Design Novel Nonlinear Controller Applied to Robot Manipulator: Design New Feedback Linearization Fuzzy Controller With Minimum Rule Base Tuning Method

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Abstract

In this paper, fuzzy adaptive base tuning feedback linearization fuzzy methodology to adaption gain is introduced. The system performance in feedback linearization controller and feedback linearization fuzzy controller are sensitive to the main controller coefficient. Therefore, compute the optimum value of main controller coefficient for a system is the main important challenge work. This problem has solved by adjusting main fuzzy controller continuously in real-time. In this way, the overall system performance has improved with respect to the classical feedback linearization controller and feedback linearization fuzzy controller. Adaptive feedback linearization fuzzy controller solved external disturbance as well as mathematical nonlinear equivalent part by applied fuzzy supervisory method in feedback linearization fuzzy controller. The addition of an adaptive law to a feedback linearization fuzzy controller to online tune the parameters of the fuzzy rules in use will ensure a moderate computational load. Refer to this research; tuning methodology can online adjust coefficient parts of the fuzzy rules. Since this algorithm for is specifically applied to a robot manipulator.

Keywords: Feedback Linearization Controller, Fuzzy Logic Methodology, Feedback Linearization Fuzzy Controller, Adaptive Methodology, Fuzzy Adaptive Feedback Linearization Fuzzy Methodology.

1. INTRODUCTION, BACKGROUND AND MOTIVATION

One of the important challenges in control algorithms is a linear behavior controller design for nonlinear systems. When system works with different parameters and hard nonlinearities this technique is very useful in order to be implemented easily but it has some limitations such as working near the system operating point[2]. Some of robot manipulators which work in industrial processes are controlled by linear PID controllers, but the design of linear controller for robot manipulators is extremely difficult because they are nonlinear, uncertain and MIMO[1, 6]. To reduce above challenges the nonlinear robust controllers is used to systems control. One of the powerful nonlinear robust controllers is feedback linearization controller (FLIC), this controller has been analyzed by many researchers [7].This controller is used in wide range areas such as in robotics, in control process, in aerospace applications and in power converters. Even though, this controller is used in wide range areas but, pure FLIC has challenged in uncertain (structured and unstructured) system. A multitude of nonlinear control laws have been developed called "computed-torque" or "inverse dynamic" controller in the robotics literature [1-3]. These controllers incorporate the inverse dynamic model of robot manipulators to construct. The computed-torque controllers have their root in feedback linearization control methodology [4, 9]. The idea is to design a nonlinear feedback (maybe calculated using the inverse dynamic model of the robot manipulator to be controlled) which cancels the nonlinearities of an actual robot manipulator. In this manner the closed-loop system becomes exactly linear or partly linear depending on the accuracy of the dynamic model, and then a linear controller such as PD and PID can be applied to control the robot manipulator. The main potential difficulty encountered in implementation of the computed-torque control methodology described above is that the dynamic model of the robot manipulator to be controlled is often not known accuratly. For instance, then the ideal performance (i.e., the exact linearization) of the computed-torque control has been proposed in [18, 23]. In the adaptive computed-torque contol methodology, it is assumed that the structure of the robot manipulator dynamics is perrfectly known but physcical parameters such as links mass, links inertia and friction coefficient are unknown. Therefore, the liearity in the parameters property of robot manipulator dynamic model presented in next part are exploited either to identify unnown parameters or modify the partially known parameters in order to account for the model uncertainty. The two important requirements of adaptive FLIC methodology are: the parameters must be updated such that the estimated inertia matrix remains positive definite and bounded at all times, which means the lower and upper bounds of ineritia parameters must be known a priori; and the measurment of acceleration is need in order to realize the update law [7]. Furthermore, due to the fact that parameters errors are not the sole source of imperfect decoupling and linearization of the robot manipulator dynamics, thus this control methodology cannot provie robustness against external disturbances and unstructured uncertainties [8]. Another difficulty that may be encountered in the implementation of FLIC is that the entire dynamic model (the inertia matrix and the vector of Coriolis, centrifugal, and gravitational terms) of the robot manipulator, i.e., all terms of equation in robot manipulator, must be computed on-line and in the control law, since control is now based on the nonlinear feedback of the current system state. For a robot manipulator with many joints and links, for example for a 6-DOF serial robot manipulator (Stewart-Gough platform) these computations can be complicated and time consuming. The problem of computation burden can even be increased when the adaptive FLIC is used. This is due to extra computation needed to update the parameters in each sample time. Two methods can be found in the literature to deal with the problem of computation burden described above. One method to deal with the problem of computation burden is to use feedforward computed-torque control in which the tourqe vector is computed on the basis of the desired trajectory of the joints (i.e., desired joints positions, velocities and accelerations) and FLIC the nonlinear coupling effects. As opposed to feedback FLIC, in the feedforward method it is possible to pre-compute all the terms of the dynamic model off-line and reduce the computation burden to a large extent [3-9]. The second method to deal with the problem of heavy computation burden in the FLIC is to develop a computationally efficient dynamic model. The feedback linearization-based (computed-torqe/inverse dynamic) control methodologies rely on the knowledge of the robot manipulator dynamic model and its parameters. In the case of imperfect dynamic model the closed-loop dynamics will no longer be decoupled and linearized, for detailed information the reader is referred to [4, 18, 23]. Furthermore, in the feedback linearization-based control methodology, the control law may cancel some beneficial nonlinearity such as friction [18, 23].

