International Journal of Engineering & Technology, 7 (4) (2018) 5629-5632

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.24273
Research paper

Enhancing the performance of robotic arm system using fuzzy logic and PID controller

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Abstract

The aim of this paper is to obtain the best performance of robotic arm response by using fuzzy logic controller compared with conventional PID controller. The robotic arm is simulated using dynamic model of motion equations inside Matlab environment. The high percent of overshoot found in conventional PID controller which exceeds 40% is addressed by optimizing parameters Kp, Ki and Kd by using the proposed fuzzy logic controller. The simulation results view zero percent of overshoot and fast response (settling time and rise time) found by the obtained result is implementation.

Keywords: *Fuzzy Logic controller; Matlab; PID; Robot Arm; Simulation.*

1. Introduction

The robotic arm is a manipulator programmable multi-functional designed to transport materials, spare parts and tools, or specialized devices through variable programmed motions for the performance of a variety of tasks. The computer-controlled industrial machine tools fall within the definition of the robot. The most important and difficult areas of robots is the robot dynamics [1]. Many modern control strategies in modern literature have emerged to deal with the integrity of the strong interdependence of the dynamics of the robot. The most strategies friction is neglect, reactions and other dynamics un modeled. And generally based on assuming control accurate knowledge about the structure of model designs. Classical criteria for performing feedback control system are constants and error concepts such as bandwidth and peaking in the frequency response closed-loop, high time, settling time and overshoot of the step response. Graphical tools Bode, Nyquist plots and Nichols, and placements roots belong to the basic techniques of classic and modern control. Ways important classical control system design consists of the formation of a ring of make up the difference (including integrated) control, and compensation lead and make up the difference of the lead design reactions quantitative (QFT) allows satisfactory quantitative limits on the strength of performance[2]. One of the most popular units used in the manufacture of control is three trims controller PID (Proportional, Integral and derivative), which is a simple applied and good performance in a wide range of industrial application. Between units of the robot is based on reported in the literature form control, and even unit PID controller with feed torque to the front very effectively account. It was there in evidence a growing interest in recent years in control of the robots through new strategies of controller unconventional [3].

2. The PID controller

PID algorithm is the most commonly used feedback controller in the process industry. It has been used successfully for more than 50 years. It is easy to understand powerful algorithm that can provide excellent performance control in spite of a variety of dynamic characteristics of process plants. PID algorithm consists of three basic patterns, the theory of proportional control, embedded in, and modes of derivative. When using this algorithm it is necessary to decide which media will be used (P, I or D). And then determine the parameters (or settings) for each method of use. Generally, the use of three basic algorithms P, PI, or PID [4].
The mathematical representation of ideal PID controller is:

$$\frac{U(s)}{E(s)} = k_P\left[1 + \frac{1}{T_i s} + T_D s\right] \tag{1}$$

One disadvantage of this ideally configured "textbook" is that a sudden change in the set point (and thus) will cause the derivative to become very large, providing a "derived reaction" for the final control - which is undesirable.
The implementation plan is:

$$U(s) = k_P\left[1 + \frac{1}{T_i s}\right]E(s) + T_D s k_P E(s) \tag{2}$$

Put on the measurement of derivatives and the change in the output range will move slowly and avoid a set point by point the changes worked. Thus this is a standard feature control [5].
The Mathematical representation of the series PID is:

$$\frac{U(s)}{E(s)} = k_P \left[1 + \frac{1}{T_i s}\right] T_D s \quad (3)$$

CT execution to develop a series that can include either an error or a derivative is derived on the measurement. In this case, the mathematical representation is:

$$\frac{U(s)}{E(s)} = k_P \left[1 + \frac{1}{T_i s}\right] \quad (4)$$

But in parallel PID mathematical descriptions,

$$mV(s) = k_P E(s) + \frac{1}{T_i s} E(s) + T_D s E(s) \quad (5)$$

The relative profit only works on an error [6].

