \\ &= Y(q,\dot{q},\dot{q}_r,\ddot{q}_r)\theta_0 - K_D r\end{aligned} \quad (5)$$

The quantities v, a and r is defined as;

$$v = \dot{q}^d - \Lambda\tilde{q};\ a = \dot{v};\ r = \dot{\tilde{q}} + \Lambda\tilde{q};\ \tilde{q} = q - q^d \quad (6)$$

Where K_D and Λ are positive definite matrix and q^d is reference trajectory. The control input τ is defined in terms of the nominal control vector τ_0 as [1];

$$\begin{aligned}\tau &= \tau_0 + Y(q,\dot{q},v,a)u \\ &= Y(q,\dot{q},v,a)(\theta_0 + u) - K_D r\end{aligned} \quad (7)$$

Where u is an additional control input. Substituting eq. (7) into eq. (1) it can be define;

$$M(q)\dot{r} + C(q,\dot{q})r + K_D r = Y(q,\dot{q},v,a)(\tilde{\theta} + u) \quad (8)$$

Based on these definitions, the following theorem is given.

Theorem 1: [1]

$$u = \begin{cases} -\hat{\rho}\dfrac{Y^T r}{\|Y^T r\|} & \text{if} \quad \|\hat{\rho}\, Y^T r\| > \varepsilon \\ \dfrac{-\hat{\rho}^2}{\varepsilon} Y^T r & \text{if} \quad \|\hat{\rho}\, Y^T r\| \le \varepsilon \end{cases} \quad (9)$$

and choose $\hat{\rho}$ and ε according to;

$$\begin{aligned}\dot{\hat{\rho}} &= L\,\|Y^T r\| \\ \dot{\varepsilon} &= -l\,\varepsilon\end{aligned} \quad (10)$$

The control law (7) is continuous and the closed loop system is globally convergent, i.e., the position and velocity tracking errors, $\tilde{q}$, and $\dot{\tilde{q}}$, respectively, converge asymptotically to zero while all signals remains bounded.

Proof [1]:
The stability of the system is guaranteed by using the Lyapunov function. The following part of this study is given in [1].

3 FUZZY LOGIC CONTROLLER

There are several studies related with fuzzy logic controller.[11],[12],[13],[14]. There are several vague linguistic expressions (small, medium,large) can be expressed as by membership functions. These membership functions are triangular, trapezoidal or bell curved shape. (Fig. 1). They take the values between [0,1].

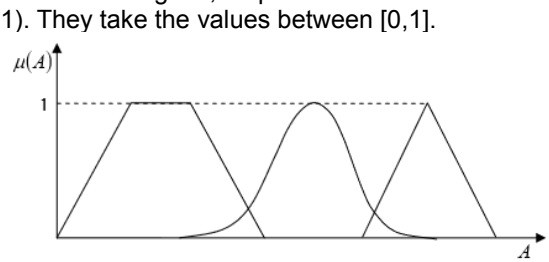

Fig. 1. *Different shapes of membership functions [15]*

There are three steps of the fuzzy logic control. In the Fuzzification stage, membership functions are defined for the variables. Thus, certain values are converted to fuzzy values. The second stage is the rule evaluation step. The rules have been prepared based on the knowledge of the system. And the output of the system is decided by the input of the system. And the final part is the defuzzification step. In this part, fuzzy values converted to certain values. Fuzzy Logic Controller has three inputs and one output. These are errors of joints (e1,e2,e3), and control parameter (L) respectively. Linguistic variables which implies inputs and output have been classified as: NONE, NB, NS, Z, PS, PB, PONE. Inputs and output are all normalized in the interval of [0, 1] as shown in Fig.2

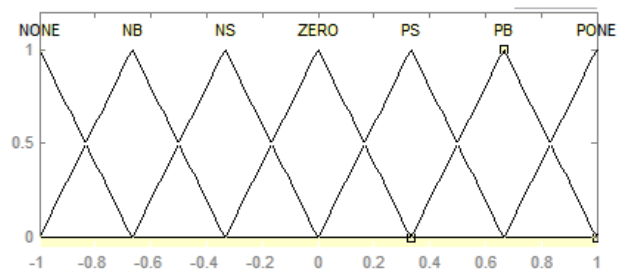

Fig. 2. *Membership functions of inputs (e1,e2,e3) and output (L)*

The linguistic labels used to describe the Fuzzy sets were "Negative One" (NONE), "Negative Big" (NB), "Negative Small" (NS), "Zero" (Z), "Positive Small" (PS), "Positive Big" (PB), "Positive One" (PONE). The fuzzy control rule is in the form of:IF e=Ei and de=dEj THEN L = L(i,j), These rules are written in a rule base look-up table which is shown in Table 1

