Synchronous Tracking Control of Gantry Stage Using Adptive Fuzzy Moving Sliding Mode Approach

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***Abstract*—A cross-coupled architecture incorporating adaptive fuzzy moving sliding mode control (AFMSMC) is proposed to improve the effects of the mechanical coupling over synchronous and tracking errors in a three-axis gantry stage. We utilize the indirect and direct adaptive fuzzy sliding mode control schemes with the time-varying surface to approximate the each unknown servo-motor system of gantry stage. An online adaptive tuning law based on Lyapunov theory is derived not only to adjust the fuzzy rule's parameters on-line so that the output tracking error converges to zero in finite time, but also to achieve asymptotically stable tracking of the reference trajectory. In addition, a cross-coupled control architecture which employs the proportional-integral-derivative (PID) controller to compensate the contour error between axes for synchronization performance improvement. Extensive simulations and comparisons for relevant circle trajectory of a gantry position systems not only can perform to verify the performance of the proposed adaptive fuzzy moving sliding mode controller design with cross-coupling architecture but also preserve the asymptotic stability.**

Keywords—adaptive fuzzy moving sliding mode control; indirect and direct; gantry stage; Lyapunov theory; cross-coupled control

I. INTRODUCTION

The application of high speed and high accuracy position control of gantry framework [1] has been rapidly and extensively developed to facilitate the automatic processes in industrial and manufacturing, such as relating to circuit assembly, printed circuit board manufacturing, micro-machining, laser/water-jet cutting machines, precision metrology, and so on. For conventional multi-axis motion control systems, the widespread approaches [2-4] are independent axis controlled based on local information without regard to the other axes. These approaches can only be applied to reduce the tracking error in each individual axis. However, the decoupled motion control will lead to synchronization performance deterioration when the dynamic characteristics such as the gain margin and time constant of each axis are different or non-symmetrical disturbances imposed on the system. Therefore, the synchronous control in the gantry stage has become an increasingly important issue, which is aimed at enhancing machining accuracy and working speed during the manufacture and inspection.

In order to deal with the problem of synchronous motion, over the past decade, a number of previous studies have been attempted to use the cross-coupled technology for the multiple axes motion applications to improve synchronization performance (i.e. contouring accuracy) [5-8]. Koren and Lo [9] proposed a variable-gain cross-coupled control method to compensate each axis position error for further improving the synchronization performance of biaxial motion systems. A cross-coupled optimal synchronization controller [10] was developed by LQR scheme for a dual-drive servo system of a surface chip mounter. In addition, the contouring control for biaxial feed drive systems based on coordinate transformation was proposed [5, 6], in which the tracking error of feed drive axis is converted to error components orthogonal and tangential to the desired contour curve. A federate regulators based on fuzzy-logic-based [11] was designed to reduce the contouring error. Besides, a genetic synthesis [12] of cross-coupled controller parameters with optimal control performance was designed to reduce the contour error. Recently, many significant researches incorporated some well-known adaptive control approaches, such as model-reference adaptive control strategy [13, 14] and intelligence control theorem [15] with cross-coupled technology to enhance the tracking performance of synchronous motion systems. Although the result of above mentioned approaches can be adopted to achieve better contouring accuracy for multiple axes motion applications. However, it is quite difficult to possess enough robustness in practical applications because the control gain are always selected trial-and-error method to achieve the required control performance. Therefore, a significantly adaptive fuzzy neural network (FNN) was recently proposed to incorporate with the expert information systematically for eliminating chattering phenomena and increasing control accuracy recently; in addition, the stability can be guaranteed according to general approximation theorem.

In this paper, we propose an adaptive fuzzy moving sliding mode control (AFMSMC) by incorporating indirect and direct adaptive fuzzy control and moving sliding surface

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strategy to achieve fast response and tracking performance. In addition, a cross-coupled controller is utilized for reducing contouring error for biaxial contour following tasks. The proposed fuzzy systems are mainly designed to approximate each servomechanism and then to derive the equivalent control force. Moreover, an on-line parameter adaption turning law is used to make the system output track the desired reference trajectory. Thus, the practical motion systems can efficiently follow the reference trajectory even in case of a hard nonlinearity.

