International Journal of u-and e-Service, Science and Technology
Vol.7, No.5 (2014), pp.105-116
http://dx.doi.org/10.14257/ijunnesst.2014.7.5.10

Fuzzy Hype-Plane Variable Sliding Mode Control to Reduce Joint Vibrations

Mahmoud Reza Safaei Nasrabad[1], Ehsan Pouladi[1], Ghasem Sahamijoo[1], Alireza Salehi[1], Farzin Piltan[1] and Nasri b. Sulaiman[1,2]

[1]Intelligent System and Robotic Lab, Iranian Institute of Advance Science and Technology (IRAN SSP), Shiraz/Iran
[2]Faculty of Electrical and Electronic Engineering, Department of Engineering, University Putra Malaysia (UPM), Malaysia
Email: piltan_f@iranssp.com, WWW.IRANSSP.COM/english

Abstract

The sliding mode controller is used to speed up the error convergence when the error is greater than one. To reduce the error terminal sliding mode controller is recommended in this research. Fuzzy hype-plane variable sliding mode controller is adopted to guarantee the error convergence to zero in a finite time when the error is around the zero. The chattering in the conventional sliding model control systems is avoided with the employed continuous controller. To increase the system robustness in presence of uncertainty fuzzy logic controller is recommended. This technique is used to adjust the band of terminals. The simulation results show that the proposed scheme has strong robust against the uncertainties and disturbances, as well as leads to the convergence of the output to the desired value quickly and precisely than employing either sliding mode controller or terminal sliding mode controller alone.

Keywords*: Fuzzy hype-plane variable sliding mode controller, fuzzy logic theory, flexible robot manipulator, robustness, stability, tuning the terminal*

1. Introduction

Controller (control system) is a device which can sense information from linear or nonlinear system (*e.g.*, robot arm) to improve the systems performance and the immune system behavior [1-2]. In feedback control system considering that there are many disturbances and also variable dynamic parameters something that is really necessary is keeping plant variables close to the desired value. Feedback control system development is the most important thing in many different fields of safety engineering. The main targets in design control systems are safety stability, good disturbance rejection to reach the best safety, and small tracking error [3-4]. At present, in some applications robot arms are used in unknown and unstructured environment, therefore strong mathematical tools used in new control methodologies to design nonlinear robust controller with an acceptable safety performance (*e.g.*, minimum error, good trajectory, disturbance rejection). According to the control theory, systems' controls are divided into two main groups: conventional control theory and soft computing control theory. Conventional control theories are work based on manipulator dynamic model. This technique is highly sensitive to the knowledge of all parameters of nonlinear robot manipulator's dynamic equation. Conventional control theory is divided into two main groups: linear control theory and nonlinear control theory. Soft computing (intelligent) control theory is free of some challenges associated to conventional

ISSN: 2005-4246 IJUNESST
Copyright ⓒ 2014 SERSC

control theory. This technique is worked based on intelligent control theory. This theory is divided into the following groups: fuzzy logic theory, neural network theory, genetic algorithm and neuro-fuzzy theory.

To control of this system sliding mode controller is recommend in this research. Sliding mode controller is an influential nonlinear controller to certain and uncertain systems which it is based on system's dynamic model. Sliding mode controller is a powerful nonlinear robust controller under condition of partly uncertain dynamic parameters of system [5-6]. This controller is used to control of highly nonlinear systems especially for continuum robot. Chattering phenomenon and nonlinear equivalent dynamic formulation in uncertain dynamic parameter are two main drawbacks in pure sliding mode controller [7-9]. The chattering phenomenon problem in pure sliding mode controller is reduced by using linear saturation boundary layer function but prove the stability is very difficult. Although the fuzzy-logic control is not a new technique, its application in this current research is considered to be novel since it aimed for an automated dynamic-less response rather than for the traditional objective of uncertainties compensation [8]. The intelligent tracking control using the fuzzy-logic technique provides a cost-and-time efficient control implementation due to the automated dynamic-less input. This in turn would further inspire multi-uncertainties testing for continuum robot [9].

Although the fuzzy-logic control is not a new technique, its application in this current research is considered to be novel since it aimed for an automated dynamic-less response rather than for the traditional objective of uncertainties compensation[10]. The intelligent tracking control using the fuzzy-logic technique provides a cost-and-time efficient control implementation due to the automated dynamic-less input. This in turn would further inspire multi-uncertainties testing for continuum robot [11].