TABLE 1
DECISION TABLE (L)

e1\e2\e3	NONE	NB	NS	Z	PS	PB	PONE
NONE	NONE	NONE	NB	NB	NS	NS	Z
NB	NONE	NB	NB	NS	NS	Z	PS
NS	NB	NB	NS	NS	Z	PS	PS
Z	NB	NS	NS	Z	PS	PS	PB
PS	NS	NS	Z	PS	PS	PB	PB
PB	NS	Z	PS	PS	PB	PB	PONE
PONE	Z	PS	PS	PB	PB	PONE	PONE

4 DYNAMIC EQUATIONS OF THE THREE AXIS ROBOT ARM

Kinematic equations of the robot arm is produced by Lagrange method.

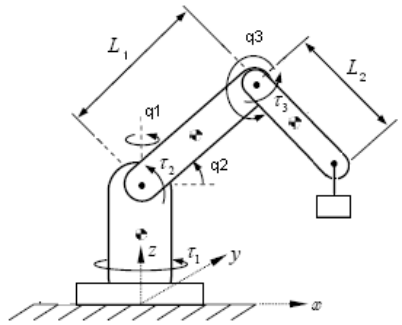

***Fig. 3**. Three axis robot arm [16]*

Where m_1 and m_2 are masses of the links, L_1 and L_2 are the lengths of the links, I_1, I_2 and I_3 are the mass inertia of the links and q_1, q_2 and q_3 are the angles of the links. Also the torques are represented in a matrix form like in (11) [17]

$$\tau = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \ddot{q}_3 \end{bmatrix} + \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} + \begin{bmatrix} G_{11} \\ G_{21} \\ G_{31} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad (11)$$

$$M_{11} = I_1 + (m_1(\frac{l_1}{2})^2 + I_2)\cos^2 q_2 + m_2 l_1[l_2 \cos q_2 + l_3 \cos q_{23} \cos q_2] + (m_2(\frac{l_2}{2})^2 + I_3)\cos q_{12}$$

$$M_{12} = 0, M_{13} = 0, M_{21} = 0, M_{31} = 0$$

$$M_{22} = (m_1(\frac{l_1}{2})^2 + I_2) + m_2 l_1^2 + m_2 l_1 l_2 \cos q_3 + (m_2(\frac{l_2}{2})^2 + I_3)$$

$$M_{23} = m_2 l_1(\frac{l_2}{2})^2 \cos q_3 + m_2(\frac{l_2}{2})^2 + I_3$$

$$M_{32} = m_2 l_1(\frac{l_2}{2})^2 \cos q_3 + m_2(\frac{l_2}{2})^2 + I_3,$$

$$M_{33} = m_2(\frac{l_2}{2})^2 + I_3$$

$$C_{11} = 2((m_2(\frac{l_2}{2})^2 + I_3)\sin q_{23} \cos q_{23}(\dot{q}_2 + \dot{q}_3))$$

$$C_{12} = 2\left\{ \begin{matrix} (m_1(\frac{l_1}{2})^2 + I_2)\sin q_2 \cos q_2 \\ + m_2 l_1^2 \sin q_2 \cos q_2 + m_2 l_1(\frac{l_2}{2})^2 \sin q_2 \cos q_{23} \end{matrix} \right\} \dot{q}_1$$

$$C_{13} = (2 m_2 l_1(\frac{l_2}{2})^2 \cos q_2 \sin q_{23})\dot{q}_1$$

$$C_{21} = -\left\{ \begin{matrix} (m_1(\frac{l_1}{2})^2 + I_2)\sin q_2 \cos q_2 + m_2 l_1^2 \sin q_2 \cos q_2 + \\ m_2 l_1(\frac{l_2}{2})^2 \sin q_2 \cos q_{23} + (m_2(\frac{l_2}{2})^2 + I_3)\sin q_{23} \cos q_{23} \end{matrix} \right\} \dot{q}_1$$

$$C_{22} = (2 m_2 l_1(\frac{l_2}{2})^2 \sin q_3)\dot{q}_3$$

$$C_{23} = (m_2 l_1(\frac{l_2}{2})^2 \sin q_3)\dot{q}_3$$

$$C_{31} = -\left\{ \begin{matrix} (m_2 l_1(\frac{l_2}{2})^2 \sin q_2) \\ + (m_2(\frac{l_2}{2})^2 + I_3)\sin q_{23} \end{matrix} \right\} \cos q_{23}\dot{q}_1$$

$$C_{32} = -(m_2 l_1(\frac{l_2}{2})^2 \sin q_3)\dot{q}_2$$

$$C_{33} = 0$$

$$G_{11} = 0$$

$$G_{21} = g m_1 \frac{l_1}{2}\cos q_2 + g m_2 l_1 \cos q_2 + g m_2 \frac{l_2}{2}\cos q_{23}$$

$$G_{31} = g m_2 \frac{l_2}{2}\cos q_{23} \quad (12)$$

The simulations have been done under the maximum uncertainty (worse case) using the control law (9). In order to investigate the performance of the new and previous controller [1], each control law with the same control parameters such as K_d= diag(30 30 30) and Λ=diag(30 30 30) is applied to the same model system using same trajectory. The obtained results for K_d and Λ are plotted in Figures 4-9.