2. ROBOT MANIPULATOR DYNAMICS, OBJECTIVES, PROBLEM STATEMENTS AND FEEDBACK LINEARIZATION FORMULATION

Robot manipulator dynamic formulation: The equation of an *n-DOF* robot manipulator governed by the following equation [1, 3, 15-29]:

$$M(q)\ddot{q} + N(q,\dot{q}) = \tau \quad \textbf{(1)}$$

Where τ is actuation torque, M (q) is a symmetric and positive define inertia matrix, $N(q,\dot{q})$ is the vector of nonlinearity term. This robot manipulator dynamic equation can also be written in a following form:

$$\tau = M(q)\ddot{q} + B(q)[\dot{q}\,\dot{q}] + C(q)[\dot{q}]^2 + G(q) \quad \textbf{(2)}$$

Where B(q) is the matrix of coriolios torques, C(q) is the matrix of centrifugal torques, and G(q) is the vector of gravity force. The dynamic terms in equation (2) are only manipulator position. This is a decoupled system with simple second order linear differential dynamics. In other words, the component $\ddot{q}$ influences, with a double integrator relationship, only the joint variable q_i, independently of the motion of the other joints. Therefore, the angular acceleration is found as to be [3, 10-29]:

$$\ddot{q} = M^{-1}(q).\{\tau - N(q,\dot{q})\} \quad \textbf{(3)}$$

Feedback Linearization Control: This technique is very attractive from a control point of view. The central idea of FLIC is feedback linearization so, originally this algorithm is called feedback linearization controller. It has assumed that the desired motion trajectory for the manipulator $q_d(t)$, as determined, by a path planner. Defines the tracking error as:

$$e(t) = q_d(t) - q_a(t) \quad \textbf{(4)}$$

Where e(t) is error of the plant, $q_d(t)$ is desired input variable, that in our system is desired displacement, $q_a(t)$ is actual displacement. If an alternative linear state-space equation in the form $\dot{x} = Ax + BU$ can be defined as

$$\dot{x} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ I \end{bmatrix} U \quad \textbf{(5)}$$

With $U = -M^{-1}(q).N(q,\dot{q}) + M^{-1}(q).\tau$ and this is known as the Brunousky canonical form. By equation (4) and (5) the Brunousky canonical form can be written in terms of the state $x = [e^T \; \dot{e}^T]^T$ as [1]:

$$\frac{d}{dt}\begin{bmatrix} e \\ \dot{e} \end{bmatrix} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} . \begin{bmatrix} e \\ \dot{e} \end{bmatrix} + \begin{bmatrix} 0 \\ I \end{bmatrix} U \quad \textbf{(6)}$$

With

$$U = \ddot{q}_d + M^{-1}(q).\{N(q,\dot{q}) - \tau\} \quad \textbf{(7)}$$

Then compute the required arm torques using inverse of equation (7), is;

$$\tau = M(q)(\ddot{q}_d - U) + N(\dot{q},q) \quad \textbf{(8)}$$

This is a nonlinear feedback control law that guarantees tracking of desired trajectory. Selecting proportional-plus-derivative (PD) feedback for U(t) results in the PD-computed torque controller [7-9, 18-23];

$$\tau = M(q)(\ddot{q}_d + K_v\dot{e} + K_p e) + N(q,\dot{q}) \quad \textbf{(9)}$$

and the resulting linear error dynamics are

$$(\ddot{q}_d + K_v\dot{e} + K_p e) = 0 \quad \textbf{(10)}$$

According to the linear system theory, convergence of the tracking error to zero is guaranteed [6]. Where K_p and K_v are the controller gains. The result schemes is shown in Figure 1, in which two feedback loops, namely, inner loop and outer loop, which an inner loop is a compensate loop and an outer loop is a tracking error loop. However, mostly parameter $N(q,\dot{q})$ is all unknown. So the control cannot be implementation because non linear parameters cannot be determined. In the following section computed torque like controller will be introduced to overcome the problems.

