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TWO LINK ROBOT CONTROLLERS BASED ON FUZZY TYPE-2 AND HIGHER ORDER SLIDING MODE

Ali Panjeshahi, Assef Zare, Saeed Balochian*
Department of Electrical Engineering, Gonabad Branch, Islamic Azad University, Gonabad, Iran
(panjeshahiali@yahoo.com)(saeed.balochian@gmail.com)

Abstract

In this paper, the multi-variable control of a two-link robot is considered. Industrial robots, such as robot of two degrees, are the high acceptance in industry and academic environments. They are also a classic problem in robotics for testing and evaluating the new controllers. In this research, two controllers based on fuzzy type 2 and higher order silding mode are employed for this case. The implementation of these controllers on robot models shows a proper tracking for each link.

***Key words:** 2-Link Robot- Higher Order Sliding Mode-Type-2 Fuzzy*

NOMENCLATURE	
m_1	Mass of first link
m_2	Mass of second link
l_1	Length of first link
l_2	Length of second link
θ_1	Angle of first link
θ_2	Angle of second link
$\dot{\theta}_1$	Angular velocity of first link
$\dot{\theta}_2$	Angular velocity of second link
$\ddot{\theta}_1$	Angular acceleration of first link
$\ddot{\theta}_1$	Angular acceleration of second link
C_1	$\cos(\theta_1)$
C_2	$\cos(\theta_2)$
C_{12}	$\cos(\theta_1+\theta_2)$
S_1	$\sin(\theta_1)$
S_2	$\sin(\theta_2)$
τ_1	First link torque
τ_2	Second link torque

INTRODUCTION

The dynamics of the robot consist of two parts, the direct and inverse dynamics [1]. Purpose of direct dynamics, to gain the momentum, velocity and acceleration of the robot tool holding forces and torques applied to the joints or is irritating, but the inverse dynamic modeling with knowledge of routes, velocities and accelerations of the robot tool, or momenta forces driving the joints are calculated. Among classical methods for the calculation of dynamic robot models, methods, Lagrange, D'Alember method, Newton, Euler equations, virtual work and Hamilton [2]. Nowadays, many robots need to work quickly and efficiently, are used. Such as the use of robots on assembly lines, medical, machining and many other applications mentioned. The use of industrial robots in the production process and automation industry has grown considerably in recent decades. Most machine tool spindle apparatus is used for the series chain kinematics. Due to the widespread use of dynamic structures, control is vital to the comment [3]. Cervantes, in 2001, the movement of the robot arm is done by a PID controller [4-7]. Lopez et al., considered in 2008, a proportional controller, derivative and integral on a six degree of freedom parallel robot [8]. Controller of proportional, derivative and integral are always used in different industrial lines. Another branch of the robot can be controlled on the references [9-11] can be seen. One of the important issues in designing a robot controller design is resistant to the uncertainty of the mass of such change. Robust control theory, the sliding mode control law to form a simple procedure could bring into existence [10]. Because of the importance of using a non-linear sliding mode controller is that it has long been noted. Many systems have used this type of approach. References, an example of this method is widely used in engineering sciences as a controller, an estimation and optimization are presented. One of the main difficulties is that sliding mode controller is on the way. There are chattering, through the use of strategies that have been proposed so far [12]. To reduce and eliminate the classical sliding mode control can be used up. The super twist algorithm comes, data entry need not change the sliding surface, and hence, the algorithm is suitable for many dynamic systems. In the year 1993, Levant, introduced second order sliding mode in his paper [13]. The theory of fuzzy sets in 1965 by Lotfi Ali Asker Zadeh, was introduced [14]. In complex systems, they are faced with the challenges and *issues* that are associated with reasoning and decision making, Fuzzy logic as a tool can be employed. Select a system is highly dependent on the complexity of its internal systems. Fuzzy type 2 sets in recent years could be a possible substitute for traditional sets. They consider the uncertainties of system dynamics [15-21]. Mendel, Wu, reviewed and gives some benefit points in their papers. Wu, also published a tutorial for training fuzzy type 2 in MATLAB [22, 23]. This paper is organized as follows: In Part 2, the dynamic equations of the robot and the direct dynamic solution process. In Part 3, the sliding mode controller is designed in second order, and type-2 fuzzy logic is described. In section 4, the simulation is done in MATLAB-SIMULINK by ode45 solver and finally in section 5, the paper is concluded.