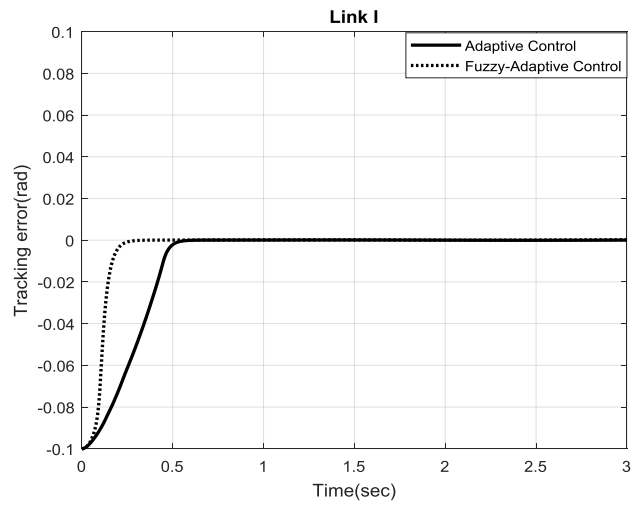

***Fig. 4.** Response using the adaptive control law (9) and fuzzy-adaptive control law with (0.1*cos(t)) trajectory when K_d=diag (30 30 30) Λ=diag (30 30 30).*

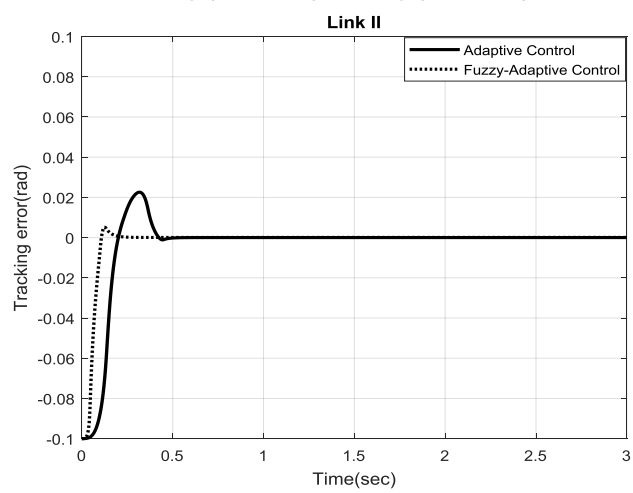

***Fig. 5.** Response using the adaptive control law (9) and fuzzy-adaptive control law with (0.1*cos(t)) trajectory when K_d=diag (30 30 30) Λ=diag(30 30 30),*

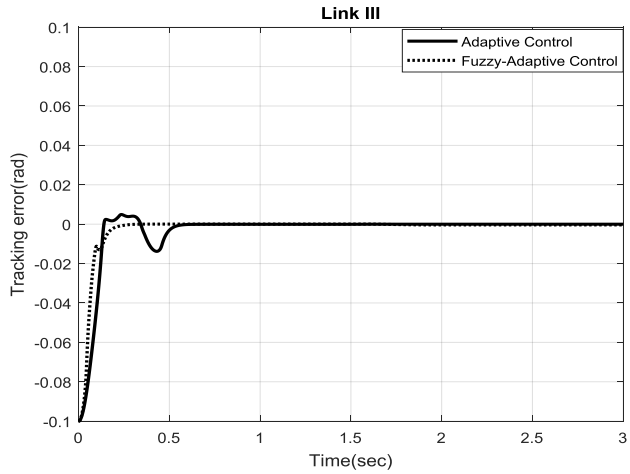

Fig. 6. *Response using the adaptive control law (9) and fuzzy- adaptive control law with (0.1*cos(t)) trajectory when Kd=diag (30 30 30) Λ=diag(30 30 30),*

