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 differentialequations. Because closed-form solutions are not available, the equations of motion are numericallystudied 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

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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. Afuzzy 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 thekinematics 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.

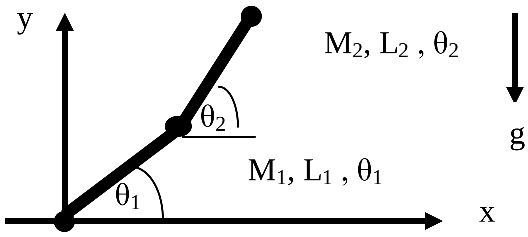

Fig. 1: A simplified model of a two--link manipulator

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 barrotates about the endpoint of the first bar, respectively.

2.1 Kinetic Energy

The kinetic energy is based on the x-yaxis labeled on the first link. The velocities are only going to occur in the x-yplane. The velocity v_i, i = 1,2is 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 barring that only moves in the *x*-*y*plane.The equation for the kinetic energy can be written as

$$KE=1/2m_1[(dx_1/dt)^2+dy/dt)^2]+1/2m_2[(dx_2/dt)^2+(dy_2/dt)^2] \quad \dots (1)$$

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. Thepotential energy of the arm-link is

$$PE_i\ (\theta)=m_i\ g\ h_i(\theta) \quad \dots (2)$$

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

where $h_i$is the height of the center of mass of the *i*arm, *g*is the acceleration due to gravityconstant, and$l_1$is the length of the link 1, θ_1 is the angle of the link connection 1, θ_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

$$\mathcal{L} = KE - PE \quad \dots (3)$$

Substituting the values for the kinetic and potential energies in for KEand PEwe get :

$$\mathcal{L} =1/2m_1[(dx_1/dt)^2+dy/dt)^2]+1/2m_2[(dx_2/dt)^2+ dy_2/dt)^2] + m_1\ g\ l_1\ sin(\theta_1) + m_2\ g(l_1\ sin\ (\theta_1) + \ l_2\ sin(\theta_2)) \quad (4)$$

The equations for the x-position and the y-position of $M_1$are given by

$x_1 = l_1 \cos\theta_1$ … (5)

And

$y_1 = l_1 \sin \theta_1$ … (6)

Similarly, the equations for the x-position and the y-position of $M_2$are given by

$x_2 = l_1 \cos\theta_1 + l_2 \cos\theta_2$ … (7)

and

$y_2 = l_1 \sin \theta_1 + l_2 \sin \theta_2$ … (8)

Next, we define the velocity of M_1as

$v_1 = \sqrt{[(dx_1/ dt)^2 + (dy_1/dt)^2]}$ …(9)

Similarly, the velocity of $M_2$is defined as

$v_2 = \sqrt{[(dx_2/ dt)^2 + (dy_2/dt)^2]}$ … (10)

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

$T=A(\Theta)\ \ddot{\theta} + B(\Theta,\ddot{\theta}) + C(\Theta)$ …(11)

Where;

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

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

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

$T_1=A_{11}\ddot{\theta}_1+A_{12}\ddot{\theta}_2+A_{122}\ddot{\theta}^2{}_2+A_{112}\ddot{\theta}_1\ddot{\theta}_2+D_1\ddot{\theta}_1+A_1$ … (12)

$T_2 = A_{21}\ddot{\theta}_1 + A_{22}\ddot{\theta}_2 + A_{211}\ddot{\theta}^2{}_2 + D_2\ddot{\theta}_2 + A_2$ … (13)

Where:

$A_1 = m_1\ g\ s_1 \sin \Theta_1 + m_2 g(l_1 \sin \Theta_1 + s_2 \sin(\Theta1+\Theta2))$
$A_2 = m_2\ g\ s_2 \sin\Theta_2$
$A_{11}=m_1\ s_1^2 + m_2\ (l^2{}_1 + s^2{}_2 + 2\ l_1 s_2 \cos\Theta_2)$

$A_{12}= m_2 (s^2_2 + l_1s_2\cos\Theta_2)$
$A_{122}=-m_2l_1s_2\sin\Theta_2$
$A_{112}= - 2m_2 l_1s_2\sin\Theta_2$
$A_{21}= A_{12}$. $A_{22}=m_2 s_2^2 + j_m$. $A_{211}=m_2 l_1s_2\sin\Theta_2$

Where :

m_1 is the mass of the link1
m_2 is the mass of the link2
l_1 is the length of the link 1
Θ_1 is the angle of the link connection 1
Θ_2 is the angle of the link connection 2
l_{12} is the length of the link2
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 aFuzzy 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 isexecuted 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].

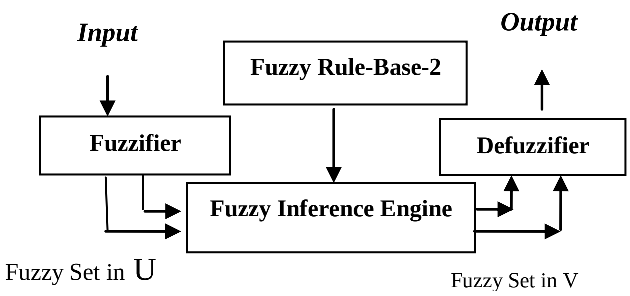

Fig.(2). A Fuzzy Logic Controller

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 ofposition 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

$e(k) = \Delta\theta_r(k) - \Delta\theta_c(k)$

$\Delta e(k) = e(k) - e(k-1)$ … (14)

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

e \ Δe	**N**	**Z**	**P**
N	**P**	**N**	**Z**
Z	**N**	**Z**	**P**
P	**Z**	**P**	**N**

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

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

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

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

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

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

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

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

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

IF e is "P " AND Δe 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 m^2

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.