II. Modeling and System Description

The experiment study of this paper adopts the gantry structure, as illustrated in Fig. 1. Two AC servo motors are used to drive the gantry system, which are widely used in industrial applications.

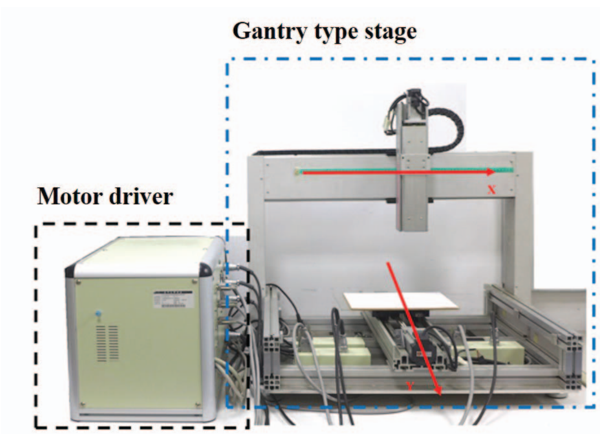

Fig. 1. Appearance of the Gantry type stage

The synchronization of position control for gantry systems requires strictly to avoid servo mismatch. To improve the tracking error and contouring error simultaneously, the proposed architecture of the biaxial motion control system with a coupling mechanism is illustrated in Fig. 2. Two adaptive controllers are independent applied in the each motor control.

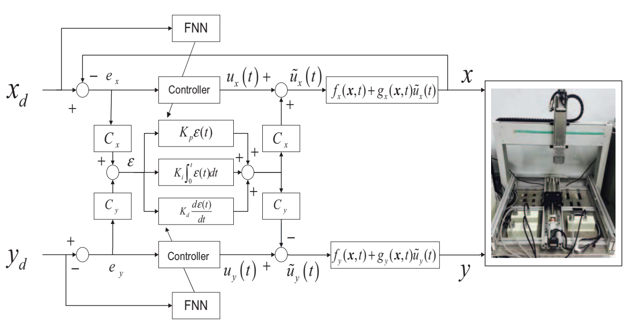

Fig. 2. Architecture of biaxial motion control system with the cross-coupling controller

where $f_x(\boldsymbol{x}, t)$ and $f_y(\boldsymbol{x}, t)$ are the nonlinear models of the X-axis and Y-axis motors, respectively; x_d and y_d are the desired trajectory for each axis; e_x and e_y are the position errors along the X and Y axes, respectively. ε is the contouring error. For independent axis controller design, we present an adaptive fuzzy moving sliding mode control (AFMSMC) approach to reduce the position error (i.e. tracking error) in each axis. In addition, we also adopt the cross-coupled controller based on the proportional-integral-derivative (PID) to further improve the tracking performance and contour accuracy.

III. Adaptive Fuzzy Moving Sliding Mode Controller of Each Axis

The design method of two axes motion controller is employed by the adaptive fuzzy moving sliding mode controller for single axis, based on the requirement of the position tracking precision for the dynamic characteristic in each axis. Here, we apply the AC motor-driven system of X-axis and Y-axis to describe the adaptive fuzzy moving sliding mode controller design. Here, the dynamics of the n-order nonlinear models of the each axis motor can be expressed as:

$$\begin{aligned} x^{(n)} &= f(\boldsymbol{x}, t) + g(\boldsymbol{x}, t)u + d(t) \\ \boldsymbol{x} &= (x \ldots x_n, \dot{x} \ldots \dot{x}_n)^T, \quad y = x^{(n)} \end{aligned} \tag{1}$$

where $\boldsymbol{x} \in \Re^2$ is the state vector of the system; $u_x \in \Re$ and $y_x \in \Re$ are the control input and output of the X-axis motor, respectively. $d_x(t)$ is the unknown external disturbance. The control object is to design the control input u_x to force the output y_x to track a desired state x_d. Hence, the tracking error e_x is specified as

