Precise Tracking Control of Robot Manipulator Using Fuzzy Logic

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Abstract

This paper describes a fuzzy position control scheme designed for a three-link manipulator. The proposed control scheme is based on nonlinear dynamic model derived using Lagrange-Euler formulation. This fuzzy controller controls the position of each link independently and provides compensation for gravity acting on the third link. Computer simulation results on three link robot manipulators are presented to show the results, which indicate good position tracking performance.

1. INTRODUCTION

A main concern of robotic application is to find an effective controller to achieve accurate tracking of desired motions. Robots are high-speed processes that are highly nonlinear, dynamically coupled and often of high order, it is not adequate to use linear servo control, if accurate performance in high bandwidth operations is desired. Many efforts have been made in developing control scheme to achieve the precise tracking control of robot manipulators. [1]-[3].

Conventional control techniques such as PID control, nonlinear feedback control, adaptive control, sliding mode control, LQG control and H_∞ control have many advantages. When the values of the control parameters are known, the control signals are generated exactly. Also, when the underlying assumptions are satisfied, many of these provide good stability, robustness to model uncertainties, disturbances and speed of response. However there are several disadvantages. The control algorithms are hard or inflexible and cannot generally handle 'soft' intelligent control which may involve reasoning, inference making using incomplete vague, non crisp, qualitative information, learning, self organization through past experience and knowledge.

Knowledge based control, expert control and intelligent control are somewhat synonymous and fuzzy control is a particular type of intelligent control. Fuzzy logic control has a great potential since it is able to compensate for the uncertain nonlinear dynamics using the programming capability of human control behavior. The main features of fuzzy control is that a control knowledge base is available within the controller and control actions are generated by applying existing conditions or data to the knowledge base, making us of inference mechanism. Also, the knowledge base and inference mechanism can handle non-crisp, incomplete information; the knowledge itself will improve and evolve through learning and past experience.

Fuzzy logic control does not require a conventional model of the process, whereas most conventional techniques require either an analytical model or an experimental model. Fuzzy logic control is particularly suitable for complex and ill-defined process in which analytical modeling is difficult due to the fact that the process is not completely known and experimental model identification is not feasible because the required inputs and output of the process may not be measurable. This paper proposes a fuzzy position control method, which is much simpler and only uses feedback control. An important advantage of proposed position control method is that it works even for trajectory tracking at high speed where Coriolis and centrifugal forces cannot be ignored.

The paper is organized as follows. Section II presents the mechanical issues and the dynamic model of three-link SCARA robot. The fuzzy position control scheme is described in section III; gravitational influence compensation is also discussed. Computer Simulation results are presented for the precise tracking control of three link SCARA robot in section IV and conclusions are drawn in section in V.

2. DYNAMIC MODEL

Optimal performance can be obtained from a robotic manipulator if sophisticated control strategies are employed. However, precise control of high-speed motion requires the use of a realistic dynamic model of the arm. Complex dynamic systems can be modeled in a relatively simple, elegant fashion using an approach called the Lagrangian formulation. Lagrange Euler formulation, which is based on the concepts of generalized coordinates, energy and generalized force. This approach has the advantage that each of the terms in the final closed form equation has a simple physical interpretation in terms of such things as manipulator inertia, gravity, friction, Coriolis and Centrifugal forces.
The Lagrange-Euler Equation,

$$D(q)\ddot{q} + C(q,\dot{q}) + h(q) + b(\dot{q}) = \tau \qquad (1)$$

Where $D(q)\ddot{q}$ = Inertia associated with the distribution of mass
$C(q,\dot{q})$ = Interaxis velocity coupling due to Centrifugal and Coriolis forces
$h(q)$ = Loading due to gravity
$b(\dot{q})$ = Effects of friction.
The applied torques to each link are,

$$\tau_1 = [(m_1/3+m_2+m_3)a_1^2+(m_2+2m_3)a_1a_2\cos(q_2)+(m_2/3+m_3)a_2^2]\ddot{q}_1 - [(m_2/2+m_3)a_1a_2\cos(q_2)+(m_2/3+m_3)a_2^2]\ddot{q}_2$$
$$+b_1(\dot{q}_1)-a_1a_2\sin(q_2)[(m_2+2m_3)\dot{q}_1\dot{q}_2 - m_2/2+m_3)\dot{q}_2^{\,2}] \qquad (2)$$