Dynamic Equations and Simulated Robots

Inverse dynamics equations of the robot are described in detail in reference to the robot. Only the final equations are given below.

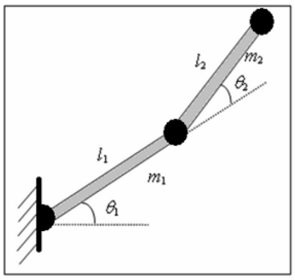

Fig1. Schematic of two-link series robot[1]

$$\begin{cases} \tau_1 = m_2 l_2^2 \left(\ddot{\theta}_1 + \ddot{\theta}_2\right) + m_2 l_1 l_2 C_2 \left(2\ddot{\theta}_1 + \ddot{\theta}_2\right) + \left(m_1 + m_2\right) l_1^2 \ddot{\theta}_1 \\ \quad - m_2 l_1 l_2 S_2 \dot{\theta}_2^2 - 2 m_2 l_1 l_2 S_2 \dot{\theta}_1 \dot{\theta}_2 + m_2 l_2 g C_{12} + \left(m_1 + m_2\right) l_1 g C_1 \\ \tau_2 = m_2 l_1 l_2 C_2 \ddot{\theta}_1 + m_2 l_1 l_2 S_2 \dot{\theta}_1^2 + m_2 l_1 g C_{12} + m_2 l_2^2 \left(\ddot{\theta}_1 + \ddot{\theta}_2\right) \end{cases} \tag{1}$$

For a robot motion control, it's needed to know the amount of torque required to achieve the desired movement of the joint. This approach, the so-called robot, called direct dynamics. A direct dynamic solution of the robot, because of differential operators, has been associated with different challenges. In this paper, the nonlinear equations of robots, written in MATLAB environment and programming techniques have been used in SIMULINK. Figures 2 and 3 show the main body of the robot model in SIMULINK.

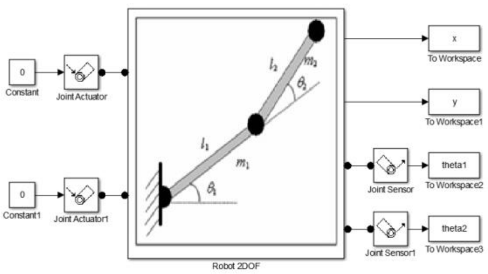

Fig2. Schematic model of the series robot by SIMMECHANICS in SIMULINK

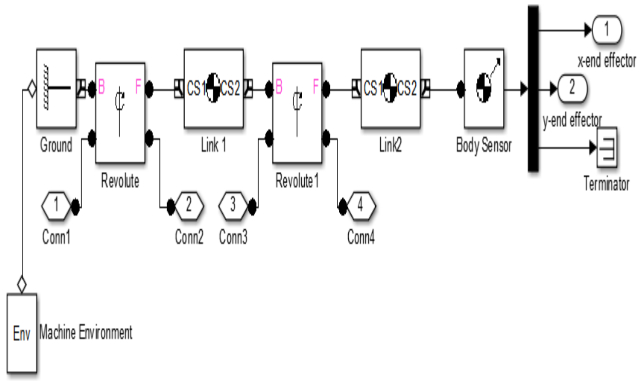

Fig3. Joint modeling of multiple robots by means of SIMMECHANICS

Second Order Sliding Mode Controller Designing

Consider the following Dynamic system, Single input - single output:

$$\dot{x} = f(x) + u \qquad (2)$$

x , is the desired output and u , is the Control input. Nonlinear function $f(x)$ is composed of two parts: deterministic and non-deterministic. The aim of control is to maintain the state at zero and for this purpose the sliding mode control theory employ the surface Slip as the tracking error:

$$S = x \qquad (3)$$

Then the Control problem is to remain on the surface s which is equivalent to be $S = 0$. Generally, sliding mode control is composed of two main parts. The first part called the equivalent control has the phase slip when the system is uncertain. This section of the sliding mode control, is said Holder. Although using this controller can align the system in uncertainties. But the chattering achieved by increasing the control effort is not admissible. Using higher order sliding mode is one method of reducing unwanted chattering in sliding mode control. This method retains the advantage of the original standard methods (robustness), it also eliminates the Chattering. The main problem in the implementation of high order sliding mode is increasing demand for information.

