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 such a plant under parameter variations and load disturbances is one of the important problems. The aim of this work is to design Geno-Fuzzy, PSO based, and imperialist competitive algorithms based controller suitable for online applications to control single link rigid robot 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 a mathematical model of a dynamic system using experimental data from that system [3]. Identification is an important and integral part in the control of dynamic systems. There are two types of identification methods, the first is the forward identification, and the second is the inverse identification [4]. The problem of identification consists of setting up a suitably parameterized identification model and adjusting the parameters of the model to optimize a performance function. Two forms of identification are currently used in modern adaptive systems: The forward identification and inverse identification. Based on the form of identification used, there exist two techniques of control: The parallel model following scheme and the inverse model following scheme. In this work, inverse identification method is previewed with its simulation results. Genetic-fuzzy inverse online control, PSO based, and imperialist competitive algorithms based controller is structured 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 loop kinematic chain and parallel manipulator designed using closed loop kinematic chains. This article handles serial manipulators. Robot manipulator consists of a collection of n-links that are connected together by joints. Each one of these joints has a motor allowing the motion to the commanded link. The motors have feedback sensors to measure the output (e.g., position, velocity, and torque) at each instant. Links and joints form a kinematic chain connected to ground from one side, and the other is free. At the end of the open side, the end-effectors (e.g., gripper, welding tool, or another tool) are used to do some tasks as welding, or handle materials [2]. Robot manipulator is named according to number of DOF, which refers to the number of joints. As an example, robot manipulator has 5 joints, which mean the robot has 5 DOF, and so on. In physical applications, it is important to describe the position of the end effectors of the robot manipulator in one global coordinate system. In transforming, the coordinates of the end effectors from the local position to the global position, the robot movements are represented by a series of movements of rigid links. Each link defines a proper transformation matrix relating the position of the current link to the previous one. As mentioned previously, robot manipulator whose all joints are prismatic is known as a Cartesian manipulator while the robot whose joint variables are revolute is called an articulated manipulator. Fig. 1 shows the robot arm with two joints.
The dynamic equation of a robot with n-degree of freedom using Newton-Euler method is as follows;

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

(1)

Where $q=[q_1,...,q_n]^T$ is the position vector, $\dot{q}=[\dot{q}_1,...,\dot{q}_n]^T$ and $\ddot{q}=[\ddot{q}_1,...,\ddot{q}_n]^T$ are the velocity and acceleration, respectively. The dynamic equation for a robot arm with two joints is given as follows [6]:

$$\tau_1 = m_2 l_2^2 (\ddot{q}_1 + \ddot{q}_2) + m_2 l_1 l_2 c_2 (2\dot{q}_1 + \ddot{q}_2) + (m_1 + m_2) l_1^2 \ddot{q}_1$$

$$-m_2 l_1 l_2 s_2 \dot{q}_2^2 - 2m_2 l_1 l_2 s_2 \dot{q}_1 \dot{q}_2 + m_2 l_2 g c_{12} + (m_1 + m_2) l_1 g c_1$$

$$\tau_2 = m_2 l_1 l_2 c_1 \ddot{q}_1 + m_2 l_1 l_2 s_2 \ddot{q}_2^2 + m_2 l_1 g c_{12} + m_2 l_2^2 (\ddot{q}_1 + \ddot{q}_2)$$

(2)

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

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

$$C(q,\dot{q}) = \begin{bmatrix}
-m_2 l_1 l_2 s_2 & -m_2 l_1 l_2 s_2 \\
m_2 l_1 l_2 s_2 & 0
\end{bmatrix}$$

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

(3)

Where, $c_1 = \cos(q_1), c_2 = \cos(q_2), s_1 = \sin(q_1), s_2 = \sin(q_2), c_{12} = \cos(q_1 + q_2)$. Then, the equations of the system can be expressed as:

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

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

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

(4)

Where,
\[ M_{11} = (m_1 + m_2 + m_3)l_1^2 + (m_2 + m_3)l_2^2 + 2(m_2 + m_3)l_1l_2c_2 \]
\[ M_{12} = (m_2 + m_3)l_2^2 + (m_2 + m_3)l_1l_2c_2 \]
\[ M_{21} = M_{21} \]
\[ M_{22} = (m_2 + m_3)l_2^2 \]
\[ C_{11} = -2(m_2 + m_3)l_1\dot{q}_2s_2 \]
\[ C_{12} = -(m_2 + m_3)l_1\dot{q}_2s_2 \]
\[ C_{21} = (m_2 + m_3)l_2\dot{q}_1s_2 \]
\[ G_1 = (m_1 + m_2 + m_3)gl_1c_1 + (m_2 + m_3)gl_2c_{12} \]
\[ G_2 = (m_2 + m_3)gl_2c_{12} \]

(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 (Yan et al., 1994), (Van der Rhee, 1990), (Gupta et al., 1979). The general structure of a fuzzy logic control is presented in Fig. 2.

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.
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.

### Table 1. Fuzzy rules

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

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<tr>
<td>$m_1$</td>
<td>0.1kg</td>
</tr>
<tr>
<td>$m_2$</td>
<td>0.1kg</td>
</tr>
<tr>
<td>$g$</td>
<td>9.8m/s²</td>
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</table>

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 online forward controller is structured. The plant parameters of are identified by forward genetic fuzzy identification model and then used by the controller to control this plant. The identification process is continuing in the normal conditions or disturbance conditions. The work identifier in the normal conditions to make the tracking is more accurate as well as for the small variations in some plant 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.

REFERENCES