$$\tau_2 = -[(m_2/2+m_3)a_1a_2\cos(q_2)+(m_2/3+m_3)a_2^2]\ddot{q}_1 + (m_2/3+m_3)a_2^2]\ddot{q}_2 + (m_2/2+m_3)a_1a_2\sin(q_2)\dot{q}_1^{\,2} + b_2(\dot{q}_1) \qquad (3)$$

$$\tau_3 = m_3\ddot{d}_3 - g_0 m_3 + b_3(\dot{d}_3) \qquad (4)$$

The state space model is derived and given by,

$$\ddot{q} = D(q)^{-1}[\tau - C(q,\dot{q}) - h(q) - b(\dot{q})] \qquad (5)$$

For n axis robotic arm, an appropriate set of generalized coordinates is the vector of n joint variables q. Vector joint variables $q = [q_1\ q_2\ d_3\ ]^T$

The first three axes of a SCARA robot position the tool tip, while the fourth axis orients the tool through a roll motion. The links of a robotic manipulator tend to become progressively smaller and less massive as one proceeds from the base joints to the tool. To keep the dynamic model simple, it is assumed that the moss of the fourth link and any tool attached to it are sufficiently small in comparison with other links.

Once a nominal trajectory is determined there remains the problem of issuing the commands to the joints actuators that will cause the manipulator to faithfully track or follow the planned trajectory. High performance control of robotic manipulators through torque regulation is difficult task. The difficulty arises from the complexity of the dynamic model of the arm.

3. FUZZY POSITION CONTROLLER

The principal design elements in a general fuzzy logic control system (shown in Figure 1.) are as follows:
(1) Fuzzification (2) Control rule base establishment (3) Defuzzification.

3.1 MEMBERSHIP FUNCTIONS

In the proposed fuzzy controller, the measured error and derivative of error are scaled to some real numbers in the interval of [-1 1] and are mapped to linguistic variables error E and derivative of the error DE by fuzzification operator. The values of linguistic variables are composed of linguistic terms PL positive large, PS positive small, ZO zero, NS Negative small, NL Negative Large, which are all fuzzy sets. Control performance depends on the membership functions of the fuzzy sets and fuzzy control rules. Figure 5. shows the membership functions of the fuzzy sets for the position error, velocity error and controller output.

3.2 CONTROL RULES

Fuzzy control rules for the designed controller are listed in the Table 1. For Example, a rule has the following form,

If E is NL and DE is NL then U is NL;

Centre of gravity or average method is used for defuzzification i.e. to get crisp control action.
Figure. 3. depicts the block diagram of Three-link SCARA robot with fuzzy position controller.

