A FUZZY LOGIC CONTROLLER FOR A TWO-LINK FUNCTIONAL MANIPULATOR
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ABSTRACT

This paper presents a new approach for designing a Fuzzy Logic Controller "FLC" for a dynamically multivariable nonlinear coupling system. The conventional controller with constant gains for different operating points may not be sufficient to guarantee satisfactory performance for Robot manipulator. The Fuzzy Logic Controller utilizes the error and the change of error as fuzzy linguistic inputs to regulate the system performance. The proposed controller have been developed to simulate the dynamic behavior of A Two-Link Functional Manipulator. The new controller uses only the available information of the input-output for controlling the position and velocity of the robot axes of the motion of the end effectors.

KEYWORDS

Fuzzy Logic Control "FLC", Degree of Freedom "DOF", MATLAB Simulink

1. INTRODUCTION

Robotic manipulators are a major component in the manufacturing industry. They are used for many reasons including speed, accuracy, and repeatability. Increasingly, robotic manipulators are finding their way into our everyday life. In fact in almost every product we encounter a robotic manipulator has played a part in its production. The equations of motion for the two arms are described by nonlinear differential equations. Because closed-form solutions are not available, the equations of motion are numerically studied using a numerical method. Special interest is devoted to determine the motion of the two arms to yield a desired xy-position of the robot hand.

The robot is a multi-functional manipulator designed to move materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks. The industrial robot is a programmable mechanical manipulator, capable of moving along several directions, equipped at its end with a work device called the end effectors or tool and capable of performing factory ordinarily done by human beings. The term robot is used for a manipulator that has a built-in control system and is capable of stand-alone operation. The robot is one of the most important machines for industrial automations; flexible multifunctional robotic manipulators can be applied to dangerous environments or routine labor as substitutes for the workers.

Robotic manipulators are multivariable nonlinear coupling dynamic systems. Since, the robotic manipulators have complicated nonlinear mathematical models. Control systems based on the system model are difficult to design [1-6]. Controlling the position and velocity of the robot axes of motion generates the motion of the end effectors. An axes of motion in robotics means a degree of freedom in which the robot can move, The degrees of freedom, or DOF, is a very
important term to understand. Each degree of freedom is a joint on the arm, a place where it can
bend or rotate or translate. You can typically identify the number of degrees of freedom by the
number of actuators on the robot arm. Now this is very important - when building a robot arm
you want as few degrees of freedom allowed for your application!!! Why? Because each degree
requires a motor, often an encoder, and exponentially complicated algorithms and cost.

Thus, an n-degree of freedom manipulator contains n-joints, or in more general terms, n-axes of
motion. The axes of motion of the robot arm can be either rotary or linear. A rotary axis is
designed in kinematics as a revolute pair, which is simple hinge without axial sliding. It is
usually driven by an electric motor, which is coupled to the axis either directly or through a chain
or a gear system.

Control of an industrial robot includes nonlinearities, uncertainties and external perturbations that
should be considered in the design of control laws. A fuzzy controller is used for monitoring and
control the input scaling factors of the fuzzy controller according to the actual tracking position
error and the actual tracking velocity error [6,7].

This paper presents the dynamics of the robot manipulators and presents a fuzzy control for a
multi-variable nonlinear system to provide robust control characteristics. We derive the
equations of motion for a general open-chain manipulator and, using the structure present in the
dynamics, construct control laws for asymptotic tracking of a desired trajectory. In deriving the
dynamics, we will make explicit use of twists for representing the kinematics of the manipulator
and explore the role that the kinematics play in the equations of motion. We assume some
familiarity with dynamics and control of physical systems[8-10].

This paper is organized as follows; the second section describes the manipulator dynamic. The
third section is devoted to discuss a fuzzy control scheme. The fourth section is concerned with
the design of the proposed fuzzy control scheme. Finally the last section with the analysis of
simulation, and the conclusions.

2. MANIPULATOR DYNAMICS

There are two problems in robot kinematics; the first problem is referred to as the forward
kinematics problem, while the second problem is the inverse kinematics (arm solution) problem.
Robot arm dynamics deals with the mathematical formulations of the equations of robot arm
motion. The dynamic equations of motion of a manipulator are a set of mathematical equations
describing the dynamic behavior of the manipulator [3-5].

Our study of manipulators has focused on kinematics consideration only. There are two problems
related to the dynamics of a manipulator that we wish to solve. In the first problem, we are given
a trajectory point, the position, velocity, and the acceleration; we wish to find the required joint
torque. This formulation of dynamics is useful for the problem of controlling the manipulator.