$$e^{(n)} = x_d^{(n)} - x^{(n)} \tag{2}$$

The sliding surface can be defined by the space of the error state as

$$s = c_1 e + c_2 \dot{e} + \ldots + c_{n-1} e^{(n-2)} + e^{(n-1)} \tag{3}$$

where the coefficients are $c_1 > 0,\ c_2 > 0$. The tracking error vector remains on the sliding surface when $s = 0$ for all $t \geq 0$ when $x = x_d$. In order to derive an appropriate control can keep the error trajectory on the sliding surface such that the error will asymptotically reach zero, the Lyapunov direct method is used to get the control law and the Lyapunov function is defined as

$$V(s) = \tfrac{1}{2} s^2 \tag{4}$$

$V(s)$ is a non-negative function which characterizes of $V(s) > 0$ for $s \neq 0$. In other words, the derivation of the Lyapunov function is negative, to satisfy the suffice condition is given by

$$\dot{V}(s) = s\dot{s} \leq -\eta |s|, \quad \eta \geq 0 \tag{5}$$

Therefore, the detail process to formulate the control law is described as follows

$$\begin{aligned}\dot{s} &= \sum_{i=1}^{n-1} c_i e^{(i)} + e^{(n)} \\ &= \sum_{i=1}^{n-1} c_i e^{(i)} + x_d^{(n)} - f(\boldsymbol{x},t) - g(\boldsymbol{x},t)u - d(t)\end{aligned} \tag{6}$$

Thus, by setting $\dot{s}=0$, the equivalent control force u_{eq} can be described as

$$u_{eq} = \frac{1}{g(\boldsymbol{x},t)}\left(\sum_{i=1}^{n-1} c_i e^{(i)} + x_d^{(n)} - f(\boldsymbol{x},t)\right) \tag{7}$$

In order to satisfy the sliding condition (5), a switch-type control term u_{sw} needs to be appended, and hence the switching type control as

$$u_{sw} = \eta \operatorname{sgn}(s) \tag{8}$$

Therefore, the resulting sliding mode control law can be expressed as

$$u(t) = u_{eq}(t) + u_{sw}(t) \tag{9}$$

To implement the equivalent control force (7), the dynamic of motor system must be well known. However, in this paper, the motor system of each axis is a unknown nonlinear models, i.e. $f_x(\boldsymbol{x}, t)$ is unknown. In addition, the switch-type control term might cause chattering phenomenon. To solve above problems, we apply the fuzzy neural network (FNN) strategy to construct the nonlinear models of the X-axis motor, and combine an on-line parameter adaption turning law to estimate the all design parameters and slopes of the sliding surface. Next, the AFMSMC is constructed by appending moving sliding surface approach to indirect and direct fuzzy controller.

A. Indirect Adaptive Fuzzy Controller

In order to implement the equivalent control force u_{eq}, the nonlinear systems of equations $f(\boldsymbol{x}, t)$ and $g(\boldsymbol{x}, t)$ can be approximated by fuzzy neural network system $\hat{f}(\boldsymbol{x}|\boldsymbol{\theta}_f)$, $\hat{g}(\boldsymbol{x}|\boldsymbol{\theta}_g)$, respectively, which can be expressed as

$$\hat{f}(\boldsymbol{x}|\boldsymbol{\theta}_f) = \boldsymbol{\theta}_f^T \xi_f(\boldsymbol{x}) \tag{10}$$

$$\hat{g}(\boldsymbol{x}|\boldsymbol{\theta}_g) = \boldsymbol{\theta}_g^T \xi_g(\boldsymbol{x}) \tag{11}$$

where $\boldsymbol{\theta} = (y^1, y^2, ..., y^m)^T$ is a parameter vector; and fuzzy basis function vector $\xi(\boldsymbol{x})$ defined as

$$\xi(\boldsymbol{x}) = \frac{\prod_{i=1}^{n} \mu_{F_i^j}(x_i)}{\sum_{j=1}^{m}\prod_{i=1}^{n} \mu_{F_i^j}(x_i)} \tag{12}$$

where m is the number of fuzzy rules; $\mu_{F_i^j}$ is the membership function value of the fuzzy variable x_i. Thus, the resulting sliding mode control law (9) of indirect adaptive fuzzy controller can be rewritten as.

