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Optimal Fuzzy Logic Controller Design for Robot Arm Control

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ABSTRACT: This paper presents an optimal fuzzy logic based controller design procedure to control a robot arm for industrial applications. The robot is a repeated task plant. The control of sucha plant under parameter variations and load disturbances is one of theimportant problems. The aim of this work is to design Geno-Fuzzy, PSO based, and imperialist competitive algorithms basedcontroller suitable for online applications to control single link rigidrobot arm plant. The simulation results using MATLAB/SIMULINK indicated the effectiveness of the proposed controller.

Keywords**:** Fuzzy, Controller Design, Robot.

INTRODUCTION

The problem of self-adjusting the parameters of the controller to compensate for the plant parameters variations and disturbances was the origin of adaptive systems [1]. Adaptive control system can be solved using fuzzy control technique by neural-fuzzy system [2] or genetic-fuzzy model [3]. Generally, in adaptive control system, identification is an essential part to determine, online, the disturbances through either explicit or implicit techniques.The Identification is the process of constructing amathematical model of a dynamic system using experimentaldata from that system [3]. Identification is an important andintegral part in the control of dynamic systems. There are twotypes of identification methods, the first is the forwardidentification, and the second is the inverse identification [4].The problem of identification consists of setting up a suitablyparameterized identification model and adjusting theparameters of the model to optimize a performance function.Two forms of identification are currently used in modernadaptive systems: The forward identification and inverseidentification. Based on the form of identification used, thereexist two techniques of control: The parallel model followingscheme and the inverse model following scheme.In this work inverse identification method is previewed withits simulation results. Genetic-fuzzy inverse online control, PSO based, and imperialist competitive algorithms based controller isstructured with simulation results.

1. Dynamic Modeling of Robot Arm Manipulators

There are two main classes in a robot manipulator: serial manipulators designed using an open loopkinematic chain and parallel manipulator designed using closed loop kinematic chains.This article handles serial manipulators. Robot manipulator consists of a collection of n-links thatconnected together by joints. Each one of these joints has a motor allowing the motion to the commandedlink. The motors have feedback sensors to measure the output (e.g. position, velocity, and torque) at eachinstant. Links and joints form a kinematic chain connected to ground from one side, and the other is free. Atthe end of the open side, the end-effectors (e.g. gripper, welding tool, or another tool) are used to do sometasks as welding, or handle materials [2]. Robot manipulator is named according to number of DOF, whichrefers to the number of joints. As an example, robot manipulator has 5 joints, which mean the robot has5DOF, and so on. In physical applications, it is important to describe the position of the end effectors of therobot manipulator in one global coordinates. In transforming, the coordinates of the end effectors from thelocal position to the global position, the robot movements are represented by a series of movements of rigidlinks. Each link defines a proper transformation matrix relating the position of the current link to the previousone. As mentioned previously, robot manipulator whose all joints are prismatic is known as a Cartesianmanipulator while the robot whose joint variables are revolute is called an articulated manipulator. Fig. 1 shows the robot arm with two joints.

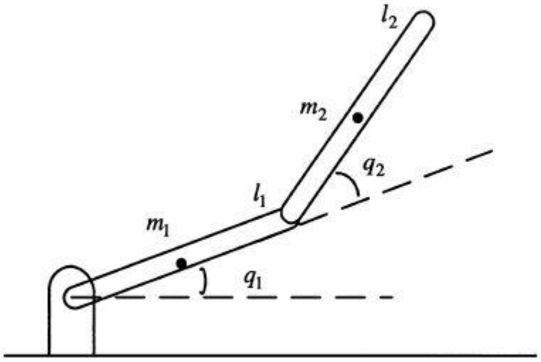

Fig. 1. Robot arm with two joints

The dynamic equation of a robot with n-degree of freedom using Newton-Euler method is as follows;

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

Where $q=[\mathrm{q}_1,...,\mathrm{q}_n]^T$ is the position vector, $\dot{q}=[\dot{\mathrm{q}}_1,...,\dot{\mathrm{q}}_n]^T$ and $\ddot{q}=[\ddot{\mathrm{q}}_1,...,\ddot{\mathrm{q}}_n]^T$ are the velocity and acceleration, respectively. The dynamic equation for a robot arm with two joints is given as follows [6]:

$$\begin{aligned}\tau_1 &= m_2 l_2^2(\ddot{q}_1+\ddot{q}_2)+\mathrm{m}_2\, l_1 l_2 c_2(2\ddot{q}_1+\ddot{q}_2)+(\mathrm{m}_1+\mathrm{m}_2)\mathrm{l}_1^2\,\ddot{q}_1\\ &-\mathrm{m}_2\, l_1 l_2 s_2\dot{q}_2^2-2\,\mathrm{m}_2\, l_1 l_2 s_2\dot{q}_1\dot{q}_2+\mathrm{m}_2\, l_2 g c_{12}+(\mathrm{m}_1+\mathrm{m}_2)l_1 g c_1\\ \tau_2 &= \mathrm{m}_2\, l_1 l_2 c_2\ddot{q}_1+\mathrm{m}_2\, l_1 l_2 s_2\dot{q}_1^2+\mathrm{m}_2\, l_1 g c_{12}+m_2 l_2^2(\ddot{q}_1+\ddot{q}_2)\end{aligned} \tag{2}$$