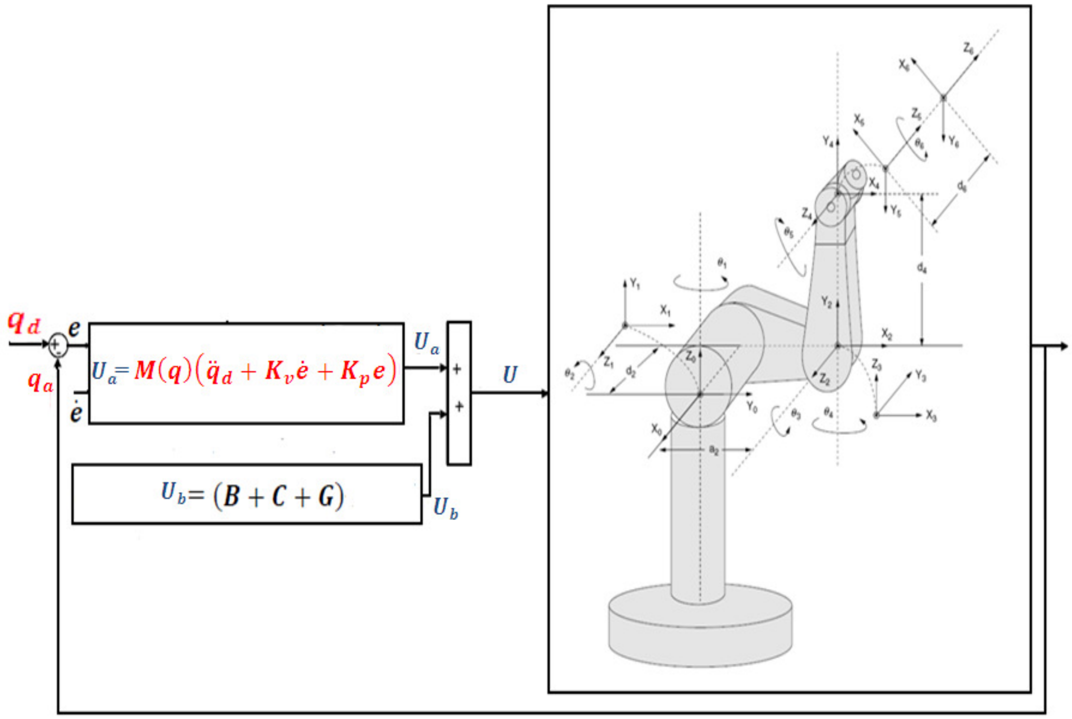

FIGURE 1: Block diagram of PD-computed torque controller (PD-CTC)

The application of proportional-plus-derivative (PD) FLIC to control of PUMA 560 robot manipulator introduced in this part. PUMA 56o robot manipulator is a nonlinear and uncertain system which needs to have powerful nonlinear robust controller such as computed torque controller.

Suppose that in (9) the nonlinearity term defined by the following term

$$N(q,\dot{q}) = B(q)\dot{q}\dot{q} + C(q)\dot{q}^2 + g(q) = \begin{bmatrix} b_{112}\dot{q}_1\dot{q}_2 + b_{113}\dot{q}_1\dot{q}_3 + 0 + b_{123}\dot{q}_2\dot{q}_3 \\ 0 + b_{223}\dot{q}_2\dot{q}_3 + 0 + 0 \\ 0 \\ b_{412}\dot{q}_1\dot{q}_2 + b_{413}\dot{q}_1\dot{q}_3 + 0 + 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} C_{12}\dot{q}_2^{\,2} + C_{13}\dot{q}_3^{\,2} \\ C_{21}\dot{q}_1^{\,2} + C_{23}\dot{q}_3^{\,2} \\ C_{31}\dot{q}_1^{\,2} + C_{32}\dot{q}_2^{\,2} \\ 0 \\ C_{51}\dot{q}_1^{\,2} + C_{52}\dot{q}_2^{\,2} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ g_2 \\ g_3 \\ 0 \\ g_5 \\ 0 \end{bmatrix} \quad (11)$$

Therefore the equation of PD-CTC for control of PUMA 560 robot manipulator is written as the equation of (12);

$$\begin{bmatrix} \hat{\tau}_1 \\ \hat{\tau}_2 \\ \hat{\tau}_3 \\ \hat{\tau}_4 \\ \hat{\tau}_5 \\ \hat{\tau}_6 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & 0 & 0 & 0 \\ M_{21} & M_{22} & M_{23} & 0 & 0 & 0 \\ M_{31} & M_{32} & M_{33} & 0 & M_{35} & 0 \\ 0 & 0 & 0 & M_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & M_{66} \end{bmatrix} \begin{bmatrix} \ddot{q}_{d1} + K_{v1}\dot{e}_1 + K_{p1}e_1 \\ \ddot{q}_{d2} + K_{v2}\dot{e}_2 + K_{p2}e_2 \\ \ddot{q}_{d3} + K_{v3}\dot{e}_3 + K_{p3}e_3 \\ \ddot{q}_{d4} + K_{v4}\dot{e}_4 + K_{p4}e_4 \\ \ddot{q}_{d5} + K_{v5}\dot{e}_5 + K_{p5}e_5 \\ \ddot{q}_{d6} + K_{v6}\dot{e}_6 + K_{p6}e_6 \end{bmatrix} \quad (12)$$