Sliding mode control methodology is used to control of continuum robot manipulator. Continuum robots represent a class of robots that have a biologically inspired form characterized by flexible backbones and high degrees-of-freedom structures [5]. Theoretically, the compliant nature of a continuum robot provides infinite degrees of freedom to these devices. However, there is a limitation set by the practical inability to incorporate infinite actuators in the device. Most of these robots are consequently under actuated (in terms of numbers of independent actuators) with respect to their anticipated tasks. In other words they must achieve a wide range of configurations with relatively few control inputs. This is partly due to the desire to keep the body structures (which, unlike in conventional rigid-link manipulators or fingers, are required to directly contact the environment) "clean and soft", but also to exploit the extra control authority available due to the continuum contact conditions with a minimum number of actuators. For example, the Octarm VI continuum manipulator, discussed frequently in this paper, has nine independent actuated degrees-of-freedom with only three sections. Continuum manipulators differ fundamentally from rigid-link and hyper-redundant robots by having an unconventional structure that lacks links and joints. Hence, standard techniques like the Denavit-Hartenberg (D-H) algorithm cannot be directly applied for developing continuum arm kinematics. Moreover, the design of each continuum arm varies with respect to the flexible backbone present in the system, the positioning, type and number of actuators. The constraints imposed by these factors make the set of reachable configurations and nature of movements unique to every continuum robot. This makes it difficult to formulate generalized kinematic or dynamic models for continuum robot hardware. Thus, the kinematics (*i.e.*, geometry based modeling) of a quite general set of prototypes of continuum manipulators has been developed and basic control strategies now exist based on these. The development of analytical models to analyze continuum arm dynamics (*i.e.*, physics based models involving forces in addition to geometry) is an active,

 Copyright ⓒ 2014 SERSC

ongoing research topic in this field. From a practical perspective, the modeling approaches currently available in the literature prove to be very complicated and a dynamic model which could be conveniently implemented in an actual device's real-time controller has not been developed yet. The absence of a computationally tractable dynamic model for these robots also prevents the study of interaction of external forces and the impact of collisions on these continuum structures. This impedes the study and ultimate usage of continuum robots in various practical applications like grasping and manipulation, where impulsive dynamics are important factors. Although continuum robotics is an interesting subclass of robotics with promising applications for the future, from the current state of the literature, this field is still in its stages of inception.

In this research the new technique of sliding mode controller is recommended, namely, terminal sliding mode controller. To modify the response of terminal sliding mode controller, on-line tuning terminal sliding mode controller is recommended in this research.

This paper is organized as follows; section 2, is served as an introduction to the dynamic of continuum robot manipulator. Part 3, introduces and describes the sliding mode controller, fuzzy logic controller and methodology algorithm. Section 4 presents the simulation results and discussion of this algorithm applied to a continuum robot and the final section describe the conclusion.

2. Theory

Dynamic Formulation of Continuum Robot: The Continuum section analytical model developed here consists of three modules stacked together in series. In general, the model will be a more precise replication of the behavior of a continuum arm with a greater of modules included in series. However, we will show that three modules effectively represent the dynamic behavior of the hardware, so more complex models are not motivated. Thus, the constant curvature bend exhibited by the section is incorporated inherently within the model. The model resulting from the application of Lagrange's equations of motion obtained for this system can be represented in the form

$$F_{coeff}\,\underline{\tau} = D\left(\underline{q}\right)\underline{\ddot{q}} + C\left(\underline{q}\right)\underline{\dot{q}} + G\left(\underline{q}\right) \quad (1)$$

where τ is a vector of input forces and q is a vector of generalized co-ordinates. The force coefficient matrix F_{coeff} transforms the input forces to the generalized forces and torques in the system. The inertia matrix, D is composed of four block matrices. The block matrices that correspond to pure linear accelerations and pure angular accelerations in the system (on the top left and on the bottom right) are symmetric. The matrix C contains coefficients of the first order derivatives of the generalized co-ordinates. Since the system is nonlinear, many elements of C contain first order derivatives of the generalized co-ordinates. The remaining terms in the dynamic equations resulting from gravitational potential energies and spring energies are collected in the matrix G. The coefficient matrices of the dynamic equations are given below,