3. Fuzzy control system

Fuzzy control system design is an attractive option especially for many of the problems of control:

1) It is strong in nature because they do not require the input precision noise and can be programming.
2) Fuzzy control system can be non-linear systems that are difficult to mathematically control modeling.

The difficult task of modelling and simulation, real complicated word for the development of Control Systems, is the implementation and especially Putt issues, and well-documented. Even if you could develop relatively accurate model of the dynamic system, it is often too complex to be used in the design of the controller, especially for many of the traditional control design procedures that require the assumption restrictive for. It's terminal for this reason that in the traditional practice controls are often placed by simple models of plant behaviour that meet the necessary assumptions, and through customized relatively simple linear or units adjust the nonlinear .regardless control, it is well known that inference intervention in the design process conventional control as long as you are concerned with the actual implementation of the monitoring system. It must be acknowledged, moreover, that the traditional control engineering approach that uses heuristics appropriate to adjust the design have been relatively successful [7].
Fuzzy Control provides a formal methodology for representation, manipulation, and the implementation of human knowledge in the heuristic for controlling the withdrawal of the system. Given the graph block fuzzy control under mysterious control appears in the control system in a closed loop. The icon of the plant output y (t), symbolized by the purchase of u (t), and symbolizes the input signal to a mysterious control by r (t).
It includes a knowledge base or knowledge of the domain application and the specifications result base. It consists of a data and rule of fuzzy control design base that required characterizes result. The description of rules based used on the knowledge of experts [8]. Usually have the form below:

if (x is A & y is B) Then (z is C)

Where x & y are the data extracted from the system (input FLC), z is control which calculates the order or diversity output, and A, B and C where language. Mechanism thinking / reasoning is the nucleus of the unity of fuzzy logic that has the ability to simulate human decision-making mechanism on the basis of clear concepts and procedures of fuzzy control controllers. The interface includes input / output of fuzzification and defuzzification blocks. Fuzzification converts the input elements to the quality grade and defuzzification gets crisp production of quality grade values, the value of values [9].

4. Formulation of dynamic models

The modeling in this paper is assumed the robotic arm has two links (see Fig.1). The hypotheses are:

1) The joints robot is working without friction.
2) The midpoint of each link is gravity of center for them. Let the masses are M_1, M_2 and the lengths for $link_1$& $link_2$ are L_1 and L_2, respectively, θ_1 is the angle make by $link_1$ with horizontal and θ_2 is the angle make by $link_2$ with vertical. The motion equations can be written in the form:

$$\tau = M(\Theta)\ddot{\Theta} + V(\Theta, \dot{\Theta}) + G(\Theta) \quad (6)$$

Where M (Θ) No (n × n) mass matrix, V (Θ , $\dot{\Theta}$) is a vector (n× 1) in terms of Coriolis and centrifugal, G (Θ) is (n×1) tankers in terms of gravity, τ is the rotation vector applied to the determination of joints, and n is the number of joints.

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix}, \quad \Theta = \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix} \quad (7)$$

The equation (7) was obtained using the Lagrangian rule given below [١٠, 11].

$$M(\Theta) = \begin{bmatrix} m_1 l_1^2/3 + m_2 l_2^2/3 + m_2 l_1 l_2 \cos(\theta_2) & m_2 l_2^2/3 + 0.5 m_2 l_1 l_2 \cos(\theta_2) \\ m_2 l_2^2/3 + 0.5 m_2 l_1 l_2 \cos(\theta_2) & m_2 l_2^2/3 \end{bmatrix} \quad (8)$$

$$V(\Theta(\dot{\Theta}) = \begin{bmatrix} -m_1 l_1 l_2 \dot{\theta}_1 \dot{\theta}_2 \sin(\theta_2) - 0.5 m_2 l_1 l_2 \dot{\theta}_1^2 \sin(\theta_2) \\ 0.5 m_2 l_1 l_2 \dot{\theta}_1^2 \sin(\theta_2) \end{bmatrix} \quad (9)$$

