Comparative Study of Advanced Controllers Techniques Applied to the Control of a Multi-articulated System

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Abstract. In this work a comparison among three control strategies is presented, with application to a multi-articulated system. The proposed control scheme is based on the dynamic model derived using Lagrange-Euler formulation. Our robot manipulator ANFIS system control's simulated in Matlab Simulink environment; the results obtained present the efficiency and the robustness of the proposed control with good performances compared with PID and the FIS method.

Keywords—Multi-articulated system, control, Adaptive Neuro-Fuzzy, PID, Fuzzy logic

1 Introduction

Research on the dynamic modeling and control of the arms manipulators has received increased attention since the last years due to their advantages.
The robot manipulator is a mechanical system multi-articulated, in which each articulation is driven individually by an electric actuator is the most robot used in industry. Many efforts have been made in developing control scheme to achieve the precise tracking control of robot manipulators.
The traditional PID controller with simple structure and stable performance is widely used. But it is difficult to meet the high precision and fast response, moreover the parameters tuning of classical PID controller is so complex.
Therefore fuzzy algorithm is introduced. Fuzzy control is a particular type of intelligent control, has a great potential since it is able to compensate for the uncertain nonlinear dynamics using the programming capability of human control behavior. The main features of fuzzy control is that a control knowledge base is available within the controller and control

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actions are generated by applying existing conditions or data to the knowledge base, making us of inference mechanism.

Also, the knowledge base and inference mechanism can handle no crisp, incomplete information; the knowledge itself will improve and evolve through learning and past experience.

Fuzzy logic control does not require a conventional model of the process, whereas most conventional techniques require either an analytical model or an experimental model. Fuzzy logic control is particularly suitable for complex and ill-defined process in which analytical modeling is difficult due to the fact that the process is not completely known and experimental model identification is not feasible because the required inputs and output of the process may not be measurable.

The Adaptive Neuro-Fuzzy Inference System (ANFIS), developed in the early 90s by Jang, combines the concepts of fuzzy logic and neural networks to form a hybrid intelligent system that enhances the ability to automatically learn and adapt.

In this work after the system modeling, simulation and control robot manipulator using two articulations for motion using MatLab/Simulink software were carried, when the proposed Anfis controlled is used to improve the articulation robot stability. Three types of control PID, Fuzzy logic and Anfis were studied; analysis and comparative studies were made.

2 Dynamic Model of Robot Manipulator

Usually, a set of rigid bodies connected in series by joints, with the base of the robot and the end body or effector.

The dynamical equation of manipulator robot of n solids articulated between us is given by the following matrix equation:

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

Where:

τ is the $(n\times 1)$ vector of joint torque, $M(q)$ is the $(n\times n)$ symmetric positive definite manipulator inertia matrix,

$C(q,\dot{q})$ present the $(n\times 1)$ vector of Coriolis and centrifugal forces, $G(q)$ is the $(n\times 1)$ vector of gravitational references and $q,\dot{q},\ddot{q}$ are : position, velocity and acceleration of each articulations.

Where:

The elements of the inertia matrix $M(q)$ in the terms of the parameters of the robot manipulator are given by:

$$M_{11}(q) = I_1 + I_2 + m_1 l_{c1}^2 + m_2 l_{c2}^2 + m_2 l_1^2 + 2m_2 l_1 l_{c2} c_2$$

$$M_{12}(q) = M_{21}(q) = I_2 + m_2 l_{c2}^2 + 2m_2 l_1 l_{c2} c_2$$

$$M_{22}(q) = 2I_2 + m_2 l_{c2}^2$$

The matrix elements $C_{ij}(q,\dot{q})(i,j=1,2)$ centrifugal and Coriolis force are:

$$C_{11}(q,\dot{q}) = -m_2 l_1 l_{c2}\dot{q}_2 s_2 \qquad C_{12}(q,\dot{q}) = -m_2 l_1 l_{c2} s_2(\dot{q}_1 + \dot{q}_2)$$