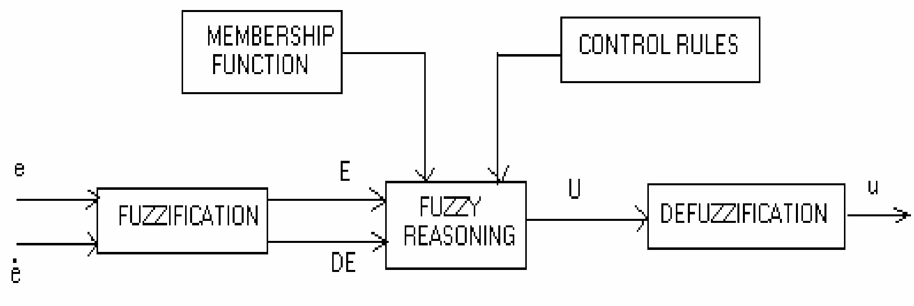

Figure 1. Fuzzy Inference System

Table 1. Control Rules

E/DE	NL	NS	ZO	PS	PL
NL	NL	NL	NL	NS	ZO
NS	NL	NL	NS	ZO	PS
ZO	NL	NS	ZO	PS	PL
PS	NS	ZO	PS	PL	PL
PL	ZO	PS	PL	PL	PL

3.3 GRAVITATIONAL INFLUENCE COMPENSATION

Gravitational force has to be taken into account in the control. Torque applied to the third link is computed using the fuzzy PD gravity control law. Once the gravity has been removed, the nonlinear robotic arm can be successfully controlled using simple linear fuzzy PD controller. The practical significance of the fuzzy PD control with gravity compensation lies in the fact that it requires no detailed knowledge of the manipulator inertia tensor D(q), the Coriolis and centrifugal coupling vector $C(q, \dot{q})$ or the friction vector $b(\dot{q})$. It does require knowledge of the gravity loading vector h(q) but this is relatively easy to determine. Because of the geometry of the SCARA robot, there is no gravity loading on the revolute joints. The gravity loading on the prismatic joint is simply $h_3(q) = m_3\, g_0$

4. COMPUTER SIMULATION

A three link SCARA robot manipulator is used in the simulation to evaluate the proposed fuzzy control scheme. The simulation parameters used are mass of the link m_1=8Kg, m_2=5Kg, m_3=3Kg; a_1=0.8m, a_2=0.3m, a_3=0.3m.

The desired trajectory

$q_{d1} = \sin(0.06328t)$

$q_{d2} = \sin(0.0628t)$

$d_{d3} = 5\sin(0.0628t)$

Surface plot depicted in Figure 2. shows the relationship between error E and Derivative of Error DE on the input side, and controller output OP on the output side. The plot results from a rule base with twenty five rules and the surface is more or less bumpy. The horizontal plateaus are due to flat peaks in the input sets. The plateau around the origin implies a low sensitivity towards changes in either Error or Derivative of error near the reference. This is an advantage if the noise sensitivity must be low when the process is near the reference. Figure 4. depicts the quiver of the proposed controller.

In the Figure 6,7,8 the dotted line depict the desired trajectory and the solid line denotes the actual joint trajectory. Figure 6,7,8 Depict the performance of the proposed controller. It can be seen that the tracking errors (Position and velocity errors shown in Figure 9,10,11,12,13,14) which occur at the starting point drop quickly in less than a few seconds in first and third link, it takes some time to decay in second link, which is due to the dynamic coupling of joints. Simulation results indicate that the suggested fuzzy position control scheme performs the precise tracking for the desired trajectory.