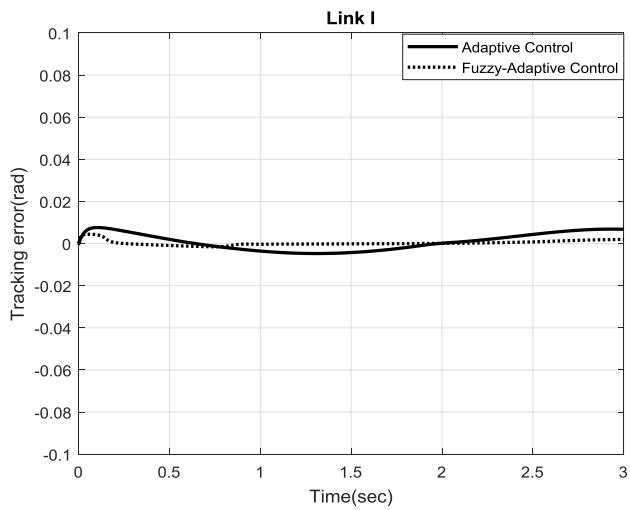

Fig. 7*. Response using the adaptive control law (9) and fuzzy-adaptive control law with (0.5*sin(t))) trajectory when K_d=diag (30 30 30) and Λ=diag(30 30 30).*

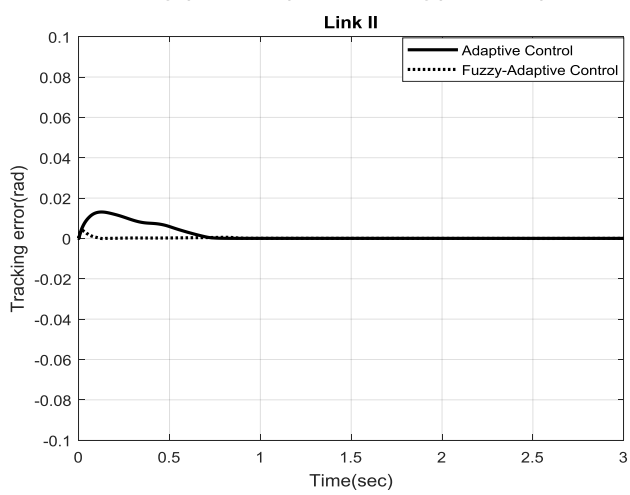

Fig. 8*. Response using the adaptive control law (9) and fuzzy-adaptive control law with (0.5*sin(t))) trajectory when K_d=diag (30 30 30) and Λ=diag(30 30 30).*

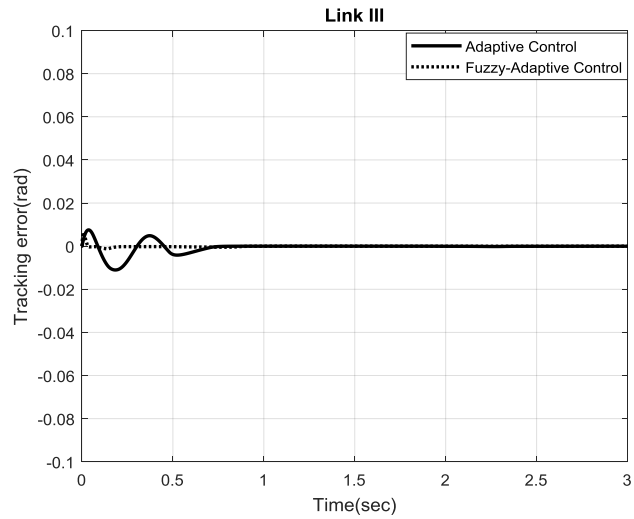

Fig. 9*. Response using the adaptive control law (9) and fuzzy-adaptive control law with (0.5*sin(t))) trajectory when Kd=diag(30 30 30) and Λ=diag(30 30 30).*

As seen from Figures 4-9, tracking performance of the system changes depending on the values of the control gain L. Tracking performance of the fuzzy-adaptive is better then the adaptive control law (9). Tracking performance of the controller is improved by the fuzzy logic control parameter of L.

5 Conclusion

The aim of this study is to develop a novel fuzzy-adaptive control law in order to increase tracking performance of the robot manipulators. For this purpose, a fuzzy logic control rule is designed for control parameter L. In the previous study [1], the control gain is constant. The novelty of this project is that the control gain is defined by fuzzy logic controllers. As shown from Fig. 4-11, tracking performance of the proposed fuzzy-adaptive control law is better than the developed adaptive control law (9). Tracking performance of the controller changes depending on the values of the control gain L, and tracking performance can be improved by using fuzzy logic controller for the control gain to appropriate values. As seen from Fig. 4-11, the proposed fuzzy-adaptive control law increases tracking performance of the system.

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Appendix A

Table 2
Parameters of the unloaded arm

m_1	m_2	l_1	l_2	l_{c1}	l_{c2}	I_0	I_1	I_2
5	15	1	1	0.5	0.5	0.02	5/12	15/12