VIBRATION SUPPRESSION OF A TWO-LINK FLEXIBLE MANIPULATOR

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Abstract: Flexible-link robot arms have advantages over the conventional ones such as less weight, less energy consumption, and smaller actuators. However, a disadvantage of the manipulators is the vibration occurred inherently due to the flexible behavior of the arms during operation. This situation may effect control performance in some applications, for example, the use of the robot for fine painting or welding. This paper describes vibration suppression of a two-link flexible manipulator by means of fuzzy sliding mode control based neural network-like structure. Simulation and experimental results shows an effectiveness and control performance of the proposed method for vibration suppression of the robot links.

Keywords: bicycle robot, fuzzy logic control, modeling, intelligent control, two wheeled robot

1 INTRODUCTION

To improve the system response, energy consumption, and the overall mass components of robot manipulators, various types of flexible link manipulators have been modeled, designed, and implemented [1-3]. In [4], modeling and control of a single flexible-link robot arm was proposed and developed. However, the two-link counterpart, in general, is more versatile than the single-link robot arm at least in the sense of reachability. Since the dynamic model and other effects of a two-link flexible manipulator is not just simply developed by direct superposition of two models of two single flexible link robot arms, the interaction of dynamic coupling between one link to the other needs to be included in the working model.

One of the problems in control of a flexible-link manipulator is the vibration during operation of this type of robot arms. The vibration occurs due to the inherite properties of the material made of the arm and its dimension. Long and slim arms have more vibration than the short and thick ones. With this common sense, one may wish to choose the appropriate dimension for the robot arm's structure to reduce the flexible nature created the vibration. Intuitively, it seems to obtain an easy and inexpensive way to suppress the vibration modes of the manipulator by enhancing the physical dimension and coping with some kind of vibration absorption material, instead of designing a sophisticate control scheme to suppress them. Some researcher prefers to work with very thin arms for the sake of enlightening the nature of vibration, while the others view the very thin arms as useless ones for many real-world applications dealt with loads. The key concept to adopt the ideas for the judgement of significant implementation between the two approaches would be the objective of the research — depending on for basic research or for applications. It is wise to investigate issues in both engineering applications and studying basic research.

Among various control schemes, variable structure control or sliding mode control (SLM) can be designed for handling nonlinear effects of the system, while having good disturbance rejection and trajectory tracking. Researchers have their own version of the similar approach for the flexible link structure [5-7]. To enhance the controller performance and remedy the chattering effects, fuzzy control, both sliding mode approach to fuzzy control and fuzzy approach to sliding mode control, has been proposed for the nonlinear systems. These fuzzy SLM controllers have been reported that the satisfactory performance is achieved for given tasks [8-9].

In this paper, a fuzzy sliding mode control has been designed for vibration suppression and tracking trajectory of a two-flexible link robot arm. Unlike the above literatures, our fuzzy SMC contains a neural network-like structure. In other words, it has a layered appearance for the standard fuzzy control procedure. The paper is organized as follows: Section 2 describes development of model. In section 3, a fuzzy sliding mode control is described in a neural network-like structure. Section 4 gives simulation results to validate the proposed control law and Section 5 summarizes the study.

2. MATHEMATICAL MODEL

A two-flexible link robot manipulator is illustrated in Figure 1 and 2. The hardware of the system is under construction. As can be seen from Figure 1, the flexible robot arms is planar ones, we then adopt the mathematical model developed by Scott in [10]. The model is derived by using the Euler-Lagrange method. The equations of motion are developed using the assume mode method. That is

$$\begin{aligned} w_1(x,t) &= \sum_{i=0}^{\infty} \phi_i(x_1)a_i(t) = \phi^T a = a^T\phi \\ w_2(x,t) &= \sum_{j=0}^{\infty} \psi_i(x_2)c_j(t) = \psi^T c = a^T\psi \end{aligned} \quad (1).$$

The kinetic energy of the first and the second link is

$$T = T_{L_1} + T_{L_2} \quad (2),$$

$$T_{L_1} = \frac{1}{2}J_1^{(1)}\dot{\theta}_1^2 + \frac{1}{2}\dot{a}^T M_a^{(1)}\dot{a} + \dot{\theta}_1\dot{a}^T M_{1a}^{(1)} \quad (3),$$

$$\begin{aligned} T_{L_2} = {} & \frac{1}{2}J_1^{(2)}\dot{\theta}_1^2 + J_{12}\dot{\theta}_1\dot{\theta}_2 + \frac{1}{2}J_2^{(2)}\theta_2^2 \\ & + \dot{\theta}_1\dot{a}^T M_{1a}^2 + \dot{\theta}_2\dot{a}^T M_{2a} + \frac{1}{2}\dot{a}^T M_a^{(2)}\dot{a} \\ & + \dot{\theta}_1\dot{c}^T M_{1c} + \dot{\theta}_2\dot{c}^T M_{2c} + \frac{1}{2}\dot{c}^T M_c\dot{c} \\ & + \dot{c}^T M_{ca}\dot{a} \end{aligned} \quad (4),$$

where the subscripts L_1 and L_2 stand for the 1st and the 2nd link, respectively. Parameters J and M with the superscripts and subscripts correspond to the inertia term of the i-th link and the feedback (or feedforward if it has transpose) from the joint angle to the generalized coordinate.