$$Fcoeff = \begin{bmatrix} 1 & 1 & cos(\theta_1) & cos(\theta_1) & cos(\theta_1+\theta_2) & cos(\theta_1+\theta_2) \\ 0 & 0 & 1 & 1 & cos(\theta_2) & cos(\theta_2) \\ 0 & 0 & 0 & 0 & 1 & 1 \\ 1/2 & -1/2 & 1/2 & -1/2 & 1/2+s_2 sin(\theta_2) & -1/2+s_2 sin(\theta_2) \\ 0 & 0 & 1/2 & -1/2 & 1/2 & -1/2 \\ 0 & 0 & 0 & 0 & 1/2 & -1/2 \end{bmatrix} \quad (2)$$

$$D\left(\underline{q}\right) = \begin{bmatrix} m_1+m_2+m_3 & m_2\cos(\theta_1)+m_3\cos(\theta_1) & m_3\cos(\theta_1+\theta_2) & -m_2s_2\sin(\theta_1)-m_3s_2\sin(\theta_1)-m_3s_3\sin(\theta_1+\theta_2) & -m_3s_3\sin(\theta_1+\theta_2) & 0 \\ m_2\cos(\theta_1)+m_3\cos(\theta_1) & m_2+m_3 & m_3\cos(\theta_2) & -m_3s_3\sin(\theta_2) & -m_3s_3\sin(\theta_2) & 0 \\ m_3\cos(\theta_1+\theta_2) & m_3\cos(\theta_2) & m_3 & m_3s_3\sin(\theta_2) & 0 & 0 \\ -m_2s_2\sin(\theta_1)-m_3s_2\sin(\theta_1)-m_3s_3\sin(\theta_1+\theta_2) & -m_3s_3\sin(\theta_2) & m_3s_2\sin(\theta_2) & m_2s_2^2+I_1+I_2+I_3+m_3s_2^2+m_3s_3^2+2m_3s_3\cos(\theta_2)s_2 & I_2+m_3s_3^2+I_3+m_3s_3\cos(\theta_2)s_2 & I_3 \\ -m_3s_3\sin(\theta_1+\theta_2) & -m_3s_3\sin(\theta_2) & 0 & I_2+m_3s_3^2+I_3+m_3s_3\cos(\theta_2)s_2 I & I_2+m_3s_3^2+I_3 & I_3 \\ 0 & 0 & 0 & I_3 & I_3 & I_3 \end{bmatrix} \quad (3)$$

$$C\left(\underline{q}\right) = \begin{bmatrix} c_{11}+c_{21} & -2m_2\sin(\theta_1)\dot{\theta}_1-2m_3\sin(\theta_1)\dot{\theta}_1 & -2m_3\sin(\theta_1+\theta_2)(\dot{\theta}_1+\dot{\theta}_2) & -m_2s_2\cos(\theta_1)(\dot{\theta}_1)+(1/2)(c_{11}+c_{21})-m_3s_2\cos(\theta_1)(\dot{\theta}_1)-m_3s_3\cos(\theta_1+\theta_2)(\dot{\theta}_1) & -m_3s_3\sin(\theta_1+\theta_2) & 0 \\ 0 & c_{12}+c_{22} & -2m_3\sin(\theta_2)(\dot{\theta}_1+\dot{\theta}_2) & -m_3s_3(\dot{\theta}_1)+(1/2)(c_{12}+c_{22})-m_3s_2(\dot{\theta}_1)-m_3s_3\cos(\theta_2)(\dot{\theta}_1) & -2m_3s_3\cos(\theta_2)(\dot{\theta}_1)-m_3s_3\cos(\theta_2)(\dot{\theta}_2) & 0 \\ 0 & 2m_3\sin(\theta_2)(\dot{\theta}_1) & c_{13}+c_{23} & -m_3s_3s_2\cos(\theta_2)(\dot{\theta}_1)-m_3s_3(\dot{\theta}_1) & -2m_3s_3(\dot{\theta}_1)-m_3s_3(\dot{\theta}_2) & (1/2)(c_{13}+c_{23}) \\ (1/2)(c_{11}+c_{21}) & 2m_3s_3\cos(\theta_2)(\dot{\theta}_1)-2m_3s_2(\dot{\theta}_1)+2m_2s_2(\dot{\theta}_1) & 2m_3s_3(\dot{\theta}_1+\dot{\theta}_2)-2m_3s_2\cos(\theta_2)(\dot{\theta}_1+\dot{\theta}_2) & 2m_3s_3s_2\sin(\theta_2)(\dot{\theta}_2)+(1^2/4)(c_{11}+c_{21}) & m_3s_3s_2\sin(\theta_2)(\dot{\theta}_2) & 0 \\ 0 & (1/2)(c_{12}+c_{22})+2m_3s_3\cos(\theta_2)(\dot{\theta}_1) & 2m_3s_3(\dot{\theta}_1+\dot{\theta}_2) & m_3s_3s_2\sin(\theta_2)(\dot{\theta}_1) & (1^2/4)(c_{12}+c_{22}) & 0 \\ 0 & 0 & (1/2)(c_{13}-c_{23}) & 0 & 0 & (1^2/4)(c_{13}+c_{23}) \end{bmatrix} \quad (4)$$

