PI-type Fuzzy Logic Control of a Dual Arm Robot

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Abstract: - In this study, as an application of robotics in hazardous tasks, a dual arm cooperative robot system is considered. The robot system is consisting of two planar arms; each of them has two degrees of freedom. The robot arms are in a task which requires handling and transporting a load in horizontal plane from its initial position to desired location with reliability. Dynamic equations of the physical model of two-arm planar robot are derived and then a PI-type fuzzy logic controller is applied to have the model maintain a desired trajectory of motion. Numerical results show promising performance such that proposed PI-type fuzzy logic controller can be used for the trajectory tracking of dual arm robots during load transportation tasks safely.

Key-Words: - Dual arm robot, PI-type Fuzzy logic controller

1 Introduction

The investigations on the coordination of cooperating robot arms have been extensively carried out in the robotics research [1, 2]. This is mainly because these robotic systems are able to handle and position large objects and assemble complex industrial parts with higher precision and confidence than single arm robots [3]. Moreover in dangerous tasks, that involve high risks for people such as disposal of explosive ordnances, these robots can be used to accomplish the same tasks instead of people [4]. Since coordination of robot arms plays a key role in the accomplishment of such hazardous tasks, the controller design which is used to maintain the desired trajectory of the arms is very important.

Fuzzy logic was first introduced by Zadeh in 1965 and since then it has become a developing area [5]. It is used in control applications widely and there are two main reasons for this. First one is the ability to express the knowledge coming from the experts by fuzzy rules and the second one is its applicability to systems that the mathematical model can not be obtained exactly. A systematic fuzzy logic controller design for a multi-input multi-output nonlinear dynamic system was proposed by Emami et al. and applied to a four degrees of freedom robot manipulator and superior tracking performance was obtained [6]. Fuzzy logic is also widely used in tuning schemes of conventional controllers. Bekit et al. used fuzzy logic to tune the PID gains and has shown its efficiency by applying it to a two degrees of freedom planar manipulator [7].

In general there are two main types of fuzzy logic controllers namely PD-type and PI-type fuzzy logic controller. In both types the inputs are usually error and its derivative whereas the outputs are different. The output for the PD-type fuzzy logic controller is the control signal and the output for the PI-type fuzzy logic controller is the incremental change in the control signal [8]. It is well known that PD-type fuzzy logic controllers have better transient response but can cause steady state errors [9]. Thus, PI-type fuzzy logic is known to be more practical and it is preferred in this study.

2 Physical Model

The dual arm robotic system considered in this study is consisting of two planar robot arms with actuating motors at revolute joints and it is seen in Figure 1. The system has four degrees of freedom (DoF). When the robots handle the object, because of the constraints, the DoF of the system reduces to two. Note that the load is not allowed to rotate. In physical model of the robot system m_i, I_i and L_i represents the mass, mass moment of inertia and length of the related links. k_i is the distance of the mass center and θ_i is the joint angle of the related links. Also, there are viscous frictions on all of the joints denoted by b_i.

The robot arms move in the horizontal xy-plane and gravity acts in negative z-direction. There are two periods in the motion of the robots. First, robots start from their home position and move towards the rectangular load. Then, in the second part robots handle the load and move it to its new position while tracking the given trajectory.

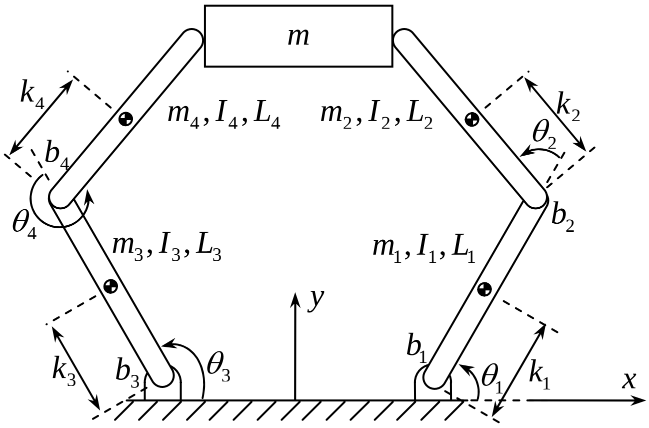


Fig. 1 Physical model of the robot arms

In order to perform transportation task, robot applies F_1 force in negative x-direction and F_2 force in positive x-direction from arm tips to the load. Friction-assisted handling prevents slipping of the load from the contact points during motion.