For these equations, the matrices $G(q)$, $M(q), C(q,\dot{q})$ are;

$$M(q)=\begin{bmatrix}(m_1+m_2)l_1^2+m_2 l_2^2+2m_2 l_1 l_2 c_2 & m_2 l_2^2+m_2 l_1 l_2 c_2\\ m_2 l_2^2+m_2 l_1 l_2 c_2 & m_2 l_2^2\end{bmatrix}$$

$$C(q,\dot{q})=\begin{bmatrix}-m_2 l_1 l_1\dot{q}_2 s_2 & -m_2 l_1 l_1\dot{q}_2 s_2\\ m_2 l_1 l_1\dot{q}_2 s_2 & 0\end{bmatrix}$$

$$G(q)=\begin{bmatrix}(m_1+m_2)g l_1 c_1+m_2 g l_2 c_{12}\\ m_2 g l_2 c_{12}\end{bmatrix} \tag{3}$$

Where, $c_1=\cos(q_1), c_2=\cos(q_2), s_1=\sin(q_1), s_2=\sin(q_2), \mathrm{c}_{12}=\cos(q_1+q_2)$.

Then, the equations of the system can be expressed as;

$$M(q)=\begin{bmatrix}M_{11} & M_{12}\\ M_{21} & M_{22}\end{bmatrix}$$

$$C(q,\dot{q})=\begin{bmatrix}C_{11} & C_{12}\\ C_{21} & 0\end{bmatrix} \tag{4}$$

$$G(q)=\begin{bmatrix}G_1\\ G_2\end{bmatrix}$$

Where,

$$
\begin{aligned}
M_{11} &= (m_1+m_2+m_3)l_1^2+(m_2+m_3)l_2^2+2(m_2+m_3)l_1l_2c_2 \\
M_{12} &= (m_2+m_3)l_2^2+(m_2+m_3)l_1l_2c_2 \\
M_{12} &= M_{21} \\
M_{22} &= (m_2+m_3)l_2^2 \\
C_{11} &= -2(m_2+m_3)l_1l_2\dot{q}_2s_2 \\
C_{12} &= -(m_2+m_3)l_1l_2\dot{q}_2s_2 \\
C_{21} &= (m_2+m_3)l_1l_2\dot{q}_1s_2 \\
G_1 &= (m_1+m_2+m_3)gl_1c_1+(m_2+m_3)gl_2c_{12} \\
G_2 &= (m_2+m_3)gl_2c_{12}
\end{aligned}
\tag{5}
$$

2. *Optimal Fuzzy Logic based Controller Design*

The basic idea of Fuzzy Logic Control (FLC) centre on the labelling process in which thereading of a sensor is translated into a label as performed by human expert controllers (Yanet al., 1994), (Van der Rhee, 1990), (Gupta et al., 1979). The general structure of a fuzzy logiccontrol is presented in Fig. 2.

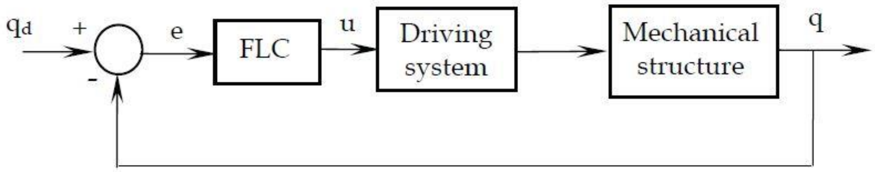

Fig. 2. General structure of a fuzzy logic control

Figures 3-4 show the membership functions considered for the error and its derivative, respectively. Fig. 5 shows the membership functions for output of fuzzy inference system. The fuzzy inference system database rule is given in Table I. Each rule defines the relation between inputs and outputs.