$$G\left(\underline{q}\right) = \quad (5)$$

 Copyright ⓒ 2014 SERSC

$$\begin{bmatrix} -m_1g - m_2g + k_{11}(s_1 + (1/2)\theta_1 - s_{01}) + k_{21}(s_1 - (1/2)\theta_1 - s_{01}) - m_3g \\ -m_2gcos(\theta_1) + k_{12}(s_2 + (1/2)\theta_2 - s_{02}) + k_{22}(s_2 - (1/2)\theta_2 - s_{02}) - m_3gcos(\theta_1) \\ -m_3gcos(\theta_1 + \theta_2) + k_{13}(s_3 + (1/2)\theta_3 - s_{03}) + k_{23}(s_3 - (1/2)\theta_3 - s_{03}) \\ m_2s_2gsin(\theta_1) + m_3s_3gsin(\theta_1 + \theta_2) + m_3s_2gsin(\theta_1) + k_{11}(s_1 + (1/2)\theta_1 - s_{01})(1/2) \\ +k_{21}(s_1 - (1/2)\theta_1 - s_{01})(-1/2) \\ m_3s_3gsin(\theta_1 + \theta_2) + k_{12}(s_2 + (1/2)\theta_2 - s_{02})(1/2) + k_{22}(s_2 - (1/2)\theta_2 - s_{02})(-1/2) \\ k_{13}(s_3 + (1/2)\theta_3 - s_{03})(1/2) + k_{23}(s_3 - (1/2)\theta_3 - s_{03})(-1/2) \end{bmatrix}$$

3. Methodology

One of the significant challenges in control algorithms is a linear behavior controller design for nonlinear systems. When system works with various parameters and hard nonlinearities this technique is very useful in order to be implemented easily but it has some limitations such as working near the system operating point [2]. Some of robot manipulators which work in industrial processes are controlled by linear PID controllers, but the design of linear controller for robot manipulators is extremely difficult because they are nonlinear, uncertain and MIMO [11]. To reduce above challenges the nonlinear robust controllers is used to systems control. One of the powerful nonlinear robust controllers is sliding mode controller (SMC), although this controller has been analyzed by many researchers but the first proposed was in the 1950 [3-7].This controller is used in wide range areas such as in robotics, in control process, in aerospace applications and in power converters because it has an acceptable control performance and solve some main challenging topics in control such as resistivity to the external disturbance. The lyapunov formulation can be written as follows,

$$V = \frac{1}{2} S^T . D . S \tag{6}$$

the derivation of V can be determined as,

$$\dot{V} = \frac{1}{2} S^T . \dot{D} . S + S^T \ D\dot{S} \tag{7}$$

the dynamic equation of robot manipulator can be written based on the sliding surface as

$$D\dot{S} = -VS + D\dot{S} + VS + G - \tau \tag{8}$$

it is assumed that

$$S^T\big(\dot{D} - 2V\big)S = 0 \tag{9}$$

by substituting (8) in (7)

$$\dot{V} = \frac{1}{2} S^T \dot{D} S - S^T V S + S^T\big(D\dot{S} + VS + G - \tau\big) = S^T\big(D\dot{S} + VS + G - \tau\big) \tag{10}$$

suppose the control input is written as follows

$$\hat{\tau} = \widehat{\tau_{eq}} + \widehat{\tau_{dis}} = \big[\widehat{D^{-1}}\big(\hat{V} + \hat{G}\big) + \dot{S}\big]\hat{D} + K.sgn(S) + K_v S \tag{11}$$

by replacing the equation (11) in (10)

$$\dot{V} = S^T(D\dot{S} + VS + G - \hat{D}\dot{S} - \hat{V}S - \hat{G} - K_v S - Ksgn(S) = S^T\Big(D\dot{S} + \tilde{V}S + \tilde{G} - K_v S - Ksgn(S)\Big) \tag{12}$$