$$+\begin{bmatrix} b_{112}\dot{q}_1\dot{q}_2 + b_{113}\dot{q}_1\dot{q}_3 + 0 + b_{123}\dot{q}_2\dot{q}_3 \\ 0 + b_{223}\dot{q}_2\dot{q}_3 + 0 + 0 \\ 0 \\ b_{412}\dot{q}_1\dot{q}_2 + b_{413}\dot{q}_1\dot{q}_3 + 0 + 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} C_{12}\dot{q}_2^{\,2} + C_{13}\dot{q}_3^{\,2} \\ C_{21}\dot{q}_1^{\,2} + C_{23}\dot{q}_3^{\,2} \\ C_{31}\dot{q}_1^{\,2} + C_{32}\dot{q}_2^{\,2} \\ 0 \\ C_{51}\dot{q}_1^{\,2} + C_{52}\dot{q}_2^{\,2} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ g_2 \\ g_3 \\ 0 \\ g_5 \\ 0 \end{bmatrix}$$

The controller based on a formulation (12) is related to robot dynamics therefore it has problems in uncertain conditions.

Problem Statement: feedback linearization controller is used in wide range areas such as in robotics, in control process, in aerospace applications and in power converters because it has an acceptable control performance and solve some main challenging topics in control such as resistivity to the external disturbance. Even though, this controller is used in wide range areas but, pure FLIC has the following disadvantage: the main potential difficulty encountered in implementation of the computed-torque control methodology described above is that the dynamic model of the robot manipulator to be controlled is often not known accuratly. On the other hand, pure fuzzy logic controller (FLC) works in many areas, it cannot guarantee the basic requirement of stability and acceptable performance[8]. Although both FLIC and FLC have been applied successfully in many applications but they also have some limitations. Proposed method focuses on substitution fuzzy logic system applied to main controller to compensate the uncertainty in nonlinear dynamic equivalent equation to implement easily and avoid mathematical model base controller. To reduce the effect of uncertainty in proposed method, adaptive method is applied in feedback linearization fuzzy controller in robot manipulator.

Objectives: The main goal is to design a position controller for robot manipulator with acceptable performances (e.g., trajectory performance, torque performance, disturbance rejection, steady state error and RMS error). Robot manipulator has nonlinear dynamic and uncertain parameters consequently; following objectives have been pursuit in the mentioned study.

- To design and implement a position feedback linearization fuzzy controller in order to solve the uncertainty in nonlinear parameters problems in the pure feedback linearization control.
- To develop a position adaptive feedback linearization fuzzy controller in order to solve the disturbance rejection.

3. METHODOLOGY: DESIGN A NOVEL ADAPTIVE FEEDBACK LINEARIZATION FUZZY ESTIMATION CONTROLLER

First step, Design feedback linearization fuzzy controller: In recent years, artificial intelligence theory has been used in robotic systems. Neural network, fuzzy logic, and neuro-fuzzy are combined with nonlinear methods and used in nonlinear, time variant, and uncertainty plant (e.g., robot manipulator). This controller can be used to control of nonlinear, uncertain, and noisy systems. This method is free of some model-based techniques that used in classical controllers. The main reasons to use fuzzy logic technology are able to give approximate recommended solution for unclear and complicated systems to easy understanding and flexible. Fuzzy logic provides a method which is able to model a controller for nonlinear plant with a set of IF-THEN rules, or it can identify the control actions and describe them by using fuzzy rules. Besides applying fuzzy logic in the main controller of a control loop, it can be used to design adaptive control, tuning parameters, working in a parallel with the classical and non classical control method. However the application area for fuzzy control is really wide, the basic form for all command types of controllers consists of;

- Input fuzzification (binary-to-fuzzy[B/F]conversion)
- Fuzzy rule base (knowledge base)
- Inference engine
- Output defuzzification (fuzzy-to-binary[F/B]conversion).

As a summary the design of fuzzy logic controller based on Mamdani's fuzzy inference method has four steps, namely, fuzzification, fuzzy rule base and rule evaluation, aggregation of the rule output (fuzzy inference system), and deffuzzification [10-15, 29].