The potential energy V is

$$V = \frac{1}{2}\int_0^{L_1}(EI)_1(w_1'')^2 dx_1 + \frac{1}{2}\int_0^{L_2}(EI)_2(w_2'')^2 dx_2 \quad (5).$$

We now have the Lagrangian L = T-V by using (2)-(5). With some lengthy calculation by inserting the obtained Lagrangian L into the Euler-Lagrange equation and the aid of Mathcad software package, we can arrange the result in state-space form

$$\dot{x} = Ax + Bu \quad (6),$$

where the state vector is defined as

$$x = \begin{bmatrix} \theta_1 & \theta_2 & a^T & c^T & \dot{\theta}_1 & \dot{\theta}_2 & \dot{a}^T & \dot{c}^T \end{bmatrix}^T \quad (7).$$

Figure 1. Photograph of the arms made of aluminum (under construction).

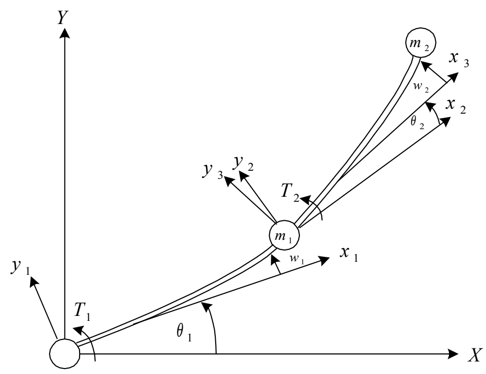

Figure 2. A two-link flexible robot manipulators.

We now arrive at

$$\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\phi}_L \\ \dot{\psi}_L \\ \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{\phi}_L \\ \ddot{\psi}_L \end{bmatrix} = \begin{bmatrix} 0 & I \\ -inv(M_{sys})K_{sys} & 0 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \phi_L \\ \psi_L \\ \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\phi}_L \\ \dot{\psi}_L \end{bmatrix} + \begin{bmatrix} 0 \\ inv(M_{sys})f \end{bmatrix} u \qquad (8).$$

For more detailed calculation and derivation, the reader is referred to [10].

3. FUZZY SLIDING MODE CONTROL DESIGN

The mathematical model of a two-flexible link robot arm is described in the last section. This section provides detailed design and analysis of a fuzzy sliding mode controller in a neural network structure. The neural network is structurally (not functionally) employed to illustrate the equivalent structure of the standard fuzzy control method (fuzzification, inference engine, and defuzzification). Figure 3 shows the hybrid digital-analog overall control system architecture, in which sampling and signal holding devices are not shown for the sake of convenience. The membership function and the singleton output membership function of S and dS are shown in Figure 4 and 5.

We now define the error signal e(t), according to Figure 3, as e(t) = r(t) – y(t), where r(t) is the tracking reference or set point value and y(t) is the output. These parameters are in vector forms and the elements of the vectors are corresponding to the link being consideration. The sliding variable and its derivative can be defined, as usual,

$$S = \dot{e} + \lambda e \qquad (9),$$
$$dS = \frac{S(t+T) - S(t)}{T}$$

and λ is a selected positive constant.

Traditionally, the designed sliding mode control input u(t) is defined in the form of signum function u = H sgn(S), where H is the bounded control input signal. Upon observing this switching control law, it is easy to see that, as witness by many simulations and various practical applications, the signum or sign function can lead the system into chattering trajectory around the sliding surface. To improve and remedy, the fuzzy control law based on the input variables can be categorized in Table 1. The control rule used here is derived based on natural tracking [4]. Parameters α and β in Figure 5 are two parameters to be determined from the trial and error process.

Table 1. The control rule for the action

IF		THEN
S	dS	Decision
>0	>0	H_1
>0	0<	H_2
0<	>0	H_3
0<	0<	H_4

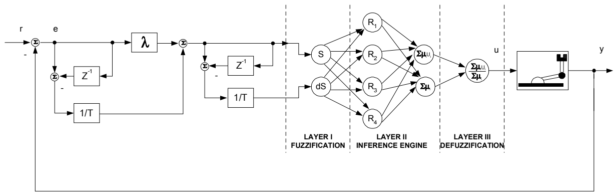

Figure 3. The fuzzy sliding mode based neural network-like structure.

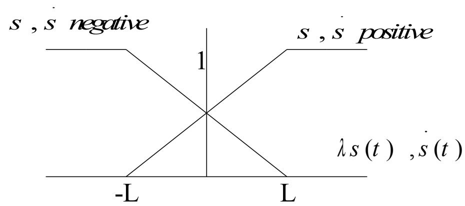

Figure 4. Input membership function of S and dS.