it is obvious that

$$\big|\tilde{D}\dot{S} + \tilde{V}S + \tilde{G} - K_v S\big| \le \big|\tilde{D}\dot{S}\big| + \big|\tilde{V}S\big| + \big|\tilde{G}\big| + |K_v S| \tag{13}$$

the Lemma equation in robot manipulator system can be written as follows

$$K_u = \left[\left|\tilde{D}\dot{S}\right| + |VS| + |G| + |K_v S| + \eta\right]_i , \qquad i = 1,2,3,4,\dots \quad (14)$$

the equation (14) can be written as

$$K_u \geq \left|\left[\tilde{D}\dot{S} + VS + G - K_v S\right]_i\right| + \eta_i \quad (15)$$

therefore, it can be shown that

$$\dot{V} \leq -\sum_{i=1}^{n} \eta_i \, |S_i| \quad (16)$$

Based on above discussion, the control law for a multi degrees of freedom robot manipulator is written as:

$$U = U_{eq} + U_r \quad (17)$$

Where, the model-based component U_{eq} is the nominal dynamics of systems and U_{eq} can be calculate as follows:

$$U_{eq} = \left[D^{-1}(f + C + G) + \dot{S}\right]D \quad (18)$$

and U_{SWITCH} is computed as;

$$U_{sat} = K \cdot \mathrm{SGN}(S) \quad (19)$$

by replace the formulation (9) in (7) the control output can be written as;

$$U = U_{eq} + K . \mathrm{SGN}(S) \quad (20)$$

By (10) and (8) the sliding mode control of robot manipulator is calculated as;

$$U = \left[D^{-1}(f + C + G) + \dot{S}\right]D + K \cdot \mathrm{SGN}(S) \quad (21)$$

For the terminal sliding mode control part, the hype-plane is defined as

$$S = \lambda . e^{P} + \dot{e} \quad (22)$$

Where $0 < p < 1$

Based on foundation of fuzzy logic methodology; fuzzy logic controller has played important rule to design nonlinear controller for nonlinear and uncertain systems [11]. However the application area for fuzzy control is really wide, the basic form for all command types of controllers consists of;

Input fuzzification (binary-to-fuzzy [B/F] conversion)

Fuzzy rule base (knowledge base), Inference engine and Output defuzzification (fuzzy-to-binary [F/B] conversion). Figure 1 shows a fuzzy controller part.

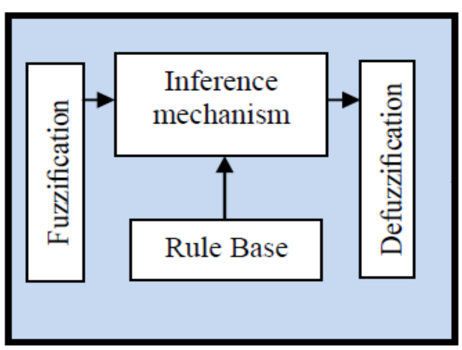

Figure 1. Fuzzy Controller Part

 Copyright ⓒ 2014 SERSC

The fuzzy inference engine offers a mechanism for transferring the rule base in fuzzy set which it is divided into two most important methods, namely, Mamdani method and Sugeno method. Mamdani method is one of the common fuzzy inference systems and he designed one of the first fuzzy controllers to control of system engine. Mamdani's fuzzy inference system is divided into four major steps: fuzzification, rule evaluation, aggregation of the rule outputs and defuzzification. Michio Sugeno uses a singleton as a membership function of the rule consequent part. The following definition shows the Mamdani and Sugeno fuzzy rule base

$$\begin{aligned}&\boldsymbol{if\ x\ is\ A\ and\ y\ is\ B\ then\ z\ is\ C\ 'mamdani'}\\&\boldsymbol{if\ x\ is\ A\ and\ y\ is\ B\ then\ z\ is\ f(x,y)'sugeno'}\end{aligned} \quad (23)$$

When x and y have crisp values fuzzification calculates the membership degrees for antecedent part. Rule evaluation focuses on fuzzy operation (AND/OR) in the antecedent of the fuzzy rules. The aggregation is used to calculate the output fuzzy set and several methodologies can be used in fuzzy logic controller aggregation, namely, Max-Min aggregation, Sum-Min aggregation, Max-bounded product, Max-drastic product, Max-bounded sum, Max-algebraic sum and Min-max. Two most common methods that used in fuzzy logic controllers are Max-min aggregation and Sum-min aggregation. Max-min aggregation defined as below;

$$\boldsymbol{\mu_U(x_k,y_k,U) = \mu_{\cup_{i=1}^{r} FR^i}(x_k,y_k,U) = \max\left\{\min_{i=1}^{r}\left[\mu_{R_{pq}}(x_k,y_k),\mu_{p_m}(U)\right]\right\}} \quad (24)$$