The second problem is to calculate how the mechanism will move under application of a set of
joint torques that is given a torque to calculate the resulting motion of manipulator, the position,
the velocity, and the acceleration, this useful for simulation. The motion control problem consists
of obtaining dynamic models of the manipulator, and using these models to determine control
laws to achieve the desired system response and performance. The dynamic model of multi-link
robot arm can be described by [3,4,11]. The simplified model of a two-link manipulator system is
shown in Fig.1.
The system consists of two masses connected by weightless bars. The bars have length $L_1$ and $L_2$. The masses are denoted by $M_1$ and $M_2$, respectively. Let $\theta_1$ and $\theta_2$ denote the angles in which the first bar rotates around the origin and the second bar rotates about the endpoint of the first bar, respectively.

2.1 Kinetic Energy

The kinetic energy is based on the $x$-$y$ axis labeled on the first link. The velocities are only going to occur in the $x$-$y$ plane. The velocity $v_i$, $i = 1, 2$ is the magnitude of the $xy$ velocity of the center of mass of each link. We have no velocities in the $z$ axis because this problem had the joints fixed in a barriing that only moves in the $x$-$y$ plane. The equation for the kinetic energy can be written as

$$KE = \frac{1}{2} m_1 [(dx_1/dt)^2 + (dy_1/dt)^2] + \frac{1}{2} m_2 [(dx_2/dt)^2 + (dy_2/dt)^2]$$

... (1)

Where $m_1$ is the mass of the link 1, $m_2$ is the mass of the link 2.

2.2 Potential Energy

We have to understand the potential energy due to gravity of each arm. The potential energy of the arm-link is

$$PE_i(\theta) = m_i g h_i(\theta)$$

... (2)

$$= m_1 g l_1 \sin(\theta_1) + m_2 g (l_1 \sin(\theta_1) + l_2 \sin(\theta_2))$$

where $h_i$ is the height of the center of mass of the $i$ arm, $g$ is the acceleration due to gravity constant, and $l_i$ is the length of the link 1. $\theta_1$ is the angle of the link connection 1, $\theta_2$ is the angle of the link connection 2, $l_2$ is the length of the link 2.

The definitions for kinetic energy and potential energy can be considered by Lagrange Dynamics, we form the Lagrangian which is defined as

$$\mathcal{L} = KE - PE$$

... (3)

Substituting the values for the kinetic and potential energies in for $KE$ and $PE$ we get:

$$\mathcal{L} = \frac{1}{2} m_1 [(dx_1/dt)^2 + (dy_1/dt)^2] + \frac{1}{2} m_2 [(dx_2/dt)^2 + (dy_2/dt)^2] + m_1 g l_1 \sin(\theta_1) + m_2 g (l_1 \sin(\theta_1) + l_2 \sin(\theta_2))$$

... (4)

The equations for the x-position and the y-position of $M_i$ are given by
\[ x_1 = l_1 \cos \theta_1 \]  
\[ y_1 = l_1 \sin \theta_1 \]  
\( \theta_1 \) 
\[ \theta_2 = l_2 \cos \theta_2 \]  
\[ y_2 = l_2 \sin \theta_2 \]  
\( \theta_2 \)

Similarly, the equations for the x-position and the y-position of \( M_2 \) are given by:

\[ x_2 = l_1 \cos \theta_1 + l_2 \cos \theta_2 \]  
\[ y_2 = l_1 \sin \theta_1 + l_2 \sin \theta_2 \]

Next, we define the velocity of \( M_1 \) as:

\[ v_1 = \sqrt{\left( \frac{dx_1}{dt} \right)^2 + \left( \frac{dy_1}{dt} \right)^2} \]

Similarly, the velocity of \( M_2 \) is defined as:

\[ v_2 = \sqrt{\left( \frac{dx_2}{dt} \right)^2 + \left( \frac{dy_2}{dt} \right)^2} \]

The dynamic model of the robot arm excluding the dynamic of the joint motors, backlash, and gear friction can be obtained from lagrange-euler or Newton-euler approach. It is often convenient to express the dynamic equations of a manipulator in a single equation:

\[ T = A(\Theta) \ddot{\theta} + B(\Theta, \dot{\theta}) + C(\Theta) \]

Where:

- \( T \) is the generalized vector of joint torques.
- \( \Theta, \dot{\theta} \) are the generalized joint coordinate angle and acceleration vectors.
- \( A(\Theta) \) is the n*n mass matrix.
- \( B(\Theta, \dot{\theta}) \) is the n*1 vector of centrifugal and coriolis terms.
- \( C(\Theta) \) is the n*1 n-vector of gravity terms.