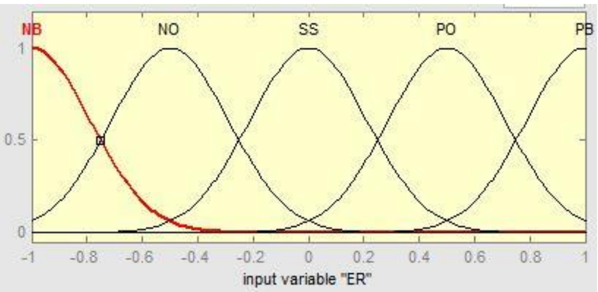

Fig. 3. Membership function for error

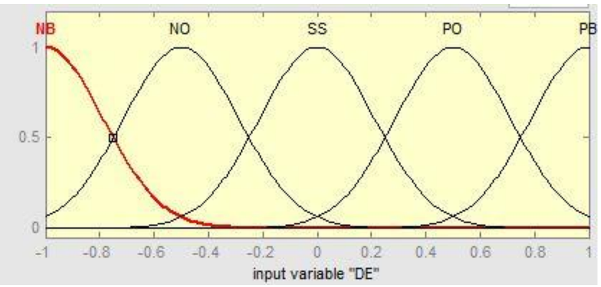

Fig. 4. Membership functions for derivative of error

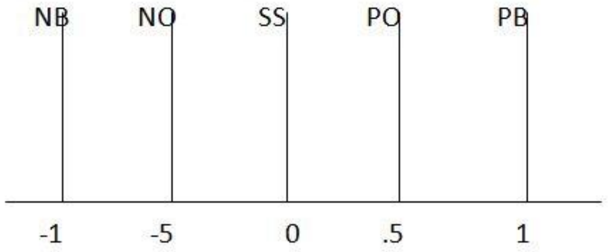

Fig. 5. Membership functions for output of fuzzy inference system

Table 1. Fuzzy rules

		$\dot{e}$				
		NB	NO	SS	PO	PB
e	NB	NB	NB	NO	NO	SS
	NO	NB	NO	NO	SS	PO
	SS	NO	NO	SS	PO	PO
	PO	NO	SS	PO	PO	PB
	PB	SS	PO	PO	PB	PB

3. *Simulation Results*

Fig. 6 shows the implemented MATLAB/SIMULINK model. The values of the parameters considered in the simulations are given in Table II. The objective function has been optimized using three methods: GA-FLC (Genetic Algorithm based Fuzzy Logic Controller), ICA-FLC (Imperialist Competitive Algorithm based Fuzzy Logic Controller), and PSO-based FLC (Particle Swarm Optimization method based Fuzzy Logic Controller). The optimization of the objective function using these methods is shown in Fig. 7. Reference tracking performance of the first and second joint of robot arm using three methods is shown in Figs. 8-9. This results show the effectiveness of the proposed artificial intelligence based methods in controlling the robot arm in the term of reference tracking and good accuracy.

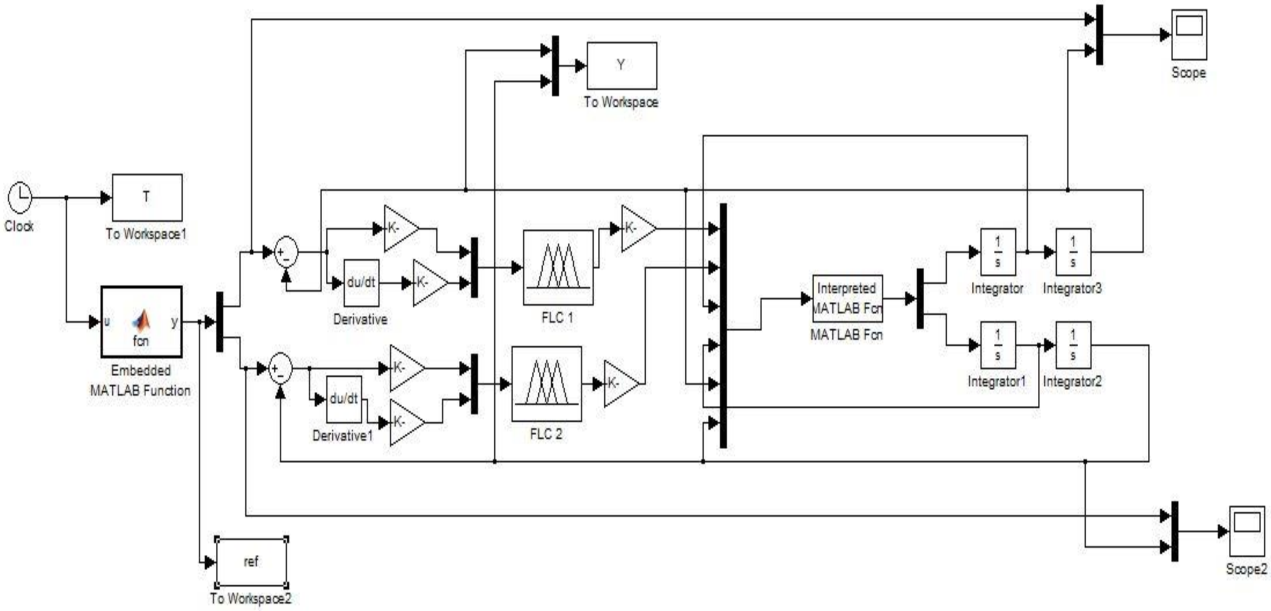

Fig. 6. Implemented studied model

Table 2. The values of the parameters considered in the simulations

Parameter	**Value**
l_1	**0.8m**
l_2	**0.4m**
m_1	**0.1kg**
m_2	**0.1kg**
g	**9.8m/s^2**