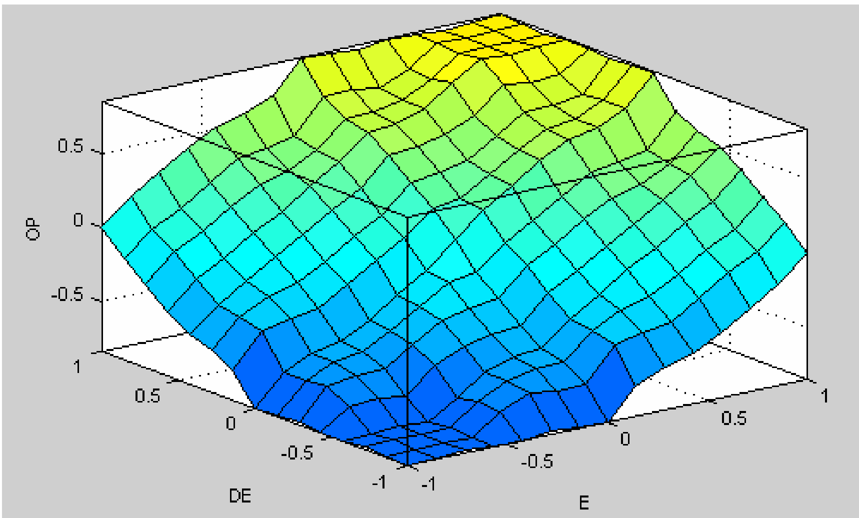

Figure 2. Control Surface

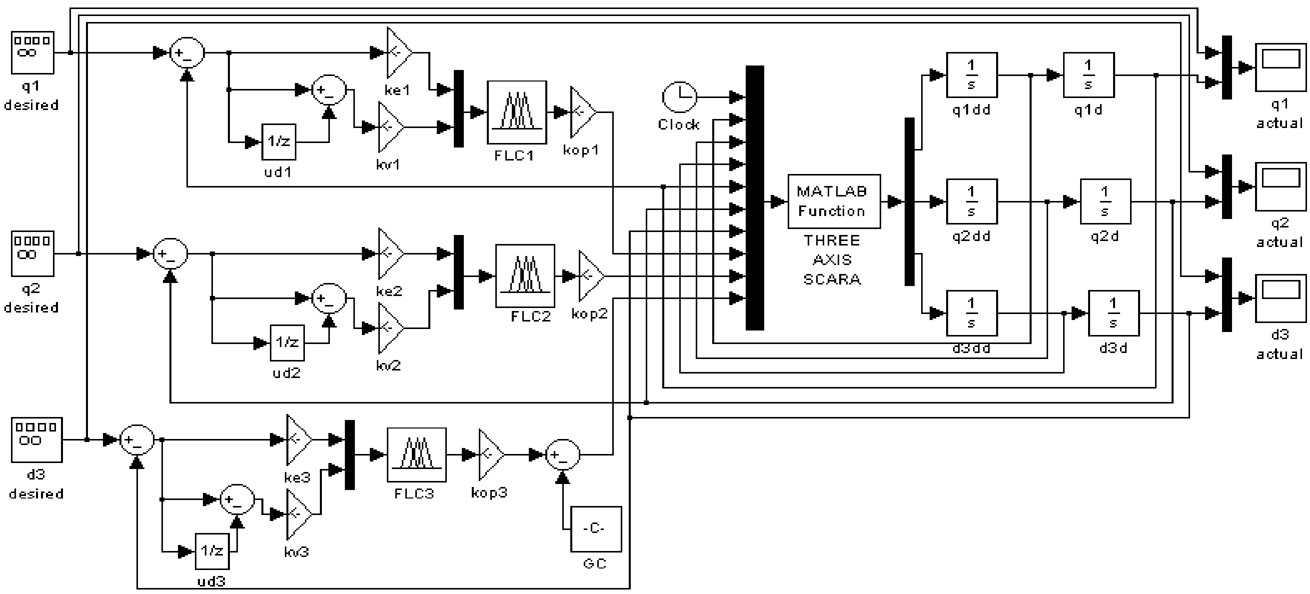

Figure 3. Block Diagram of three- link SCARA Robot

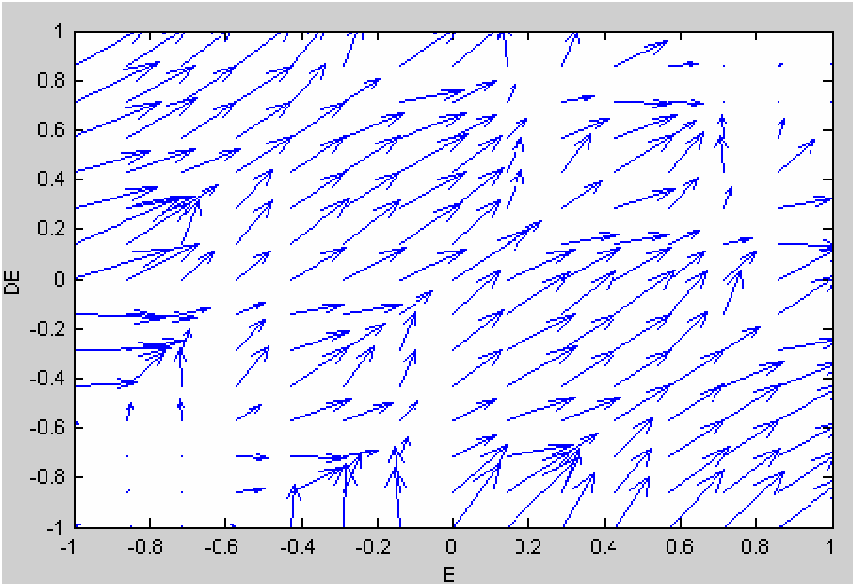

Figure 4. Quiver

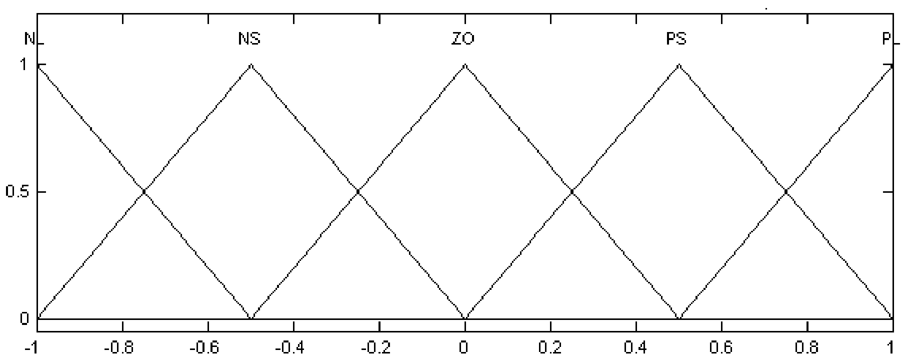

Figure 5. Membership Functions

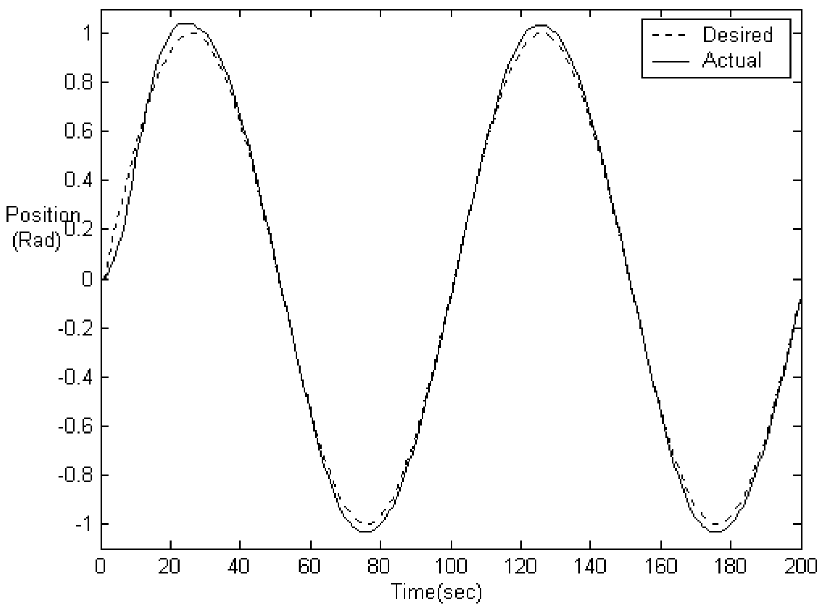

Figure 6.. Tracking Result of joint 1