Each element of \( A(\Theta) \) and \( C(\Theta) \) are complex function which depend on the angle \( \Theta \), the position of all the joints of the manipulator, and each element of \( B(\Theta, \dot{\theta}) \) is a complex function of both the angle \( \Theta \), and the rate of change of the angle \( \Theta \).

The dynamic model of multi-link robot arm can be described by:

\[ T_1 = A_{11} \ddot{\theta}_1 + A_{12} \ddot{\theta}_2 + A_{112} \ddot{\theta}_1 \ddot{\theta}_2 + A_{111} \ddot{\theta}_1 + D_1 \ddot{\theta}_1 + A_1 \]  
\[ T_2 = A_{21} \ddot{\theta}_1 + A_{22} \ddot{\theta}_2 + A_{211} \ddot{\theta}_1 \ddot{\theta}_2 + D_2 \ddot{\theta}_2 + A_2 \]

Where:

\[ A_1 = m_1 g s_1 \sin \Theta_1 + m_2 g l_1 \sin \Theta_1 + s_2 \sin(\Theta_1 + \Theta_2) \]  
\[ A_2 = m_2 g s_2 \sin \Theta_2 \]  
\[ A_{11} = m_1 s_1^2 + m_2 (l_1^2 + s_2^2 + 2 l_1 s_2 \cos \Theta_2) \]

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\[ A_{12} = m_2 \left( s_2^2 + l_1 s_2 \cos \Theta_2 \right) \]
\[ A_{122} = -m_2 l_1 s_2 \sin \Theta_2 \]
\[ A_{112} = -2m_2 l_1 s_2 \sin \Theta_2 \]
\[ A_{21} = A_{12}, \quad A_{22} = m_2 s_2^2 + J_m \]
\[ A_{211} = m_2 l_1 s_2 \sin \Theta_2 \]

Where:
- \( m_1 \) is the mass of the link 1
- \( m_2 \) is the mass of the link 2
- \( l_1 \) is the length of the link 1
- \( \Theta_1 \) is the angle of the link connection 1
- \( \Theta_2 \) is the angle of the link connection 2
- \( l_{12} \) is the length of the link 2
- \( S_1 \) is the center of gravity of the link 1
- \( S_2 \) is the center of gravity of the link 2
- \( J_m \) is the moment of inertia

The motion equations of a manipulator are coupled, and nonlinear second-order ordinary differential equations.

### 3. A Fuzzy Logic Controller "FLC"

Fig. (2) Shows a Fuzzy Logic Controller usually takes the form of an iteratively adjusting model. In such a system, input values are normalized and converted to fuzzy representations, the fuzzy rule base is executed to produce a consequent fuzzy region for each solution variable, and the consequent regions are defuzzified to find the expected value of each solution variable [8, 11].

On the other hand, a Fuzzy Logic Controller adjusts its control surface in accord with parameters, and not only adjusts to time, or process phased conditions, but also changes the supporting system control, [7, 10].

### 4. Proposed Fuzzy Logic Controller

In such a system input values are normalized and converted to fuzzy representations, the model’s rule base is executed to produce a consequent fuzzy region for each solution variable, and the consequent regions are defuzzified to find the expected value of each solution variable. On the other hand, a Fuzzy Logic Controller adjusts its control surface in accord with parameter, the system can be made monitoring and controlling by adding a facility for changing the normalization of the universe of discourse.
The proposed rules depend on the following concepts [9-11]:

- The fuzzy controller maintains the output value, when the output value is set value and the steady state error changes is zero
- Depending on the magnitude and signs of position error and velocity error changes, the output value will return to the set value

The error “e” and the error change “Δe” are defined as a difference between the set point value and the current output value

\[
e(k) = \Delta \theta_r (k) - \Delta \theta_c (k)
\]

\[
\Delta e(k) = e(k) - e(k-1)
\]  

That is,

\[
\Delta \theta_r (k) = \Delta \theta_r (k-1)
\]

This assumption is also satisfied in most cases:

Case (1) 
\(e(k) < 0\) and \(\Delta e(k) > 0\)