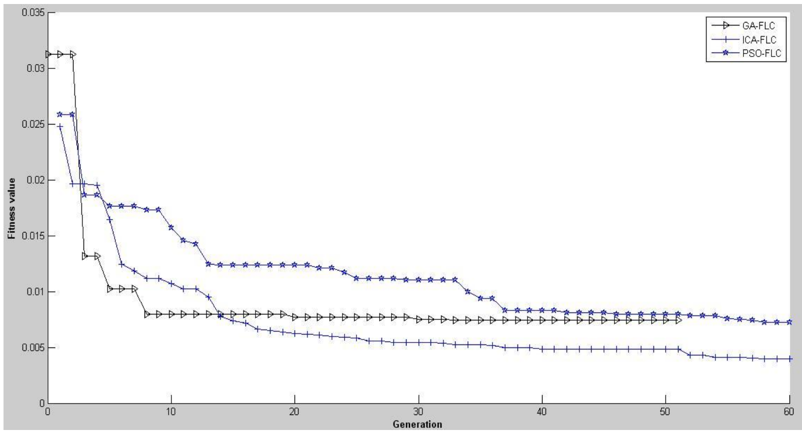

Fig. 7. The objective function for GA-FLC, ICA-FLC and PSO-based FLC

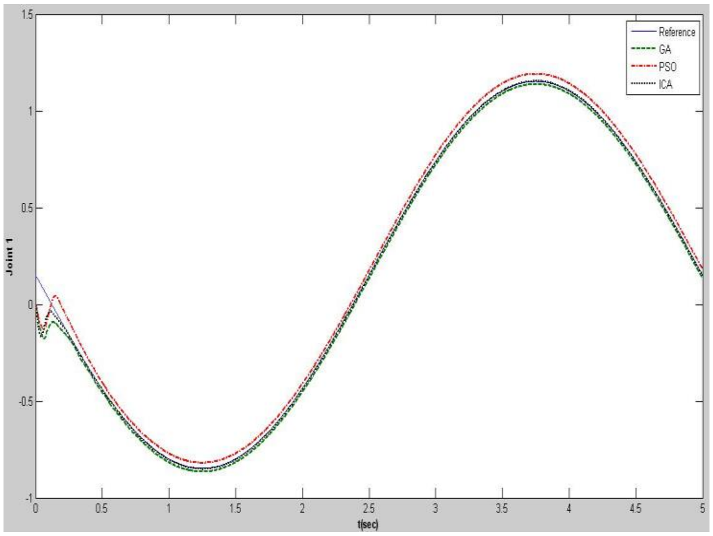

Fig. 8. Reference tracking performance of the first joint of robot arm using three methods

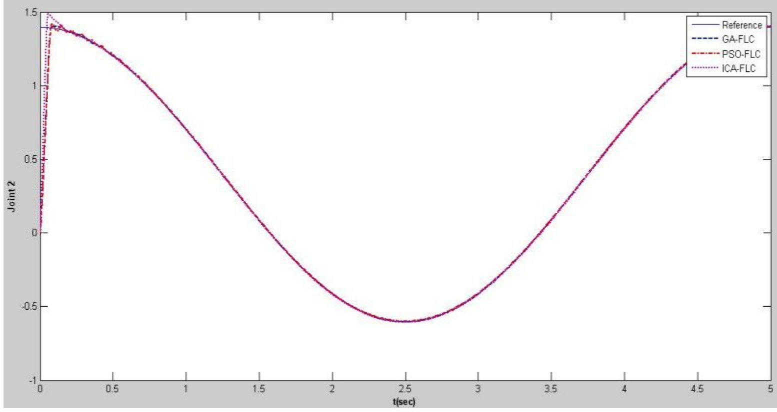

Fig. 9. Reference tracking performance of the second joint of robot arm using three methods

CONCLUSION

In this work, genetic-fuzzy onlineforward controller is structured. Theplant parameters of are identified byforward genetic fuzzy identificationmodel and then used by the controller tocontrol this plant.The identification process iscontinuing in the normal conditions ordisturbance conditions. The workidentifier in the normal conditions tomake the tracking is more accurate aswell as for the small variations in someplant parameters. The objective function was optimized using for GA-FLC, ICA-FLC and PSO-based FLC. The simulation results showed the suitability of the proposed artificial intelligence based methods to control the robot arm joints accurately.

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