The Sum-min aggregation defined as below

$$\boldsymbol{\mu_U(x_k,y_k,U) = \mu_{\cup_{i=1}^{r} FR^i}(x_k,y_k,U) = \sum \min_{i=1}^{r}\left[\mu_{R_{pq}}(x_k,y_k),\mu_{p_m}(U)\right]} \quad (25)$$

where r is the number of fuzzy rules activated by x_k and y_k and also $\mu_{\cup_{i=1}^{r} FR^i}(x_k,y_k,U)$ is a fuzzy interpretation of $i-th$ rule. Defuzzification is the last step in the fuzzy inference system which it is used to transform fuzzy set to crisp set. Consequently defuzzification's input is the aggregate output and the defuzzification's output is a crisp number. Centre of gravity method (COG) and Centre of area method (COA) are two most common defuzzification methods, which COG method used the following equation to calculate the defuzzification

$$\boldsymbol{COG(x_k,y_k) = \frac{\sum_i U_i \sum_{j=1}^{r} .\ \mu_u(x_k,y_k,U_i)}{\sum_i \sum_{j=1}^{r} .\ \mu_u(x_k,y_k,U_i)}} \quad (26)$$

and COA method used the following equation to calculate the defuzzification

$$\boldsymbol{COA(x_k,y_k) = \frac{\sum_i U_i .\ \mu_u(x_k,y_k,U_i)}{\sum_i \mu_U .\ (x_k,y_k,U_i)}} \quad (27)$$

Where $COG(x_k,y_k)$ and $COA(x_k,y_k)$ illustrates the crisp value of defuzzification output, $U_i \in U$ is discrete element of an output of the fuzzy set, $\mu_U.(x_k,y_k,U_i)$ is the fuzzy set membership function, and r is the number of fuzzy rules.

The new fuzzy hype-plane variable can be written as:

$$\boldsymbol{S = \alpha.S_T + (1-\alpha).S = \alpha(\lambda.e^P + \dot{e}) + (1-\alpha).(\lambda e + \dot{e}) = \dot{e} + \lambda\alpha e^P + \lambda(1-\alpha)e} \quad (28)$$

And α is fuzzy output.

4. Results and Discussion

Fuzzy hype-plane variable sliding mode controller and conventional sliding mode controller are tested to Step response trajectory. The simulation was implemented in

Copyright ⓒ 2014 SERSC

MATLAB/SIMULINK environment. These systems are tested by band limited white noise with a predefined 30% of relative to the input signal amplitude. This type of noise is used to external disturbance in continuous and hybrid systems and applied to nonlinear dynamic of these controllers.

Trajectory Follow: Figure 2 shows the trajectory performance in fuzzy hype plane sliding mode controller and conventional sliding mode controller. Due to following graph SMC has moderate chattering but proposed method can eliminate it.