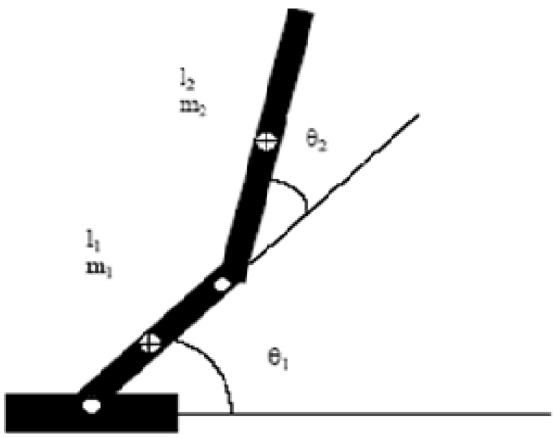

Fig. 1: The Two Link Manipulator.

5. Problem statement

The aim of this paper is to applied the vertical position of the upper (θ_1 is equal to 90^0 & θ_2 is equal to 0^0) of the system and the balance in this position. The initial position of the system is the bottom of the vertical (θ_1 is equal to -90^0 & θ_2 is equal to 0^0). It can be show the information of the initial position for the stable equilibrium while the final position is the formation of an unstable equilibrium. This is done by reducing the steady-state error and percent of overshoot to zero.

6. Simulation data and variables

For simulation, following parameters have been used:
The $link_1$ length: 0.5 m, The $link_2$ length: 0.75 m

The $link_1$ mass: 2 Kg, The $link_2$ mass: 3 Kg
The joint robotic arm for Initial and final have been specified as:

θ_1(initial) is equal to -90^0 & θ_1(final) is equal to 90^0

θ_2(initial) is equal to0^0 & θ_2(final) is equal to 0^0

7. Simulation of dynamic model

The dynamic model simulation for robotic arm was done by using Matlab. The simulator consists of two types files in Matlab, the 1st is M file, which set up the values of parameters and the 2nd is MDL file, which solve the differential equations (7, 8, 9, 10 and 11). The mathematical model of robot arm can be done by using Matlab/ simulink as shown in Figure 2:

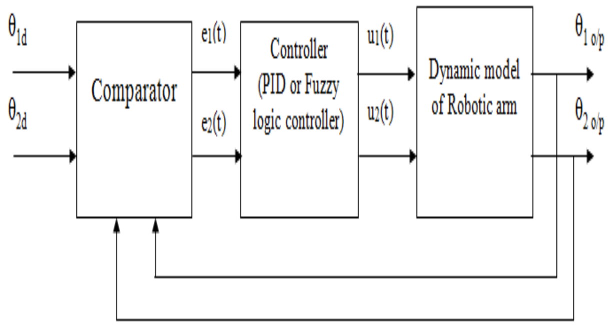

Fig. 2: The General Block Diagram of the Proposed PID Controller Using Fuzzy Logic

Where:
θ_{1d} , θ_{2d} : The angles desired.

$e_1(t)$, $e_2(t)$: The signals of error for θ_1 and θ_2 respectively.

$u_1(t)$, $u_2(t)$: The signals of control for θ_1 and θ_2 respectively.

$\theta_{1o/p}$ $\theta_{2o/p}$: The angles output.

The step response of the robotic arm system without controller as shown in Figure 3 for θ_1 and θ_2.

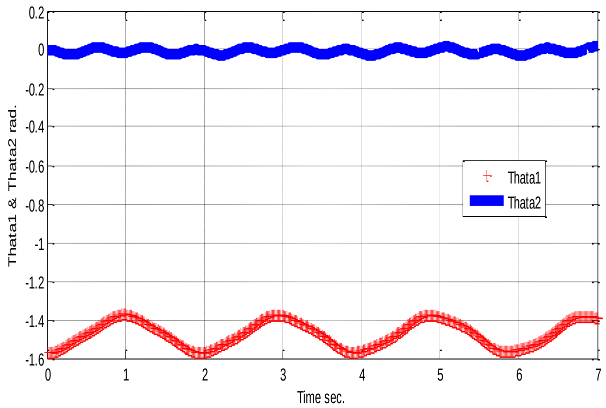

Fig. 3: The Response of Robotic Arm System without Controller.