The dynamic equations of the load with mass m are,

$$m\ddot{x}_m = F_2 - F_1 \quad (1)$$

$$m\ddot{y}_m = 2F_{s1y} = 2F_{s2y} \quad (2)$$

and the expressions for friction forces are:

$$F_{s1y}{}^2 + (\frac{mg}{2})^2 < (\mu F_1)^2 \quad (3)$$

$$F_{s2y}{}^2 + (\frac{mg}{2})^2 < (\mu F_2)^2 \quad (4)$$

Here μ represents the coefficient of dry friction and, x_m and y_m denotes the coordinates of the center of the load. F_{s1y} and F_{s1z} are friction force components in y and z-directions for the first arm and, F_{s2y} and F_{s2z} are friction force components in y and z-directions for the second arm. In this study it is aimed that the load is moved without rotation. Thus, F_{s1y} and F_{s2y} are equal preventing the rotation about z-axis. Similarly, F_{s1z} and F_{s2z} are equal since there is no rotation about y-axis, too. Then:

$$F_{s1y} = F_{s2y} \quad (5)$$

$$F_{s1z} = F_{s2z} = mg/2 \quad (6)$$

Equations of motion for the robot arms are obtained by using Lagrange equations and are given below.

$$[M(\theta)]\ddot{\theta} + \mathbf{C}(\theta,\dot{\theta}) = \mathbf{u} + J^T\mathbf{F} \quad (7)$$

Here, $[M(\theta)]$ is 4×4 mass matrix, $\mathbf{C}(\theta,\dot{\theta})$ is 4×1 vector and includes the coriolis and centrifugal terms, $\mathbf{u}$ is 4×1 generalized torque input vector produced by controller on the joints, $\mathbf{F}$ is 4×1 vector including interaction forces, and J is the Jacobian matrix.

3 Controller Design

In the design of fuzzy logic controllers there are three main stages namely fuzzification, inference and defuzzification. In the first stage, membership functions are defined for the variables used. Thus, crisp values are converted to their fuzzy counterparts. Then, in the second stage the rule base is constructed with the predefined fuzzy rules which are based on the knowledge about the system characteristics coming from the experts. Since the outputs of fuzzy controllers can not be used directly, in the last stage they are converted to crisp values using a suitable defuzzificiation method.

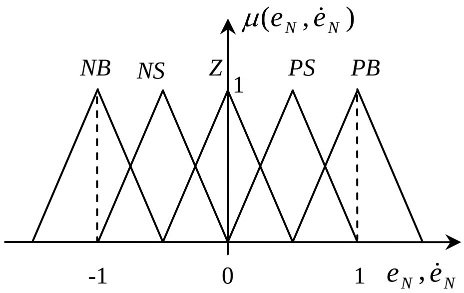
In this study PI-type fuzzy logic is used for the control of a dual arm robot system. The inputs for the controller are error e and its derivative $\dot{e}$, and the output is the incremental change in the control signal Δu. The control signal for the PI-type fuzzy controller is calculated as;

$$u(t) = \Delta u(t) + \Delta u(t - \Delta t) \quad (8)$$

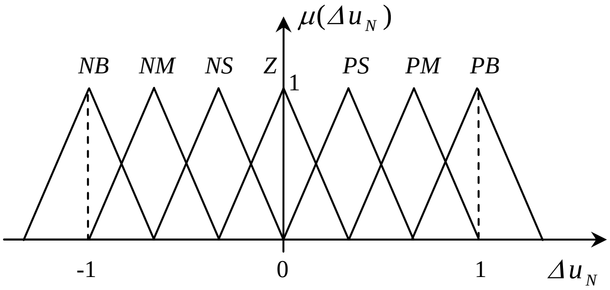
$$\Delta u(t) = SF\Delta u_N \quad (9)$$

where Δt is the sampling time and SF is output scaling factor.