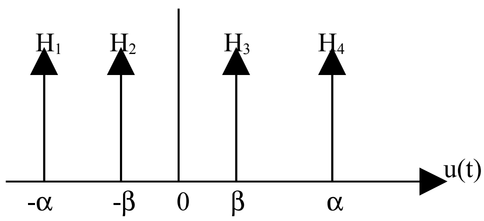

Figure 5. Output membership function.

4. SIMULATION RESULTS

Values used in simulation may be assumed, according to the dimension of the real physical system, to be shown in Table 2.

Table 2. Link Parameters

Parameters	Link 1	Link 2
Beam thickness	0.002 (m)	0.002 (m)
Beam width	0.038 (m)	0.038 (m)
Beam length	1	0.50 (m)
Flexural rigidity	4.1 (N m^2)	0.5 (N m^2)
Mass/unit length	0.3	0.3

The simulations were performed based on the robot arm model and are presented in Figure 6 and 7. Figure 6 shows the simulation of the tracking trajectory, which the desired set points of the joint angles for the link 1 and link 2 are 60 and 40 degrees, respectively. Figure 7 illustrates the corresponding tracking errors. The Figures are shown much alleviation of vibration.

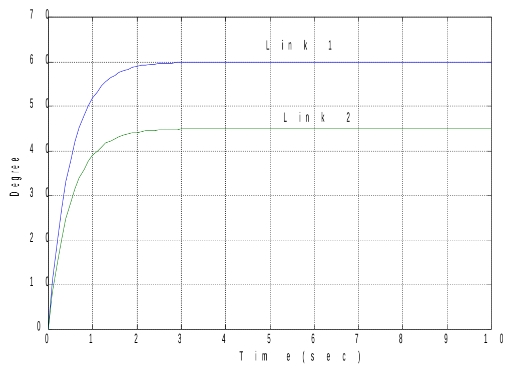

Figure 6. The tracking trajectory at the end point of the arm.

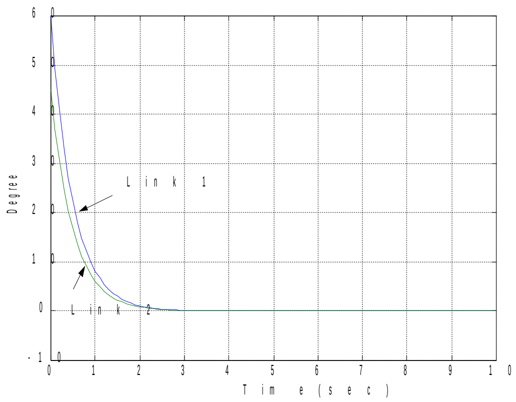

Figure 7. The tracking errors of the end point of the arm.

5. CONCLUSION

We have developed a fuzzy sliding mode controller based neural network-like structure. Our simulation results have shown that it is possible to implement the proposed control system. Further work is necessary to quantify the effectiveness of the proposed control scheme.

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REFERENCES

[1] Canon, R. H. Jr., and Schmitz, E., “Initial Experiment on the End-Point Control of flexible one-Link Robot,” *The international Journal of Robotic Research*, Vol. 3, No. 3, pp. 666-672, 1984

[2] Lin, L, and Lewis, F., ”Enhanced measurement and estimation methodology for flexible link arm control,” *Journal of Robotic System,* Vol. 11(5), pp.367-385, 1994.

[3] Ibrahimbegovic, A., and Mamouri, S., “Nonlinear dynamics of flexible beams in planar motion formulation and time-stepping scheme for stiff problems,” *Computers and Structures*, pp. 1-22, 1999.

[4] Sooraksa, P., and Chen, G., “Mathematical Modeling and Fuzzy Control of a Flexible-Link Robot Arm,” *J. of Mathematical Computing and Modeling,* Vol. 27, pp. 73-93, 1998.

[5] Drakunov, S. V., and Ozguner, U., “Vibration Suppression in Flexible Structures via the Sliding-Mode Control Approach,” *Proceedings of the 31st Conference on Decision and control,* pp. 1365-1366, 1992.

[6] Yeung, K. S., and Chen, Y. P., “Sliding mode controller design of a single link flexible manipulator under gravity,” *Int. J. Contr.,* Vol. 52, No. 1, pp. 101-117, July 1990.

[7] Sabanovic, A., and Jezernik, K., “Chattering Free Sliding modes in Robotic Manipulators Control,” *Robotica (1996),* Vol. 14, pp. 17-29, 1996.

[8] Ha, Q. P., “Sliding performance enhancement with fuzzy tuning,” *Electronics Letters 31st,* Vol.33, No.16, pp.1421-1423, July 1997.

[9] Lo, J. -C. and Kuo,Y. -H, “Decoupled Fuzzy Sliding-Mode Control” *IEEE Trans. on fuzzy systems,* Vol.6, No.3, pp.426-435, August 1998.

[10] Scott, M. A., “Time Varying Compensator Design for Reconfiguable Structures using Non-Collocated Feedback,” Ph.D. Dissertation, Aerospace Engineering Sciences, University of Colorado, 1995.