Fuzzification: the first step in fuzzification is determine inputs and outputs which, it has one input (U_α) and one output (U_{fuzzy}). The input is U_α which measures the summation of linear loop and nonlinear loop in main controller. The second step is chosen an appropriate membership function for inputs and output which, for simplicity in implementation and also to have an acceptable performance the researcher is selected the triangular membership function. The third step is chosen the correct labels for each fuzzy set which, in this research namely as linguistic variable. The linguistic variables for input (U_α) are; Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB), and it is quantized in to thirteen levels represented by: -1, -0.83, -0.66, -0.5, -0.33, -0.16, 0, 0.16, 0.33, 0.5, 0.66, 0.83, 1 and the linguistic variables to find the output are; Large Left (LL), Medium Left (ML), Small Left (SL), Zero (Z), Small Right (SR), Medium Right (MR), Large Right (LR) and it is quantized in to thirteen levels represented by: -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6.

Fuzzy Rule Base and Rule Evaluation: the first step in rule base and evaluation is provide a least structured method to derive the fuzzy rule base which, expert experience and control engineering knowledge is used because this method is the least structure of the other one and the researcher derivation the fuzzy rule base from the knowledge of system operate and/or the classical controller. Design the rule base of fuzzy inference system can play important role to design the best performance of fuzzy sliding mode controller, that to calculate the fuzzy rule base the researcher is used to heuristic method which, it is based on the behavior of the control of robot manipulator suppose that the fuzzy rules in this controller is;

F.R^1: *IF U_α is NB, THEN U_{fuzzy} is LL.* **(13)**

The complete rule base for this controller is shown in Table 1. Rule evaluation focuses on operation in the antecedent of the fuzzy rules in fuzzy sliding mode controller. This part is used AND/OR fuzzy operation in antecedent part which AND operation is used.

Aggregation of the Rule Output (Fuzzy Inference): Max-Min aggregation is used to this work which the calculation is defined as follows;

$$\mu_U(x_k, y_k, U) = \mu_{\cup_{i=1}^{r} FR^i}(x_k, y_k, U) = max\left\{min_{i=1}^{r}\left[\mu_{R_{pq}}(x_k, y_k), \mu_{p_m}(U)\right]\right\} \quad (14)$$

Deffuzzification: The last step to design fuzzy inference in our fuzzy sliding mode controller is defuzzification. This part is used to transform fuzzy set to crisp set, therefore the input for defuzzification is the aggregate output and the output of it is a crisp number. In this design the Center of gravity method (COG) is used and calculated by the following equation;

$$COG(x_k, y_k) = \frac{\sum_i U_i \sum_{j=1}^{r} \mu_u(x_k, y_k, U_i)}{\sum_i \sum_{j=1}^{r} \mu_u(x_k, y_k, U_i)} \quad (15)$$

This table has 7 cells, and used to describe the dynamics behavior of fuzzy controller.

U_α	NB	NM	NS	Z	PS	PM	PB
U_{fuzzy}	LL	ML	SL	Z	SR	MR	LR

TABLE 1: Rule table

Figure 2 is shown the feedback linearization fuzzy controller based on fuzzy logic controller and minimum rule base.

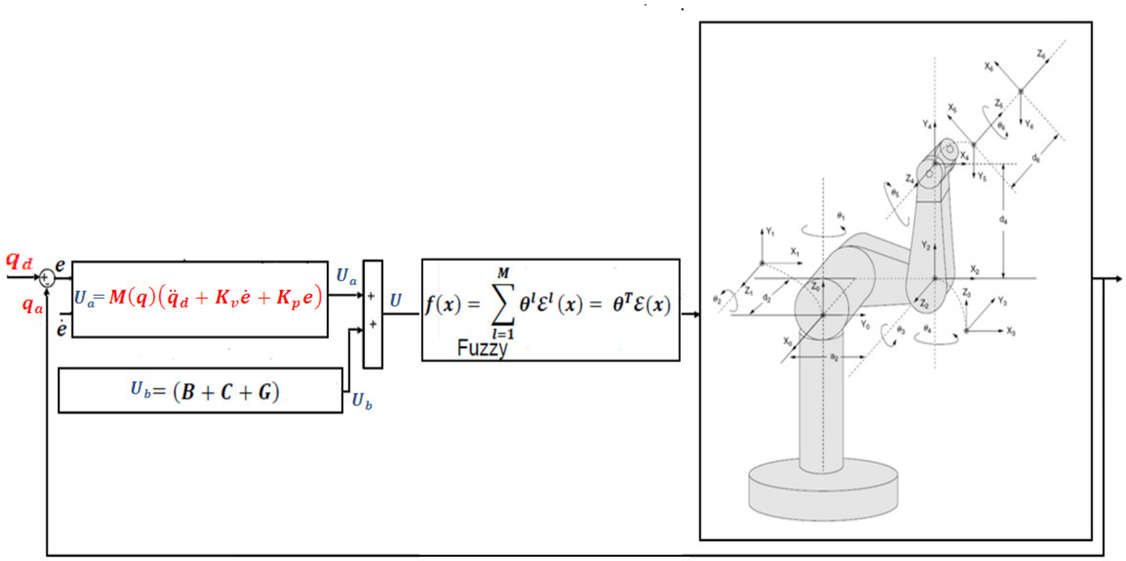

FIGURE2: Block Diagram of Feedback Linearization Fuzzy Controller with Minimum Rule Base