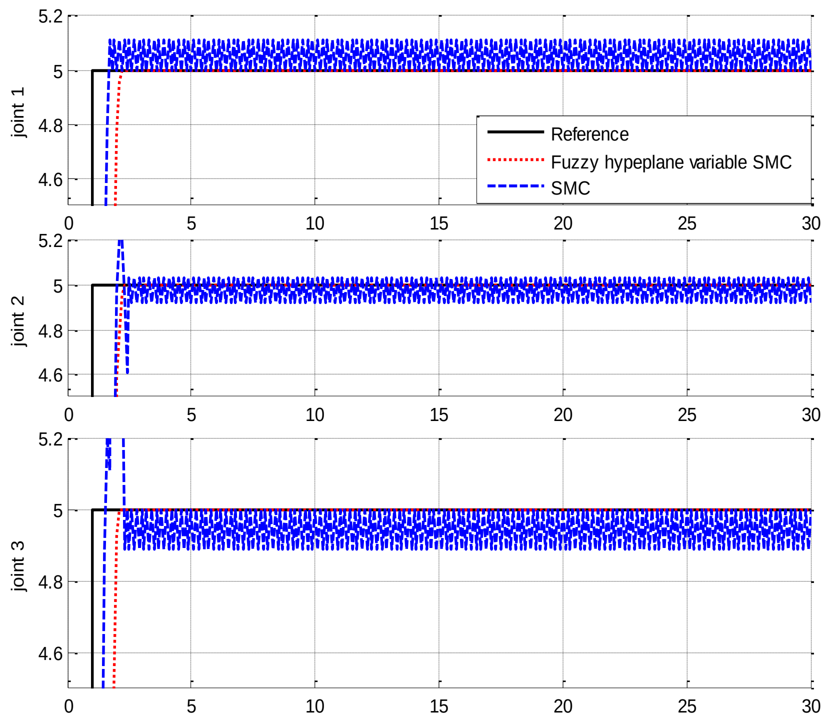

Figure 2. Trajectory Follows: Fuzzy Hype-plane Variable SMC vs. SMC

Disturbance trajectory follows: Figure 3 shows the power disturbance elimination in proposed method and pure sliding mode controller. The disturbance rejection is used to test and analyzed the robustness comparisons of these controllers for step trajectory. A band limited white noise with predefined of 30% the power of input signal value is applied to the step trajectory. It found fairly fluctuations in SMC trajectory responses. According to the following graph, pure SMC has moderate chattering in presence of external disturbance and uncertainty. However SMC has moderate chattering but this type of controller is robust. Fuzzy hype-plane variable SMC can eliminate the chattering and fluctuation in presence of uncertainty and external disturbance, therefore this type of controller is a robust.

Copyright ⓒ 2014 SERSC

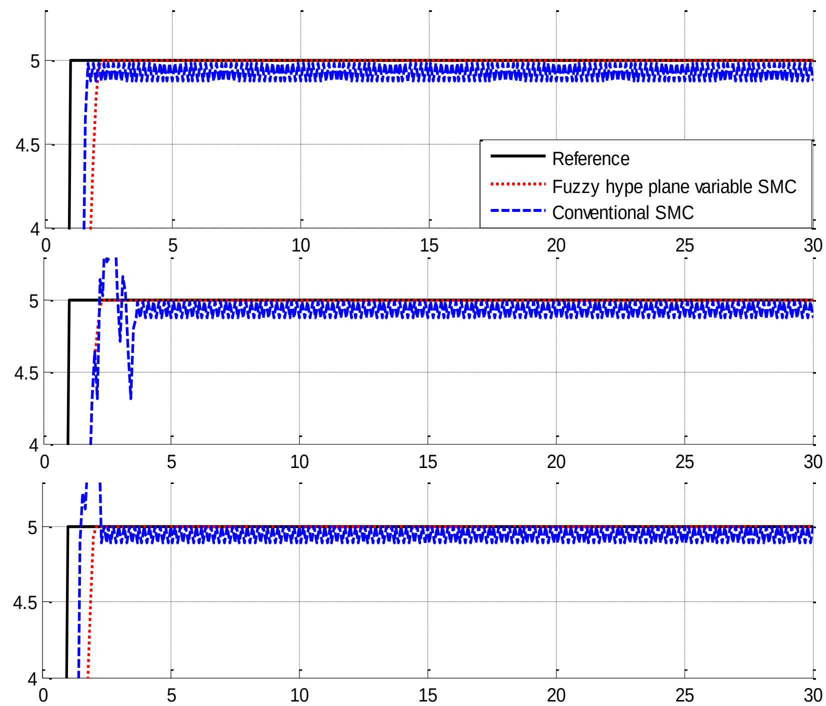

Figure 3. Disturbance Trajectory Follows: Fuzzy Hype-plane Variable SMC vs. SMC

According to above two Figures (Figure 2 and Figure 3) fuzzy hype plane variable SMC and SMC are robust but SMC has chattering and proposed method is used to improve the chattering as well as improve the robustness.

5. Conclusion

In this research two objectives are very important for researchers: the first one is reducing the chattering and the second one is improving the robustness after solve the chattering. To reach to above two objectives fuzzy hyper-plane variable sliding mode controller is recommend in this research.

In this type of method the sliding surface improved by hyper-plane methodology. In this method sliding surface is divided into two main parts: the linear sliding mode part and the terminal sliding mode part. Fuzzy logic controller is used to improve the system quality and estimate the system dynamic in uncertain condition.

According to simulation result, this type of controller is stable and robust against uncertainty and external disturbance and has a better performance than conventional SMC.