$$C_{21}(q,\dot{q}) = m_2 l_1 l_{c2}\dot{q}_1 s_2 \qquad C_{22}(q,\dot{q}) = 0$$

Finally, the elements of the vector of gravitational torques G (q) are given by:

$$G_1(q) = (m_1 + m_2) g l_{c1} c_1 + m_2 g l_{c2} c_{12}$$

$$G_2(q) = m_2 g l_{c2} c_{12}$$

3 Control law used PID

Generally, a classical PID controller of each articulation controlled independently is given with the main following formula:
The classical PID control law of first articulation is given by:

$$\tau_1(t) = K_{p1}\varepsilon_1(t) + K_{d1}\frac{d\varepsilon_1(t)}{dt} + \frac{1}{K_{i1}}\int \varepsilon_1(t)dt \tag{2}$$

When the classical PID control law of second articulation is given by:

$$\tau_2(t) = K_{p2}\varepsilon_2(t) + K_{d2}\frac{d\varepsilon_2(t)}{dt} + \frac{1}{K_{i2}}\int \varepsilon_2(t)dt \tag{3}$$

Where: ε_1 and ε_2 are the main position errors of each articulation controlled independently.
And $K_{p_i}, K_{i_i}, K_{d_i}$ are respectively the gain proportional, integral and derive.
So, the general equation of the manipulator arm by introducing parameters PID controller would be:

$$\begin{bmatrix}\ddot{q}_1\\ \ddot{q}_2\end{bmatrix} = M(q)^{-1}\left[-C(q,\dot{q}) - G(q)\right] + \begin{bmatrix}K_{p1}(q_1^* - q_1) + K_{i1}\int \varepsilon(q_1)dt - K_{d1}\dot{\varepsilon}_1\\ K_{p2}(q_2^* - q_2) + K_{i2}\int \varepsilon(q_2)dt - K_{d2}\dot{\varepsilon}_2\end{bmatrix} \tag{4}$$

4 Fuzzy logic position control strategy

In second time we replaced the classical PID control with the fuzzy logic controller. The principal design elements in a general fuzzy logic control system shown are as follows: Fuzzification, Control rule base establishment and Deffuzification.
This fuzzy controller is to be designed to automate how a human expert who is successful at this task would control the system. First, the expert tells us (the designers of the fuzzy controller) what information she or he will use as inputs to the decision-making process.
For the robot arm manipulator, we will use:

$$e(k) = q_i^* - q_i \ (i = 1, 2) \tag{5}$$

$$\dot{e}(k) = \frac{e(k) \quad e(k \quad 1)}{\Delta t} \tag{6}$$

Where Δt is sample cycle, q_i is the output signal and q_i^* is the input reference position, (5) and (6) determine the input variables on which to base decisions. Certainly, there are many other choices [4] (e.g., the integral of the error e could also be used) but this choice makes good intuitive sense.

5 Adaptive neuro fuzzy controller

5.1 Anfis structure

The ANFIS is a multilayer feed forward network which employs neural network and fuzzy logic learning algorithms to design a plan from input to output. ANFIS has shown great capabilities in control process. A typical architecture of an ANFIS is shown in Fig.1, in which a circle indicates a fixed node, whereas a square indicates an adaptive node. For simplicity, it was assumed that the desired logic system has two inputs x, y and one output z. Since the proposed neuro-fuzzy model of the ANFIS similar to the first order Sugeno fuzzy model

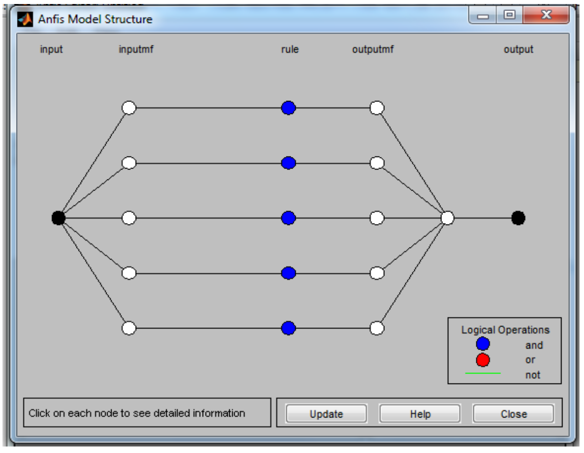

Fig. 1. ANFIS model structure

The ANFIS procedure as shown in Fig.2, in the first step initializing the fuzzy system using genfis command, in the second step learning process start and the number of epochs is set, in the third step learning process start by using anfis command and last in the fourth step validation occur with independent data.