$$u = \frac{1}{\hat{g}(\boldsymbol{x}|\boldsymbol{\theta}_g)}\left[\sum_{i=1}^{n-1} \hat{c}_i e^{(i)} - \hat{f}(\boldsymbol{x}|\boldsymbol{\theta}_f) + x_d^{(n)} + \eta \operatorname{sgn}(s)\right] \tag{13}$$

By substituting (13) into (6), then

$$\begin{aligned}\dot{s} &= \sum_{i=1}^{n-1} c_i e^{(i)} + x_d^{(n)} - f(\boldsymbol{x},t) - g(\boldsymbol{x},t)u \\ &= \sum_{i=1}^{n-1} \tilde{c}_i e^{(i)} + \boldsymbol{\theta}_f^T \xi_f + \boldsymbol{\theta}_g^T \xi_g + \omega_c - \eta \operatorname{sgn}(s)\end{aligned} \tag{14}$$

Now consider the $\tilde{\boldsymbol{\theta}}_f = \boldsymbol{\theta}_f - \boldsymbol{\theta}_f^*$, $\tilde{\boldsymbol{\theta}}_g = \boldsymbol{\theta}_g - \boldsymbol{\theta}_g^*$, $\tilde{\boldsymbol{\theta}}_g = \boldsymbol{\theta}_g - \boldsymbol{\theta}_g^*$, $\omega_c = \omega - d(t)$, $\hat{c} - c = \tilde{c}$, respectively. Meanwhile, the minimum approximation error ω is given by

$$\omega = \hat{f}(\boldsymbol{x}|\boldsymbol{\theta}_f^*) - f(x,t) + \left(\hat{g}(\boldsymbol{x}|\boldsymbol{\theta}_g^*) - g(\boldsymbol{x},t)\right)u \tag{15}$$

Hence, the optimal parameter estimation θ_f^* and θ_g^* are expressed as

$$\boldsymbol{\theta}_f^* = \arg\min_{\theta_f \in \Omega_f}\left[\sup_{x\in R}\left|\hat{f}(\boldsymbol{x}|\boldsymbol{\theta}_f) - f(\boldsymbol{x},t)\right|\right] \tag{16}$$

$$\boldsymbol{\theta}_g^* = \arg\min_{\theta_g \in \Omega_g}\left[\sup_{x\in R}\left|\hat{g}(\boldsymbol{x}|\boldsymbol{\theta}_g) - g(\boldsymbol{x},t)\right|\right] \tag{17}$$

To begin with, the Lyapunov function candidate is considered as

$$V = \frac{1}{2}s^2 + \frac{1}{2r_f}\tilde{\boldsymbol{\theta}}_f^T\tilde{\boldsymbol{\theta}}_f + \frac{1}{2r_g}\tilde{\boldsymbol{\theta}}_g^T\tilde{\boldsymbol{\theta}}_g + \frac{1}{2r_c}\hat{c}^2 \tag{18}$$

Differentiating (18) with respect to time along trajectory (14) we acquire

$$\begin{aligned}\dot{V}(s) &= \frac{1}{r_f}\tilde{\boldsymbol{\theta}}_f^T\left(r_f s \xi_f + \dot{\tilde{\boldsymbol{\theta}}}_f\right) + \frac{1}{r_g}\tilde{\boldsymbol{\theta}}_g^T\left(r_g s \xi_g u + \dot{\tilde{\boldsymbol{\theta}}}_g\right) \\ &+ \frac{1}{r_c}\sum_{i=1}^{n-1}\tilde{c}_i\left(rse^{(i)} + \dot{\hat{c}}\right) - s\eta \operatorname{sgn}(s) + s\omega_c \\ &\le -\eta|s| + s\omega_c \le 0\end{aligned} \tag{19}$$

where r_f, r_g, r_c are the learning rates of systems functions $\hat{f}(\boldsymbol{x}|\tilde{\boldsymbol{\theta}}_f)$, $\hat{g}(\boldsymbol{x}|\tilde{\boldsymbol{\theta}}_g)$ and the slope of sliding surface $\hat{c}$, respectively. By the fact $\dot{\tilde{\boldsymbol{\theta}}}_f = \dot{\boldsymbol{\theta}}_f$, $\dot{\tilde{\boldsymbol{\theta}}}_g = \dot{\boldsymbol{\theta}}_g$; therefore, the adaptive laws of the parameters of indirect adaptive laws are as follow

$$\dot{\boldsymbol{\theta}}_f = -r_f s \xi_f \tag{20}$$

$$\dot{\boldsymbol{\theta}}_g = -r_g s \xi_g u \tag{21}$$

$$\dot{\hat{c}} = -r_c s e^{(i)} \tag{22}$$

which according (19), implies that asymptotic convergence of the tracking error can be concluded by using the Barbalat's lemma[17], namely, $\lim_{t\to\infty} e(t) = 0$.