Second Step; Design Fuzzy Adaptive Feedback Linearization Fuzzy Controller With Minimum Rules: All conventional controller have common difficulty, they need to find several parameters. Tuning feedback linearization fuzzy method can tune automatically the scale parameters using artificial intelligence method. To keep the structure of the controller as simple as possible and to avoid heavy computation, a two inputs Mamdani fuzzy supervisor tuner is selected. In this method the tuneable controller tunes the PD coefficient feedback linearization controller using gain updating factors.

However proposed feedback linearization fuzzy controller has satisfactory performance but calculate the main controller coefficient by try and error or experience knowledge is very difficult, particularly when system has uncertainties; fuzzy adaptive feedback linearization fuzzy controller is recommended.

The adaption low is defined as

$$\dot{\theta}_j = \gamma_{sj}\alpha_j\zeta_j(\alpha_j) \quad \textbf{(16)}$$

where the γ_{sj} is the positive constant and $\zeta_j(\alpha_j) = [\zeta_j^1(\alpha_j), \zeta_j^2(\alpha_j), \zeta_j^3(\alpha_j), \ldots\ldots, \zeta_j^M(\alpha_j)]^T$

$$\zeta_j^1(\alpha_j) = \frac{\mu_{(A)}{}_j^l(\alpha_j)}{\sum_i \mu_{(A)}{}_j^l(\alpha_j)} \quad \textbf{(17)}$$

As a result proposed method is very stable with a good performance. Figure 3 is shown the block diagram of proposed fuzzy adaptive applied to feedback linearization fuzzy controller. The fuzzy system can be defined as below

$$f(x) = \tau_{fuzzy} = \sum_{l=1}^{M} \theta^T \zeta(x) = \psi(e, \dot{e}) \quad \textbf{(18)}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \ldots\ldots, \theta^M)^T, \zeta(x) = (\zeta^1(x), \zeta^2(x), \zeta^3(x), \ldots\ldots, \zeta^M(x))^T$

$$\zeta^1(x) = \frac{\sum_i \mu_{(xi)} x_i}{\sum_i \mu_{(xi)}} \quad \textbf{(19)}$$

where $\theta = (\theta^1, \theta^2, \theta^3, \ldots\ldots, \theta^M)$ is adjustable parameter in (18) and $\mu_{(xi)}$ is membership function.
error base fuzzy controller can be defined as

$$\alpha_{fuzzy} = \psi(e, \dot{e}) \quad \textbf{(20)}$$

the fuzzy division can be reached the best state when $\lim_{e \to \infty} e = 0$ and the error is minimum by the following formulation

$$\theta^* = \arg\min \left[Sup_{x \in U} \left| \sum_{l=1}^{M} \theta^T \zeta(x) - U_{equ} \right| \right] \tag{21}$$

Where $\theta^*$is the minimum error, $sup_{x \in U} \left| \sum_{l=1}^{M} \theta^T \zeta(x) - U_{equ} \right|$ is the minimum approximation error. The adaptive controller is used to find the minimum errors of $\theta - \theta^*$.

suppose K_j is defined as follows

$$K_j = \frac{\sum_{l=1}^{M} \theta_j^l [\mu_A(\alpha_j)]}{\sum_{l=1}^{M} [\mu_A(\alpha_j)]} = \theta_j^T \zeta_j(\alpha_j) \tag{22}$$

Where $\zeta_j(\alpha_j) = [\zeta_j^1(\alpha_j), \zeta_j^2(\alpha_j), \zeta_j^3(\alpha_j), \ldots\ldots, \zeta_j^M(\alpha_j)]^T$

$$\zeta_j^1(S_j) = \frac{\mu_{(A)_j^l}(\alpha_j)}{\sum_i \mu_{(A)_j^l}(\alpha_j)} \tag{23}$$

the adaption low is defined as

$$\dot{\theta}_j = \gamma_{sj} \alpha_j \zeta_j(\alpha_j) \tag{24}$$

where the $\gamma_{sj}$is the positive constant.