References

[1] T. R. Kurfess, “Robotics and automation handbook”, CRC, **(2005)**.
[2] J. J. E. Slotine and W. Li, “Applied nonlinear control”, Prentice hall Englewood Cliffs, NJ, vol. 461, **(1991)**.
[3] L. Cheng, *et al.*, "Multi-agent based adaptive consensus control for multiple manipulators with kinematic uncertainties",**(2008)**, pp. 189-194.
[4] J. J. D'Azzo, *et al.*, “Linear control system analysis and design with MATLAB”, CRC, **(2003)**.
[5] B. Siciliano and O. Khatib, “Springer handbook of robotics”, Springer-Verlag New York Inc., **(2008)**.

Copyright ⓒ 2014 SERSC

[6] I. Boiko, *et al.*, "Analysis of chattering in systems with second-order sliding modes," IEEE Transactions on Automatic Control, vol. 52, **(2007),** pp. 2085-2102.
[7] J. Wang, *et al.*, "Indirect adaptive fuzzy sliding mode control: Part I: fuzzy switching," Fuzzy Sets and Systems, vol. 122, **(2001),** pp. 21-30.
[8] V. Utkin, "Variable structure systems with sliding modes," Automatic Control, IEEE Transactions on, vol. 22, **(2002),** pp. 212-222.
[9] R. A. DeCarlo, *et al.*, "Variable structure control of nonlinear multivariable systems: a tutorial," Proceedings of the IEEE, vol. 76, **(2002),** pp. 212-232.
[10] K. D. Young, *et al.*, "A control engineer's guide to sliding mode control", **(2002)**, pp. 1-14.
[11] M. M. Ebrahimi, F. Piltan, M. Bazregar and A. Nabaee, "Artificial Chattering Free on-line Modified Sliding Mode Algorithm: Applied in Continuum Robot Manipulator", International Journal of Information Engineering and Electronic Business, DOI: 10.5815/ijieeb.2013.05.08, vol.5, no.5, **(2013),** pp.57-69, 2013.

Author

Mahmoud Reza Safaei Nasrabad, he is currently working as a primary researcher in the laboratory of Control and Robotic, Institute of Advance Science and Technology, IRAN SSP research and development Center. His current research interests are in the area of nonlinear control, artificial control system and robotics.

Ehsan Pooladi, he is currently working as a co researcher in Control and Robotic Lab at the institute of advance science and technology, IRAN SSP research and development Center. He is a Master in field of Mechanical Engineering from Islamic Azad University, IRAN. His current research interests are in the area of nonlinear control, artificial control system and robotics, and spherical motor.

Ghasem Sahamijoo, he is currently working as a primary researcher in the laboratory of Control and Robotic, Institute of Advance Science and Technology, IRAN SSP research and development Center. His current research interests are in the area of nonlinear control, artificial control system and robotics.

Alireza Salehi, he is currently working as a primary researcher in the laboratory of Control and Robotic, Institute of Advance Science and Technology, IRAN SSP research and development Center. His current research interests are in the area of nonlinear control, artificial control system and robotics.

 Copyright ⓒ 2014 SERSC

Farzin Piltan, he was born on 1975, Shiraz, Iran. In 2004 he is jointed Institute of Advance Science and Technology, Research and Development Center, IRAN SSP. Now he is a dean of Intelligent Control and Robotics Lab. In addition to 7 textbooks, Farzin Piltan is the main author of more than 100 scientific papers in refereed journals. He is editorial review board member for 'international journal of control and automation (IJCA), Australia, ISSN: 2005-4297; 'International Journal of Intelligent System and Applications (IJISA)', Hong Kong, ISSN: 2074-9058; 'IAES international journal of robotics and automation, Malaysia, ISSN: 2089-4856; 'International Journal of Reconfigurable and Embedded Systems', Malaysia, ISSN: 2089-4864. His current research interests are nonlinear control, artificial control system and applied to FPGA, robotics and artificial nonlinear control and IC engine modeling and control.

Nasri Sulaiman, he Received The B. Eng From University Of Putra Malaysia In 1994, M.Sc., From University Of Southampton, Uk In1999, And Phd Degrees From University Of Edinburgh, Uk In 2007, Respectively. He has more than 65 journal and conference papers. He Is Currently A Senior Lecturer In The Department Of Electrical Engineering At University Putra Malaysia Of The Program For Signal Processing, And Evolvable Harware (EHW) And Also Is Head Of Control And Automation Laboratory, Iranian Institute Of Advanced Science And Technology, Shiraz, Iran. He Is An Advisor In Spherical Motor Control.

Copyright ⓒ 2014 SERSC

 Copyright ⓒ 2014 SERSC