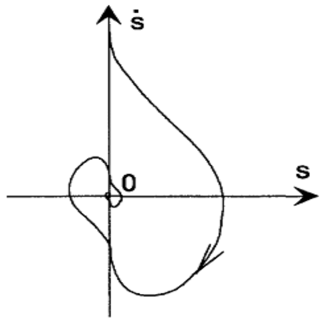

Fig4. The second-order sliding mode system[12]

In this study, it's better to neglect the using derivative products during the solution. For this reason, the best algorithm for the design of second-order sliding mode control of manipulator controller is Super Twisting Which does not use derivative of the sliding surface. The architecture of this method guarantees the robustness of controlling in the face of uncertainty:

$$U = U_{eq} - k_1 |S|^{\rho} sign(S) - k_2 \int sign(S) d\tau \qquad ,0 < \rho < 1 \qquad (4)$$

According to the relations (2), (3) and (4), the supplier of the algorithm Super Twisting followed by:

$$\dot{S} = -k_1 |S|^{\rho} sign(S) - k_2 \int sign(S) d\tau \qquad (5)$$

Given $x1 = S$, Equation (5) can be expressed as the following state equations:

$$\begin{cases} \dot{x}_1 = x_2 - k_1 |x_1|^{\rho} sign(x_1) \\ \dot{x}_2 = -k_2 sign(x_1) \end{cases} \qquad (6)$$

The main advantage of this algorithm is that it does not require any derivative information from the sliding surface but only asymptotic stability is considered. For convergence in a finite time, the following criteria must be satisfied.

$$\begin{aligned} & W > \frac{\Phi}{\Gamma_m} > 0 \\ & \lambda^2 \geq \frac{4\Phi\Gamma_m (W + \Phi)}{\Gamma_m^{\ 3} (W - \Phi)} \\ & 0 < \rho \leq 0.5 \end{aligned} \qquad (7)$$

The control law for this controller is derived from previous sections as:

$$u(t)=u_1(t)+u_2(t)$$
$$\dot{u}_1=\begin{cases}-u & |u|>1\\ -W\,sign(s) & |u|\le 1\end{cases}$$
$$u_2=\begin{cases}-\lambda|s_0|^{\rho}\,sign(s) & |s|>s_0\\ -\lambda|s|^{\rho}\,sign(s) & |s|\le s_0\end{cases} \qquad (8)$$

Controller Designing Based On FUZZY Type-2

In traditional fuzzy sets, the membership functions put on figures individually by crisp points. But in fuzzy type-2, a distance for the functions is considered. As figure 5 shows, P1 to P9 can build the as single membership function.

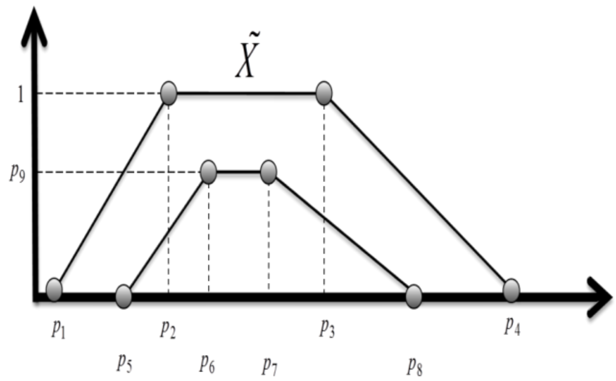

Fig5. The position of a simple fuzzy typ2 sets

The rules of these systems could be mad as relation9.

$$R^n: \text{IF } x_1 \text{ is } \tilde{X}_1^n \text{ and } \dots \text{ and } x_2 \text{ is } \tilde{X}_2^n \text{ THEN } y \text{ is } Y^n \qquad (9)$$

For controller designing, four modes are considered. If the direction of motion of each link is CCW, consider the positive and negative contrast, four of the table can be considered a robot. The programming environment for Wu Toolbox can be used by considering 9 points in figure mentioned above. Each link usually moves more than 90 or less than -90 ° and not the 1.5 and 0.5 radians and negative numbers in calculations.