B. Direct Adaptive Fuzzy Controller

The purpose of direct adaptive fuzzy control process is to adaptively approach the perfect control law by a fuzzy system.

It used fuzzy system to perform a mapping from current states to the desired input u Therefore, we utilize fuzzy rule system to approximate the direct fuzzy control $u\left(\boldsymbol{x}\middle|\boldsymbol{\theta}_u\right)$, then the so-called perfect feedback control is

$$u = u\left(\boldsymbol{x}\middle|\boldsymbol{\theta}_u\right) + \frac{1}{g\left(\boldsymbol{x},t\right)}\eta\,\mathrm{sgn}\left(s\right) \tag{23}$$

By substituting (23) into (6), then

$$\dot{s} = \sum_{i=1}^{n-1}\tilde{c}_{r(i)}e^{(i)}\left(t\right) - g\left(\boldsymbol{x},t\right)u\left(\boldsymbol{x}\middle|\tilde{\boldsymbol{\theta}}_u\right) + \eta\,\mathrm{sgn}\left(s\right) - d\left(t\right) \tag{24}$$

where $\tilde{\boldsymbol{\theta}}_u = \boldsymbol{\theta}_u - \boldsymbol{\theta}_u^*$ 、 $\omega_c = \omega - d\left(t\right)$ 、 $\hat{c} - c = \tilde{c}$

The minimum approximation error ω is given by

$$\omega = u\left(t\right) - u\left(\boldsymbol{x}\middle|\boldsymbol{\theta}_u^*\right) \tag{25}$$

In order to perform the fast and robust position tracking control, the Lyapunov function candidate is considered as

$$V = \frac{1}{2}s^2 + \frac{1}{2r_u}\tilde{\boldsymbol{\theta}}_u^T\tilde{\boldsymbol{\theta}}_u + \frac{1}{2r_c}\tilde{c}^2 \tag{26}$$

Then (26) can be as follow

$$\begin{aligned}\dot{V}\left(s\right) &= \frac{1}{r_u}\tilde{\boldsymbol{\theta}}_u^T\left(-r_u s g\left(\boldsymbol{x},t\right)\xi_u + \dot{\tilde{\boldsymbol{\theta}}}_u\right)\\ &\quad + \frac{1}{r_c}\sum_{i=1}^{n-1}c_i\left(r_c s e^{(i)}\left(t\right) + \dot{\hat{c}}\right) - s\eta\,\mathrm{sgn}\left(s\right) + s\omega_c\\ &\le -\eta\left|s\right| + s\omega_c \le 0\end{aligned} \tag{27}$$

where r_u, r_c are the learning rates of system function $u\left(\boldsymbol{x}\middle|\tilde{\boldsymbol{\theta}}_u\right)$ and the slope of sliding surface $\hat{c}$, respectively. In fact $\dot{\tilde{\boldsymbol{\theta}}}_u = \dot{\boldsymbol{\theta}}_u$; therefore, the adaptive law of the parameter of direct adaptive laws and the adaptive slope of sliding surface are as follow

$$\dot{\boldsymbol{\theta}}_u = r_u s \xi_u g\left(\boldsymbol{x},t\right) \tag{28}$$

$$\dot{\hat{c}} = -r_c s e\left(t\right) \tag{29}$$

which according(27), implies that asymptotic convergence of the tracking error can be concluded by using the Barbalat's lemma[17],namely, $\lim_{t\to\infty} e\left(t\right) = 0$.