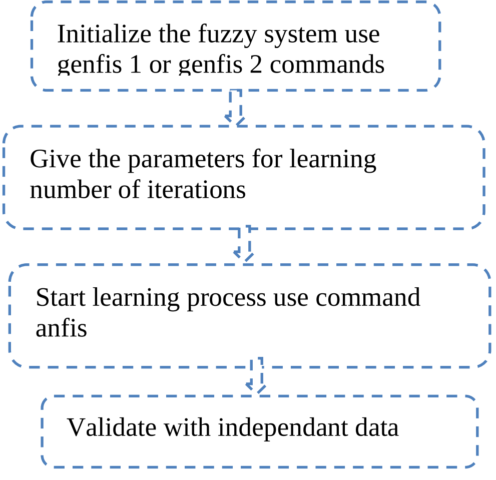

Fig. 2. ANFIS procedure

5.2 Adaptive neuro fuzzy controller

The position control of the robot arm manipulator requires two ANFIS controllers (ANFIS1 applied to the first joint and ANFIS2 applied to the second joint).
Where two inputs and one output have been considered for the ANFIS1, same thing for ANFIS2, the two inputs are e_1 (error position), $\dot{e}_1$ (change of position error) for the first controller and e_2, $\dot{e}_2$ for the second controller, the output is $\tau_1(t)$ (torque) for ANFIS1 and $\tau_2(t)$ for ANFIS2.

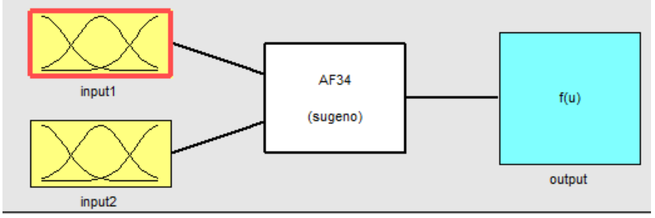

Fig. 3. Block diagram of ANFIS using Matlab

The structure of ANFIS used where the number of epochs was 50 for training, the memberships for the input variables e and de is 5 and 5, respectively the number of rules is then 25 (5*5=25) and the triangular membership functions is used for the two inputs.
Figures (3 and 4) show the rules between input and output parameters for ANFIS1 and ANFIS2.