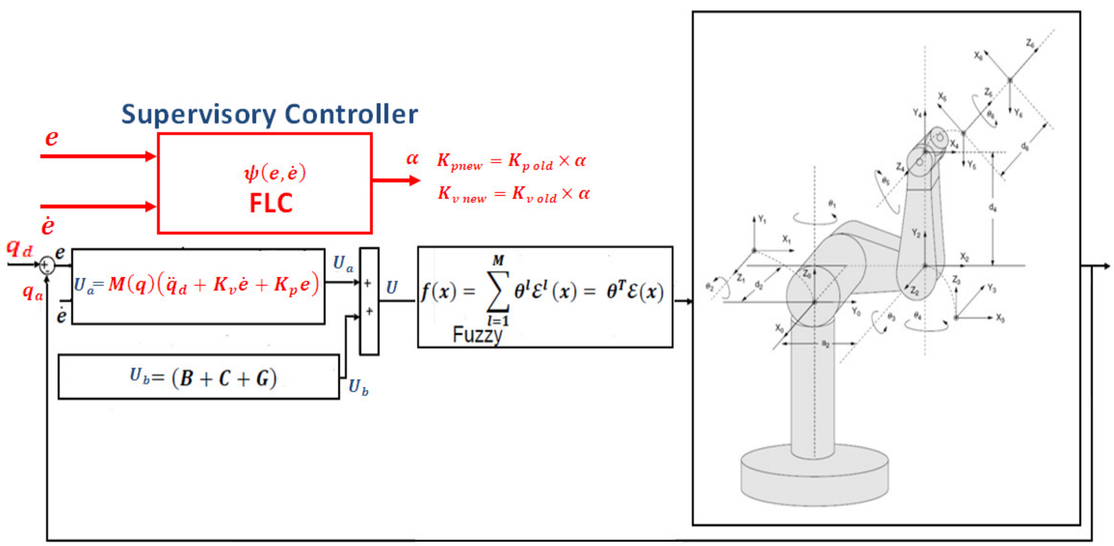

FIGURE 3: Design fuzzy adaptive feedback linearization fuzzy controllers

4 SIMULATION RESULTS

Pure feedback linearization controller (FLIC) and fuzzy adaptive feedback linearization fuzzy controller (FAFLIFC) are implemented in Matlab/Simulink environment. Tracking performance and disturbance rejection are compared.

Tracking Performances

From the simulation for first, second and third trajectory without any disturbance, it was seen that FLIC and FAFLIFC have the same performance because this system is worked on certain environment. The FAFLIFC gives significant trajectory good following when compared to pure fuzzy logic controller. Figure 4 shows tracking performance without any disturbance for FLIC and FAFLIFC.

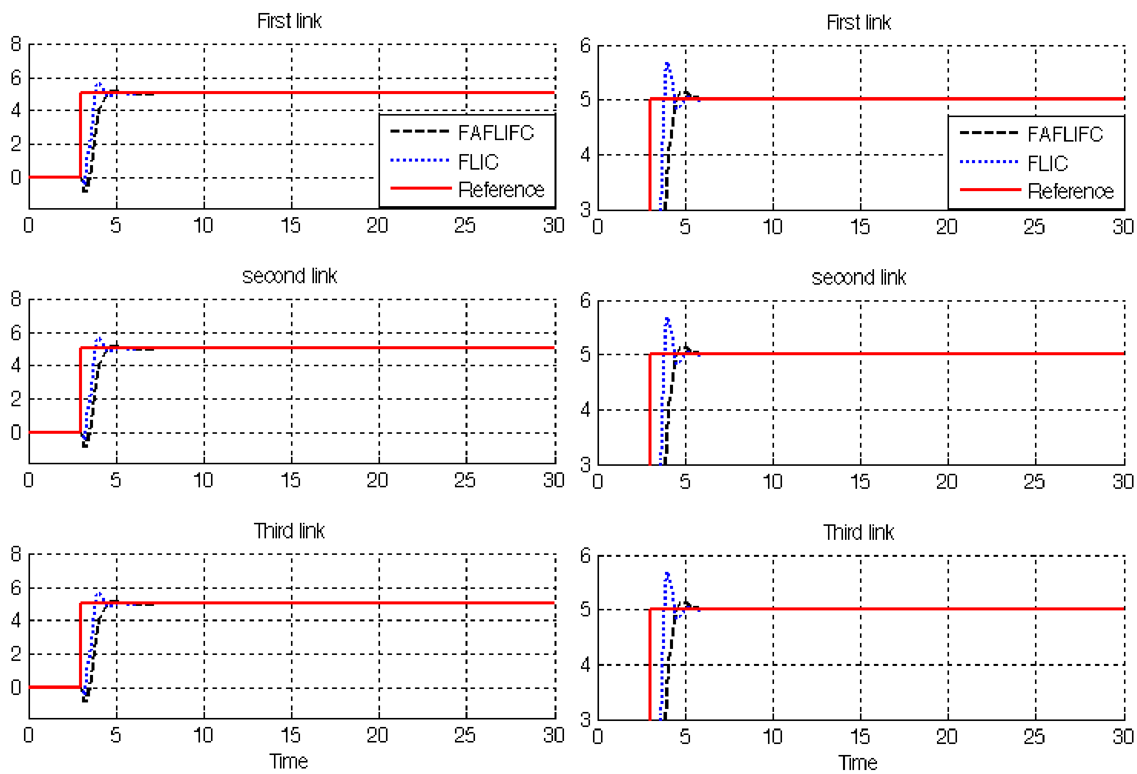

FIGURE 4: FLIC Vs. FAFLIFC: applied to 3DOF's robot manipulator

By comparing step response trajectory without disturbance in FLIC and FAFLIFC, it is found that the FAFLIFC's overshoot **(2.4%)** is lower than FLIC's **(14%)** and the rise time in FAFLIFC's **(1.2 sec)** and FLIC's **(0.8 sec)**.