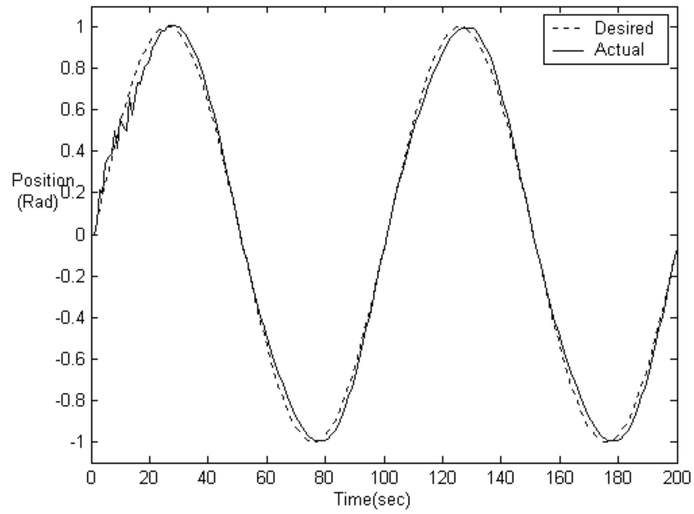

Figure 7. Tracking Result of joint 2

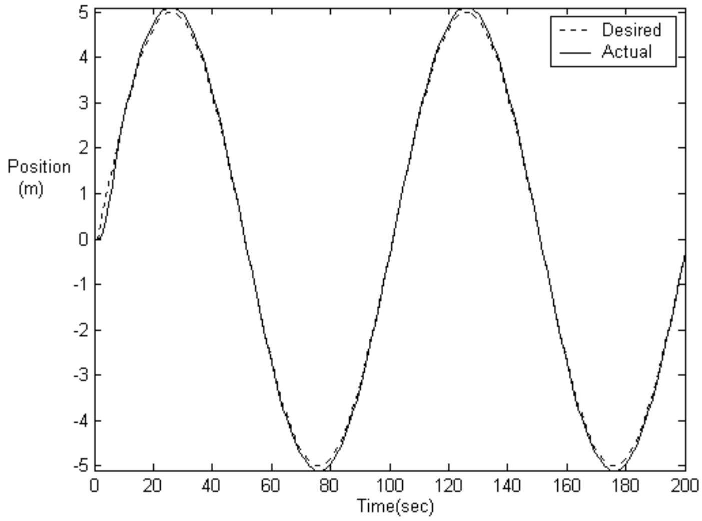

Figure 8. Tracking Result of joint 3

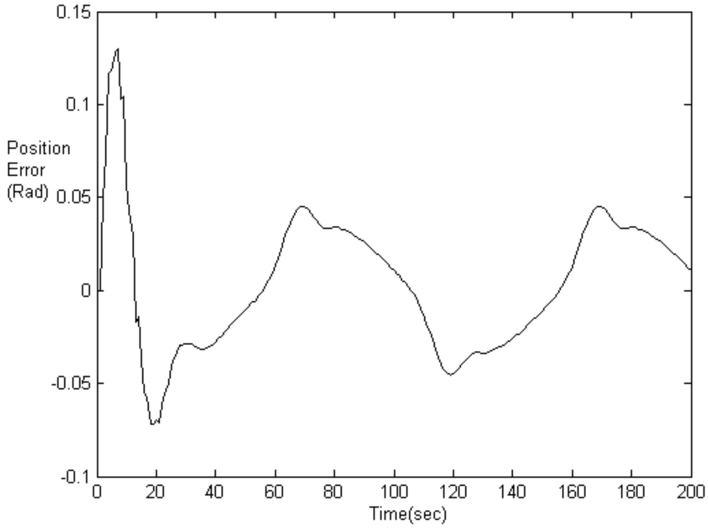

Figure 9. Position Error of joint 1

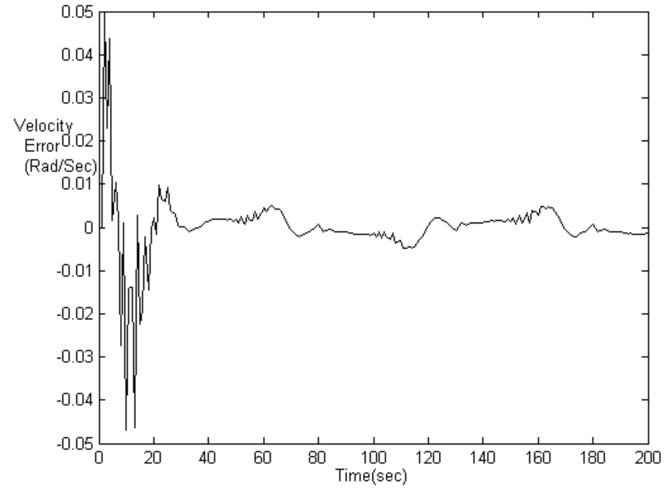

Figure 10. Velocity Error of joint 1

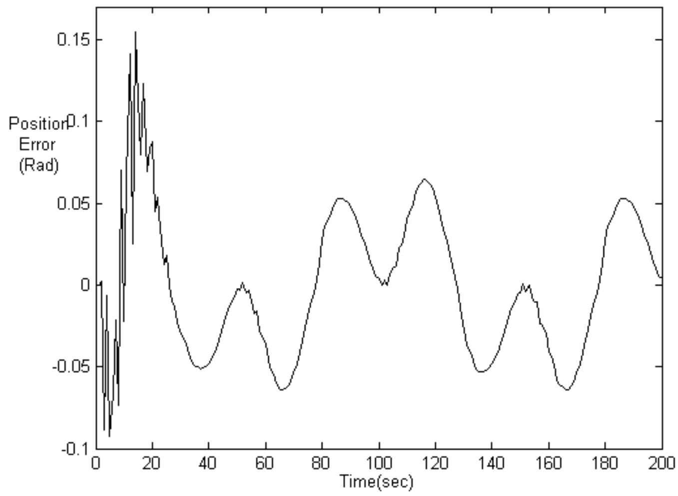