For the fuzzificaiton of the input and output variables, triangular membership functions are used as seen in Figure 2. For the membership functions used the *PB*, *PM*, *PS*, *Z*, *NS*, *NM*, *NB* stand for positive big, positive medium, positive small, zero, negative small, negative medium, and negative big respectively. All the membership functions are defined on the [-1,1] closed interval and scaling factors are used to map the fuzzified values of the variables to corresponding crisp values. In the figure subscript N denotes the normalized variable.



(a)



(b)

Fig.2 Membership functions for the a) input variables b) output variable

The rule table for the PI-type fuzzy logic controller is given in Table 1.

Table 1 Rule table for computing Δu_N

e_N \ $\dot{e}_N$	***NB***	***NS***	***Z***	***PS***	***PB***
NB	*NB*	*NB*	*NM*	*NS*	*Z*
NS	*NB*	*NM*	*NS*	*Z*	*PS*
Z	*NM*	*NS*	*Z*	*PS*	*PM*
PS	*NS*	*Z*	*PS*	*PM*	*PB*
PB	*Z*	*PS*	*PM*	*PB*	*PB*

4 Numerical Results

In this section, numerical results for the dual arm robot system are presented. There are two phases in motion of the robot arms namely approaching and transportation motions. The latter one starts after 2nd second. Initial values for the joint angles are $\theta_1(0)$=0, $\theta_2(0)=5\pi/6$, $\theta_3(0)=\pi$, $\theta_4(0)=-5\pi/6$. Additionally, the initial and final coordinates for the center of mass of the load are (x_i, y_i)=(0.5,1.75), (x_f, y_f)=(-0.5,1.25).

In Figure 3, the reference and actual (with PI-type Fuzzy Logic Controller) joint angles are given. It is seen from this figure that the fuzzy logic controlled robot arms track their trajectory precisely since the actual joint angles coincide with the reference angles completely.

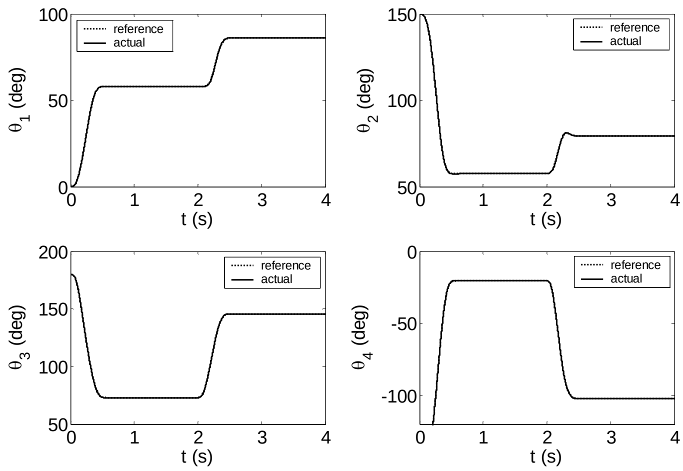


Fig.3 The reference and actual joint angles

Tracking errors for the related joints are shown in Figure 4. It is observed from this figure that the magnitudes for all the tracking errors are below 0.5 degrees and these error values converge to zero rapidly in finite time, which proves the efficiency of the fuzzy logic controller.