Disturbance Rejection

Figure 5 has shown the power disturbance elimination in FLIC and FAFLIFC. The main targets in these controllers are disturbance rejection as well as the other responses. A band limited white noise with predefined of 40% the power of input signal is applied to the FLIC and FAFLIFC. It found fairly fluctuations in FLIC trajectory responses.

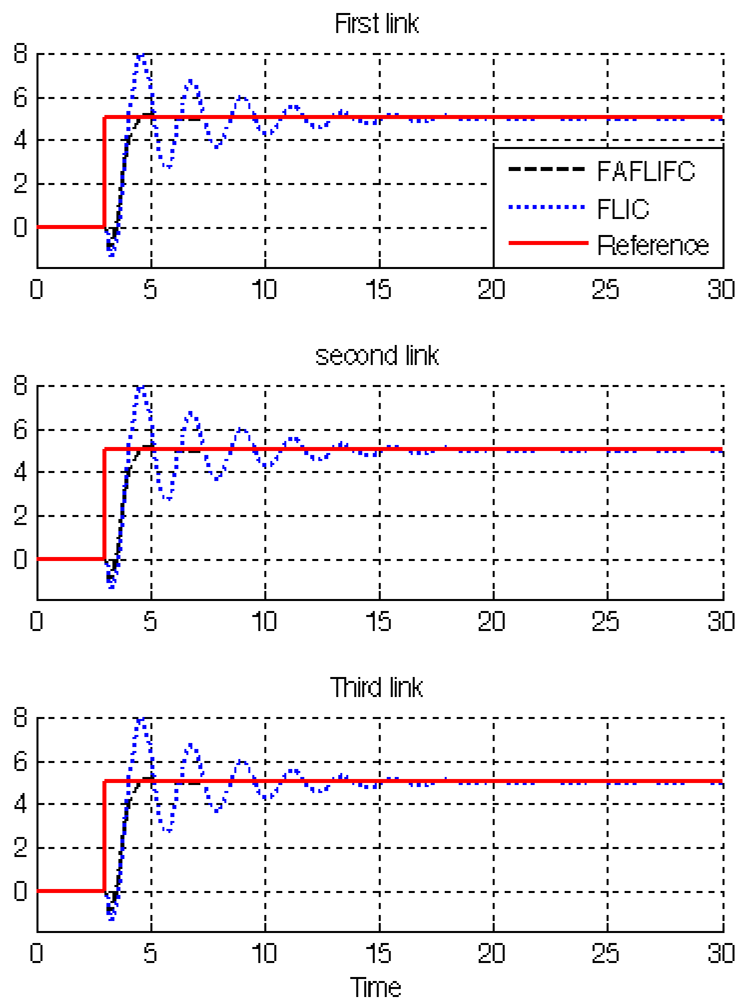

FIGURE 5: FLIC Vs. FAFLIFC: applied to robot manipulator.

Among above graph relating to trajectory following with external disturbance, FLIC has fairly fluctuations. By comparing some control parameters such as overshoot and rise time it found that the FAFLIFC's overshoot **(2.4%)** is lower than FLIC's **(60%)**, although both of them have about the same rise time**.**

5 CONCLUSIONS

In this research, fuzzy adaptive base tuning feedback linearization fuzzy methodology to outline learns of this adaption gain is recommended. Since proof of stability is an important factor in practice does not hold, the study of stability for robot manipulator with regard to applied artificial intelligence in robust classical method and adaptive low in practice is considered to be a subject in this work. The system performance in feedback linearization controller and feedback linearization fuzzy controller are sensitive to the main controller coefficient. Therefore, compute the optimum value of main controller coefficient for a system is the main important challenge work. This problem has solved by adjusting main controller coefficient of the feedback linearization controller continuously in real-time. In this way, the overall system performance has improved with respect to the classical feedback linearization controller. As mentioned in previous, this controller solved external disturbance as well as mathematical nonlinear equivalent part by applied fuzzy supervisory method in feedback linearization fuzzy controller. By comparing between fuzzy adaptive feedback linearization fuzzy controller and feedback linearization fuzzy controller, found that fuzzy adaptive feedback linearization fuzzy controller has steadily stabilised in output response but feedback linearization fuzzy controller has slight oscillation in the presence of uncertainties.

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