\(\Delta \theta_r (k) < \Delta \theta_c (k)\)

Case (2) 
\(e(k) > 0\) and \(\Delta e(k) < 0\)

\(\Delta \theta_r (k) > \Delta \theta_c (k)\)

Where

- \(\Delta \theta_r (k)\) is the reference of the fuzzy logic controller at k-th sampling interval
- \(\Delta \theta_c (k)\) is the fuzzy logic controller signal at k-th sampling interval
- \(e(k)\) is the error signal
- \(\Delta e(k)\) is the error change signal

### Rule-Base

<table>
<thead>
<tr>
<th>(e)</th>
<th>(\Delta e)</th>
<th>N</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>P</td>
<td>N</td>
<td>Z</td>
<td></td>
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<tr>
<td>Z</td>
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</tr>
<tr>
<td>P</td>
<td>Z</td>
<td>P</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

After the inputs have been fuzzified, the necessary action, i.e. output required is determined from the following linguistics rule:

IF \(e\) is "N" AND \(\Delta e\) is "N"
Then \(u\) is "P"
IF e is "N" AND ∆e is "Z"
Then u is "N"

IF e is "N" AND ∆e is "P"
Then u is "Z"

IF e is "Z" AND ∆e is "N"
Then u is "N"

IF e is "Z" AND ∆e is "Z"
Then u is "Z"

IF e is "Z" AND ∆e is "P"
Then u is "P"

IF e is "P" AND ∆e is "N"
Then u is "Z"

IF e is "P" AND ∆e is "Z"
Then u is "P"

IF e is "P" AND ∆e is "P"
Then u is "N"

The proposed programs have been developed to simulate the dynamic behavior of the robotic system. The new controller uses only the available information of the input-output. The proposed Fuzzy Logic Controller can obtain the good control performance.

The computer simulation have demonstrated the effectiveness of the proposed controller in improving drastically proposed controller be used to cope with the possible variation in system parameters. Simulation results using MATLAB SIMULINK show the transient response and the same time have removed any error in the resulting scheme.

5. SIMULATION RESULTS

Numerical simulations using the dynamic model of a three DOF planar rigid robot manipulator with uncertainties show the effectiveness of the approach in set point tracking problems. Simulation studies on a pole balancing robot and a multilink robot manipulator demonstrate the effectiveness and robustness of the proposed approach.

In the following, the parameters of a robotic model are given, each of the physical parameters used in the simulation, where l is the length of a link, s is the center of gravity, m is the mass, D is the coefficient of viscous friction, and j is the moment of inertia.[3,4,11]:

The length of link, \(l_1 = l_2 = 0.5\) m, the center of gravity, \(s_1 = s_2 = 0.25\) m, the mass \(m_1 = m_2 = 0.5\) kg, the coefficient of viscous friction \(D_1 = D_2 = 0.1\) N.m / rad/s, the moment of inertia \(J = 0.1\) kg m²

Fig.(4) shows the system response including the tracking positions and velocities using the proposed Fuzzy Logic Controller technique.
As it is expected, the Fuzzy Logic Controller has a minimum steady state error. In such controller, input values are normalized and converted to fuzzy representations, the model’s rule base is executed to produce a consequent fuzzy region for each solution variable, and the consequent regions are defuzzified to find the expected value of each solution variable. This technique should be independent of either the model structure or the model parameters.

![Closed Loop Response](image)

Fig.(4-a) The desired and simulated tracking Position of the link-1

![Closed Loop Response](image)

Fig.(4-b) The desired and simulated tracking Position of the link-2

![Closed Loop Response](image)

Fig.(4-c) The desired and simulated tracking Velocity of the link-1
CONCLUSION

We present an introduction to a proposed fuzzy logic control for realization of a linguistic controller for a multi-functional manipulator, which designed to move materials from point-to-another point. Therefore, the main objective of the fuzzy logic control scheme is to replace an expert human operator with a fuzzy rule-based control system. There is an analogous form of in mathematics, where we solved a complicated problem in the complete plant. The Fuzzy Logic Controller is faster and more accurate. The results validate that the robot dynamic response is free speed. The paper presents a fuzzy logic control strategy to ensure excellent study and guarantees the operation of interconnected power system. Simulation results show that the control performance can be obtained. Finally, we can conclude that the analysis of the operational characteristics resulted in key findings enabling a further derivation of control algorithms and examination of the fuzzy logic controller under dynamic operating conditions.

REFERENCES

AUTHORS

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