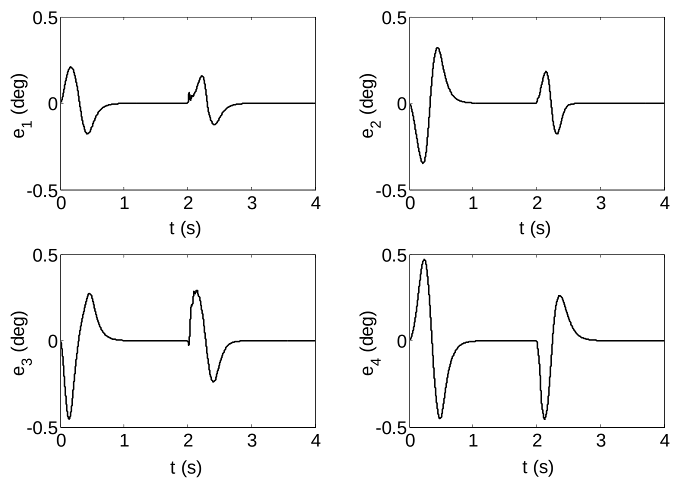


Fig.4 Tracking errors

The joint torques which are produced by fuzzy logic controller and applied on the related joints are presented in Figure 5.

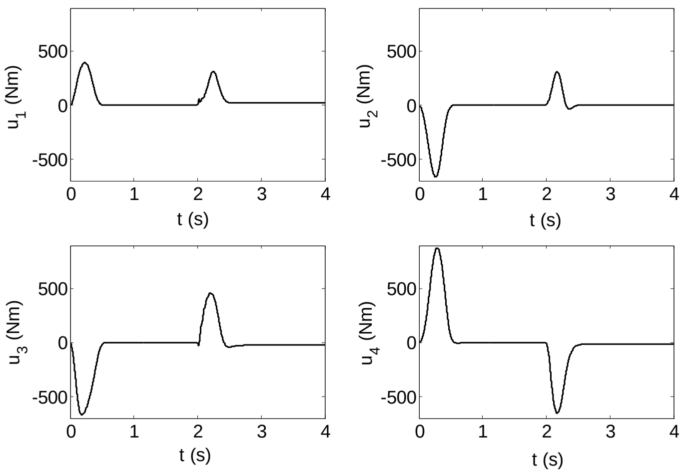


Fig.5 Joint torques

Finally, the performance of the designed PI-type fuzzy controller is compared with the classical fuzzy logic controller. It is seen from Figure 6 that the designed PI-type fuzzy logic controller outperforms the classical fuzzy logic controller, since the maximum error magnitudes for the PI-type fuzzy logic controller are less than its classical counterpart. Additionally, it is observed from this figure that the classical fuzzy logic controller could not remove the steady state errors whereas the PI-type fuzzy logic controller drives these error values to zero.

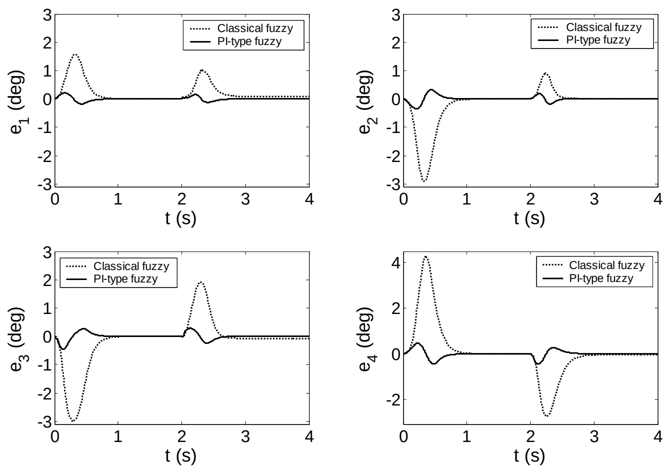


Figure 6 Comparison of the error values of the classical (PD-type) fuzzy logic controller and PI-type fuzzy logic controller

5 Conclusion

This paper is primarily concerned with the kinematic and dynamic analysis of the dual arm robot used in a task which requires handling and transporting a load in the horizontal plane. First, physical model of the robot is obtained. Then, mechanic analysis of the model is carried out and a PI-type fuzzy logic controller which produces required joint torque is applied to the robot system. It is concluded from the results that the PI-type fuzzy logic is a successful controller method such that robot arms maintain the desired trajectory with high accuracy during the load transportation.

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