$$\begin{aligned}
&R^1: \text{If } x_1 \text{ is } \tilde{X}_{11} \text{ and } x_2 \text{ is } \tilde{X}_{21}, \text{ THEN y is } Y^1\\
&R^2: \text{If } x_1 \text{ is } \tilde{X}_{11} \text{ and } x_2 \text{ is } \tilde{X}_{22}, \text{ THEN y is } Y^2\\
&R^3: \text{If } x_1 \text{ is } \tilde{X}_{12} \text{ and } x_2 \text{ is } \tilde{X}_{21}, \text{ THEN y is } Y^3\\
&R^4: \text{If } x_1 \text{ is } \tilde{X}_{12} \text{ and } x_2 \text{ is } \tilde{X}_{22}, \text{ THEN y is } Y^4
\end{aligned} \qquad (10)$$

Table 1, shows the rules tabular. In the next relations, the magnitude and number intervals are considered.

Table1. Table of Rules

X_{11}	X_{21}	Y_1
X_{11}	X_{22}	Y_2
X_{12}	X_{21}	Y_3
X_{12}	X_{22}	Y_4

$$\begin{aligned}
X_{11}&=[-1.5\ \ -1.5\ \ -0.5\ \ 0\ \ -1.5\ \ -1.5\ \ -1.5\ \ 0\ \ 0.5]\\
X_{12}&=[0.5\ \ 1.5\ \ 1.5\ \ 0\ \ 1.5\ \ 1.5\ \ 1.5\ \ 0.5\ \ 0.5]\\
X_{21}&=[-1.5\ \ -1.5\ \ -0.5\ \ 0\ \ -1.5\ \ -1.5\ \ -1.5\ \ 0\ \ 0.5]\\
X_{22}&=[0.5\ \ 1.5\ \ 1.5\ \ 0\ \ 1.5\ \ 1.5\ \ 1.5\ \ 0.5\ \ 0.5]
\end{aligned} \qquad (11)$$

$$\begin{aligned}
Y_1&=[-500\ \ 0]\\
Y_2&=[-10\ \ 500]\\
Y_3&=[-500\ \ 10]\\
Y_4&=[0\ \ 500]
\end{aligned} \qquad (12)$$

To compute the output value, it's needed to calculate the main fuzzy type-2 values as:

$$y_l=\min_{k\in[1,N-1]}\frac{\sum_{n=1}^{k}\bar{f}^n\underline{y}^n+\sum_{n=k+1}^{N}\underline{f}^n\underline{y}^n}{\sum_{n=1}^{k}\bar{f}^n+\sum_{n=k+1}^{N}\underline{f}^n}\equiv\frac{\sum_{n=1}^{L}\bar{f}^n\underline{y}^n+\sum_{n=L+1}^{N}\underline{f}^n\underline{y}^n}{\sum_{n=1}^{L}\bar{f}^n+\sum_{n=L+1}^{N}\underline{f}^n} \qquad (13)$$

$$y_r=\max_{k\in[1,N-1]}\frac{\sum_{n=1}^{k}\underline{f}^n\bar{y}^n+\sum_{n=k+1}^{N}\bar{f}^n\bar{y}^n}{\sum_{n=1}^{k}\underline{f}^n+\sum_{n=k+1}^{N}\bar{f}^n}\equiv\frac{\sum_{n=1}^{R}\underline{f}^n\bar{y}^n+\sum_{n=R+1}^{N}\bar{f}^n\bar{y}^n}{\sum_{n=1}^{R}\underline{f}^n+\sum_{n=R+1}^{N}\bar{f}^n} \qquad (14)$$

$$y=\frac{y_l+y_r}{2} \qquad (15)$$

To calculate the main parameters needed, we consider the Karnik-Mendel Algorithm. From Karnik-Mendel Algorithm, we have: $R=3$, $L=1$ [20].

Implementation and Result

In this section, both of the controllers, sliding mode and fuzzy are merged and implemented in the robot. SIMULINK environment is used for simulating. The solver ode45 is employed for solving different states. Sliding mode controls the first link and fuzzy considers the second one. Figures 6 and 7 show the SIMULINK parts for building them.