From Fig.3 show the robotic arm is unstable for θ_1 and θ_2. The two algorithms are designed for PID controller; the parameters of K_{p}, K_i and K_d are presented in Table 1.

Table 1: The Design Parameters of the Two Type's Controllers

Gains of PID Controller	θ_1 PID controller	Fuzzy logic	θ_2 PID controller	Fuzzy logic
KP	90	194	55	88
Ki	55	3	55	2
Kd	30	38	25	29

The step response for θ_1 and θ_2 with different types of controllers which obtained from output of these controllers are shown in Fig. (4 and 5).

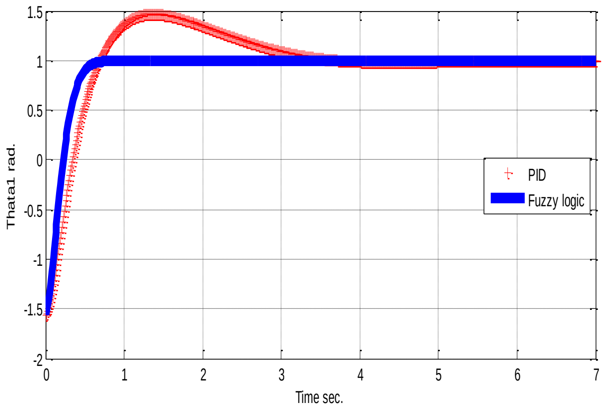

Fig. 4: The Response of the Robotic System with Different Types of Controller for Θ_1.

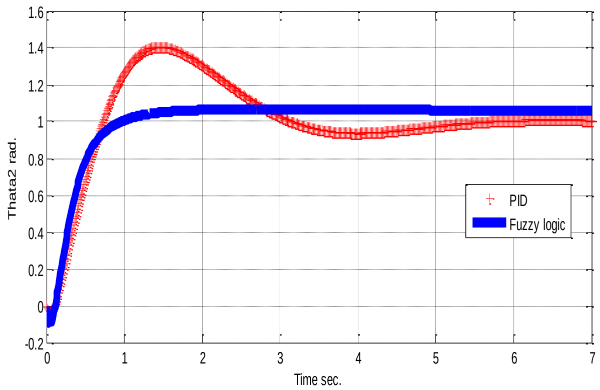

Fig. 5: The Response of the Robotic System with Different Types of Controllers for Θ_2.

The settling time, rise time, overshoot percent and steady-state error of the step response curves are measured and represented as in Table 2, in order to calculate the performance of the robotic arm system.

Table 2: The Characteristics of Robotic Arm with Different Types of Controllers

Characteristics	θ_1 PID algorithm controller	Fuzzy logic controller	θ_2 PID algorithm controller	Fuzzy logic controller
Rise time / sec.	0.7	0.35	0.55	0.55
Over shoot %	50	0	40	0
Settling time / sec.	3.5	0.45	5	0.9
Steady-state error	0	0	0	0.045

8. Conclusions

The precise performance of the robotic arm system is feature required for any application of industry. The traditional method for determining output rendering indices are required long time. The PID based approach used to check the behavior of the robotic arm system. In this paper, we have presented a comparison of two approaches by using traditional PID and fuzzy logic for the design of PID controllers to the robotic arm system. The implementation is performed using the Matlab environment, the simulation results view that the proposed PID controller design by using the fuzzy logic controller gives the best response in comparison with the traditional PID.

Acknowledgements

I am grateful to Dr. Majid S. Naghmash and Dr. Shahad Alyousif for have valuable comments and suggestions throughout the duration and preparation of this paper. I would like to take this opportunity to thank my family for all their care and support.

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