Figure 11. Position Error of joint 2

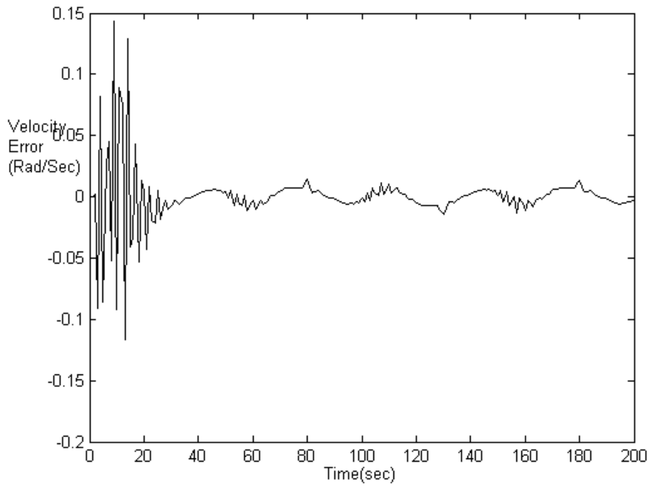

Figure 12. Velocity Error of joint 2

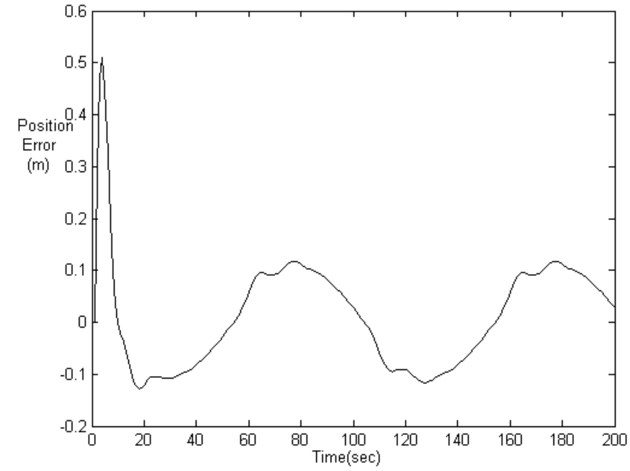

Figure 13. Position Error of joint 3

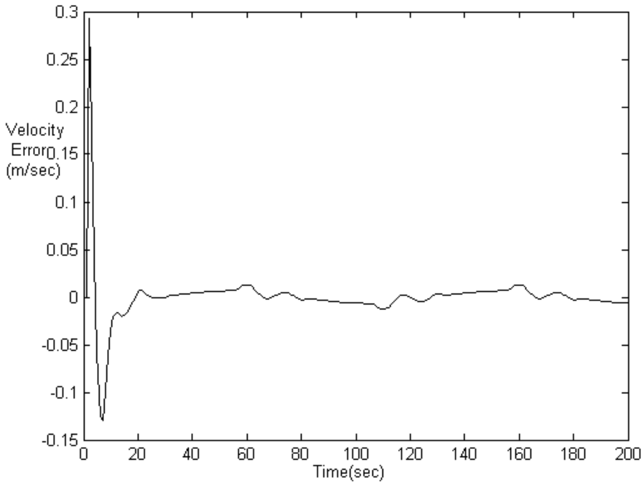

Figure 14. Velocity Error of joint 3

5. CONCLUSION

In this paper, fuzzy position control scheme for precise tracking of robot manipulator is developed. Simulation results have shown the effectiveness of the proposed scheme. Further studies on the tuning of fuzzy position controller using adaptive techniques to improve the transient performance of the proposed method are recommended as a future work.

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