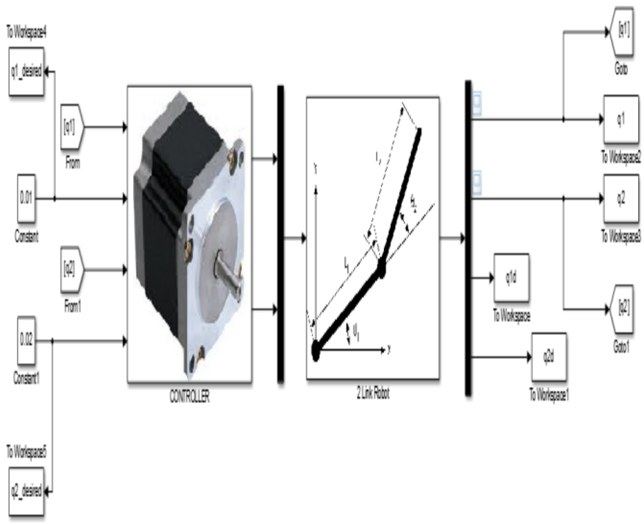

Fig6. SIMULINK environment for implementation of robot and its controllers

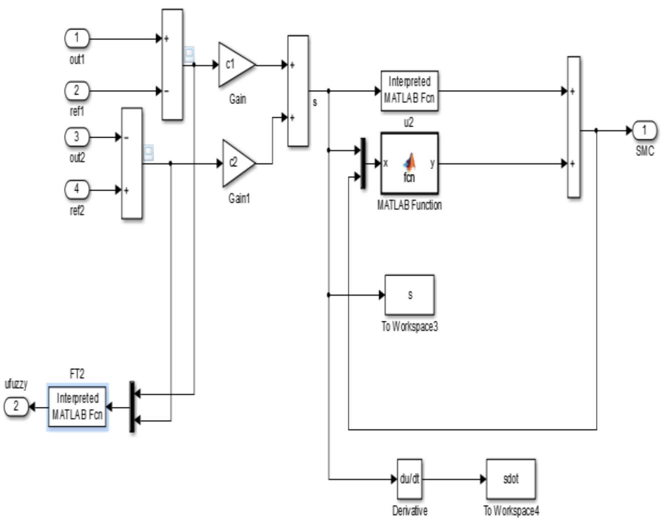

Fig7. Inside of controller block, fuzzy and sliding mode

The nominal values used in the simulation are shown in table2.

Table2. Nominal values for robot parts

m_1	5 Kg
m_2	1Kg
l_1	1m
l_2	1m

Figures 8 and 9 show the result of the controller performance. As they demonstrate, the fuzzy controller can control the random trajectory injected into robot joint.

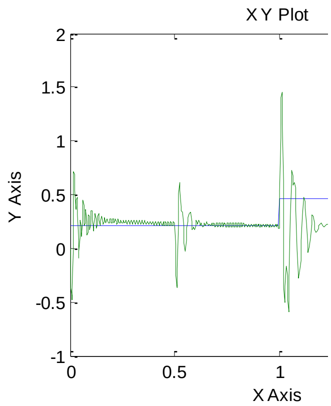

Fig8. First link controlled by SMC, second order

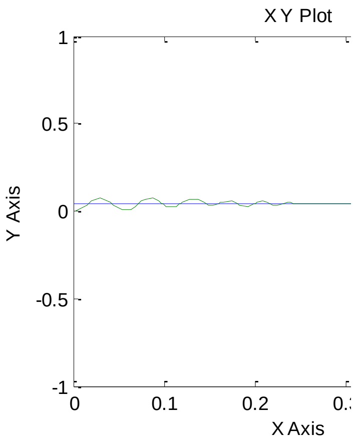

Fig9. Link 2 controlled by Fuzzy type-2

There are some points which are obtained from simulation. Both of two controllers can track the angle in elapsed time. It is important to maintain a robot link in a certain angle and also another link in a desired angle. Although the sliding mode can decrease the chattering, but a visible chattering can be found. While in figure 9, fuzzy type 2, the controller can behave as a robust controller during the uncertainty. This result can be achieved by using fuzzy type 2.

Conclusion

In this paper, the two approaches of traditional and new theories about a robot with two degrees of resistance in series were studied. Both cases were used to control the robot. First Link 2 and Link by second-order sliding mode fuzzy controller type 2, was used. Using higher-order sliding mode algorithm for super twisting, chattering become less than other controllers, which provides better control of the robot is in position. This is while the type-2 fuzzy controller can also show strength in the face of uncertainty to a large extent. The robots are modeled in the context of both traditional and wireless Mechanics modeling approach is used.

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