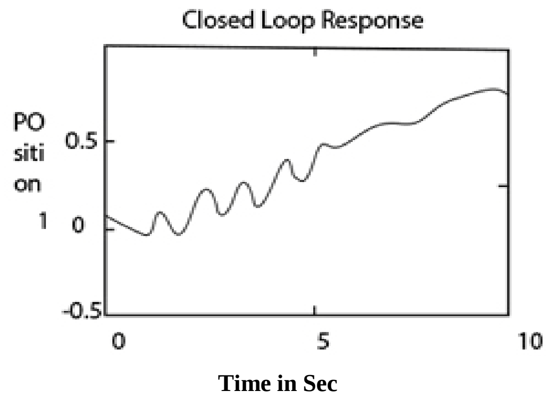

Fig.(4-a) The desired and simulated tracking Position of the link-1

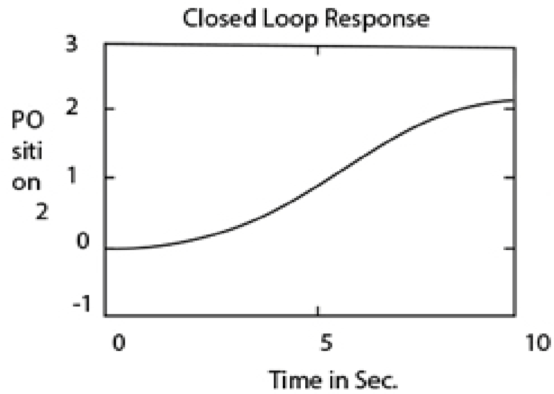

Fig.(4-b) The desired and simulated tracking Position of the link-2

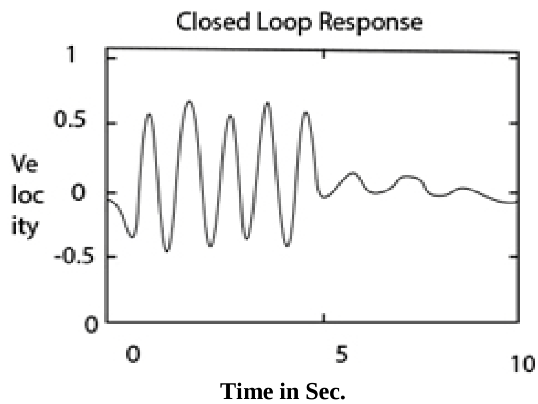

Fig.(4-c) The desired and simulated tracking Velocity of the link-1

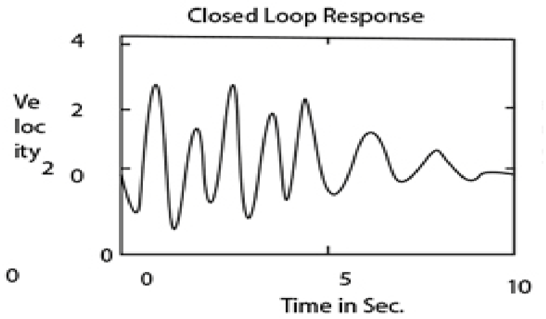

Fig.(4-d) The desired and simulated tracking Velocity of the link-2

6- 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

[1] Kantawong S."Development of RFID dressing robot using DC servo motor with fuzzy-PID control system " Communications and Information Technologies (ISCIT), 2013 13th International Symposium. Pp:14-19

[2] Nanty, A. ; Gelin, R. "Fuzzy Controlled PAD Emotional State of a NAO Robot" Technologies and Applications of Artificial Intelligence (TAAI), 2013 Conference .pp: 90 - 96

[3] Zand, R.M.; Shouraki, S.B. " Designing a fuzzylogic controller for a quadruped robot using human expertise extraction" Electrical Engineering (ICEE), 2013 21st Iranian Conference .Pp: 1 - 6

[4] Saidon, M.S. ; Desa, H. ; Nagarajan, R. ; Paulraj, M.P. " Vision based tracking control of an autonomous mobile robot in an indoor environment" Control System graduate Research Colloquium (ICSGRC), 2011 IEEE. Pp: 1-6.

[5] Jalali, L. ; Ghafarian, H. "Maintenance of robot's equilibrium in a noisy environment with fuzzy controller" Intelligent Computing and Intelligent Systems, 2009. ICIS 2009. IEEE International Conference on volume:2. Pp: 761-766.

[6] J.J. Criage "Introduction To Robotics Mechanis and Control" Addison-Wesley Pub Company 1986.

[7] C.C. Lee" Fuzzy Logic in Control Systems-Part-I" IEEE Trans. On Systems, Man and Cybernetics, Vol.20, No.2, March/April 1990.

[8] C.C. Lee" Fuzzy Logic in Control Systems-Part-II" IEEE Trans. On Systems, Man and Cybernetics, Vol.20, No.2, March/April 1990.

[9] M.H.Saleh, A.H.Elassal, and I.H.Khalifa"Fuzzy Logic Controller for Multi-Area Load Frequency Control of Electric Power Systems", The 6th. Conference on Computer and Applications, IEEE Alex. Chapter, Alexandria, Egypt, September 1996.

[10] M.H.Saleh, A.H.Elassal, and I.H.Khalifa"An Adaptive Fuzzy Controller to Improve System Performance" The 7th. Conference on Computer and Applications, IEEE Alex. Chapter, Alexandria, Egypt, September 1997.

[11] T.Abd El-Rahman, M.H.Saleh "Fuzzy Logic Design Membership Implementation Using Optical Hardware Components " BE-2902R1-Elsevier – 2012.

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