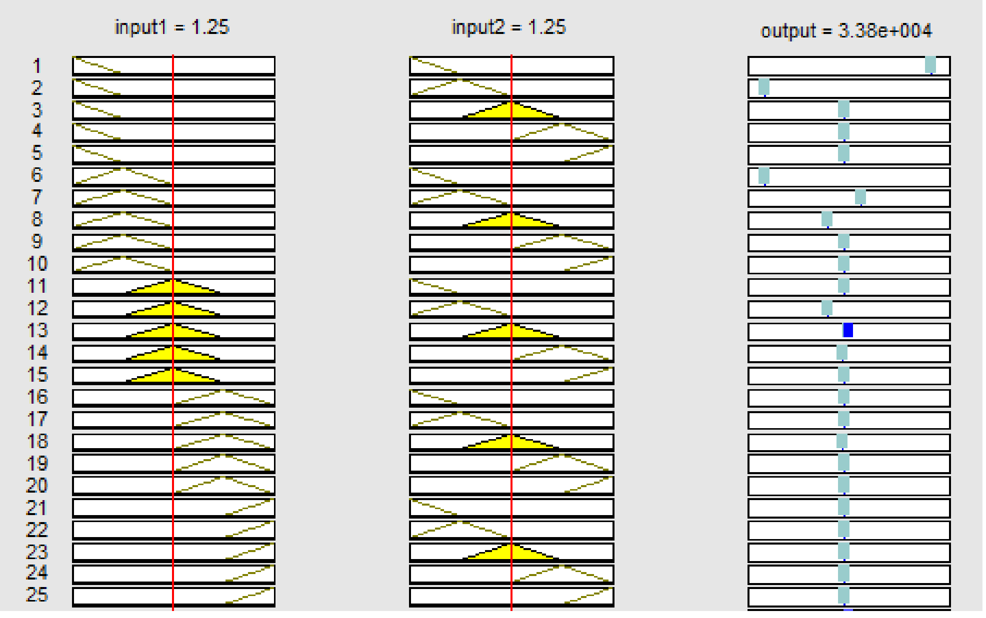

Fig. 3. Rules of the first ANFIS

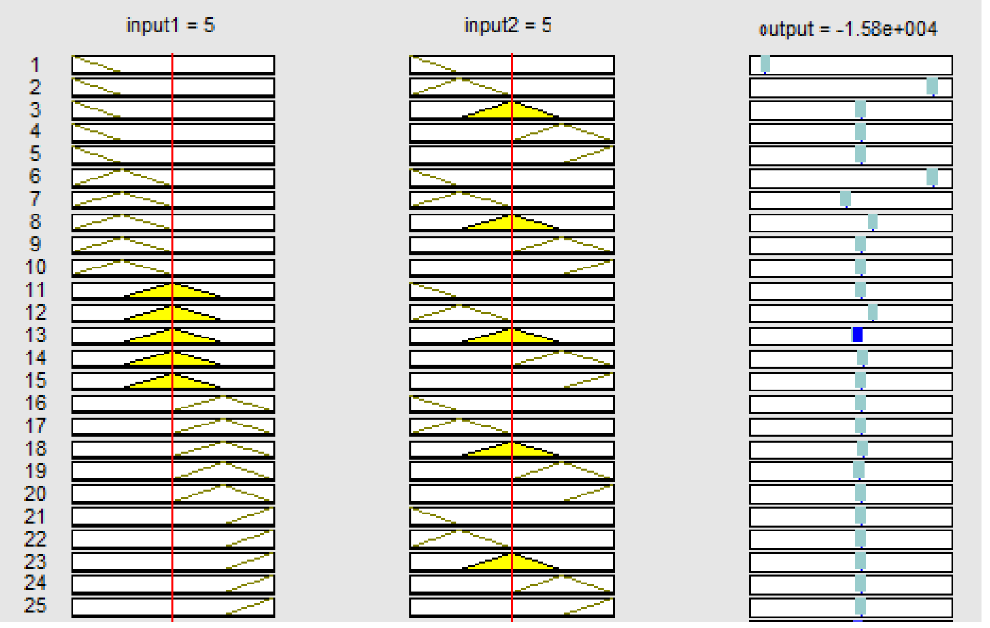

Fig. 3. Rules of the second ANFIS

6 Simulation results and discussions

The multi-articulated system is controlled by the proposed controllers in a closed loop system with unit feedback.

To show the contribution of the ANFIS and its improvements compared to the Fuzzy logic method, a simulation was approved on a model of two link manipulator. This simulation was implemented in Matlab/Simulink. Trajectory performance and position error are compared in these controllers. The Table.1 summarie the obtained results.

Table 1. PID, FLC and ANFIS results.

	PID 1	PID 2	FLC 1	FLC 2	ANFIS 1	ANFIS 2
Links	Link1	Link2	Link1	Link2	Link1	Link2
Position error [rad]	0.51	0.26	0.00372	0.00092	0.00302	0.00044

7 Conclusion

In this present work an arm manipulator robot using two degree of freedom was controlled using two types of controls strategies , SISO control based on classical control PID, intelligent adaptive FLC and ANFIS, this last one present maximum control structure of our control model and give more and more efficiency for the robot model with more position stability and good dynamical performances with no overshoot so industrials would take into account the efficiency of the developing control model for the futures robot design considerations.

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