IV. Cross-coupling controller design

Although the adaptive fuzzy moving sliding mode controller can reduce the single axis position error; although, motion control based only on the tracking ability of each axis in multiple axis motion applications does not always guarantee the high precision and control performance requirements. In general, position error exists in any motion axis, but the contouring error exists only in a multi-axis motion systems.

To improve the effects of the mechanical coupling over synchronous, i.e. contouring performance, we utilize a cross-coupling control architecture based on the PID controller to compensate the contouring error between axes. According to the Fig. 2, the approximate contour error ε is given by

$$\varepsilon = -e_x C_x + e_y C_y \tag{30}$$

where the parameters C_x and C_y are defined by as follow

$$C_x = \sin\theta - {e_x}/{2R},\quad C_y = \cos\theta + {e_y}/{2R} \tag{31}$$

The cross coupling gain estimates the contouring error by applying the PID controller and compensates for the each axis. Therefore, the cross-coupled controller of the PID is

$$u_{cross}\left(t\right) = K_p\varepsilon\left(t\right) + K_i\int_0^t\varepsilon\left(t\right)dt + K_d\frac{d\varepsilon\left(t\right)}{dt} \tag{32}$$

Therefore, the integrated control law for each axis motor can be respective described as

$$\begin{aligned}\tilde{u}_x\left(t\right) &= u_x\left(t\right) + C_x u_{cross}\left(t\right),\\ \tilde{u}_y\left(t\right) &= u_y\left(t\right) - C_y u_{cross}\left(t\right)\end{aligned} \tag{33}$$

where $u_x\left(t\right)$ and $u_y\left(t\right) \equiv u\left(t\right)$ are the indirect and direct feedback control law (13) and (23), respectively.

V. Experiment results

The gantry stage is considered as the experimental apparatus for verifying the proposed control scheme. The simulation has been conducted for circular. Here, the Matlab system identification toolbox can be used to create the two AC motor feed drive linear dynamic model of gentry systems individually. Hence, the dynamic of the X-axis AC motor driven system can be described as follow

$$\begin{aligned}\ddot{x} &= -0.7067\dot{x} - 0.0811x + u_x\\ y_x &= 0.5764x\end{aligned} \tag{34}$$

In addition, the dynamic of the Y-axis AC motor driven system can be expressed as follow

$$\begin{aligned}\ddot{y} &= -0.6647\dot{y} - 0.108y + u_y\\ y_y &= 0.5733y\end{aligned} \tag{35}$$

where x_1 and x_3 contain the drive velocities of X-axis and Y-axis motor systems, respectively; x_2 and x_4 contain the drive accelerations of X-axis and Y-axis motor systems, respectively. u_x and u_y are the control inputs of X-axis and Y-axis, respectively. In this paper, we assumed that the dynamic functions (34) and (35) of X-axis and Y-axis AC motor driven system are unknown. The task is to design a controller such that actual trajectory will track the desired reference trajectory. Let the membership functions for system states are chosen as $\mu_{NB} = 1/\left(1+\exp\left(5\left(x+2\right)\right)\right)$, $\mu_{NM} = \exp\left(-\left(x+1.5\right)^2\right)$, $\mu_{NS} = \exp\left(-\left(x+0.5\right)^2\right)$, $\mu_{PS} = \exp\left(-\left(x-0.5\right)^2\right)$, $\mu_{PM} = \exp\left(-\left(x-1.5\right)^2\right)$, $\mu_{PB} = 1/\left(1+\exp\left(5\left(x-2\right)\right)\right)$.

Hence, 36 rules are used to approximate the dynamic function f. Firstly, the systems' sampling period defined $T = 0.01s$. The initial positions of two axes are separately set by $x_1(0)=0$ and $x_3(0)=0$; the initial velocity of two axes is equal to $x_2(0)=0$ and $x_4(0)=0$, respectively. The learning rate is defined $r=0.01$. To verify the effectiveness of the proposed controller, the reference trajectories of circular are considered. The experimental results are illustrated from Fig. 3 to Fig. 4.

Fig. 3 shows the comparision of circular trajectory for different controller design, such as PID controller, conventional sliding mode control, adaptive fuzzy moving sliding mode cotrol (AFMSMC) for signle axis, and the AFMSMC with cross-coupled controller (CCC).

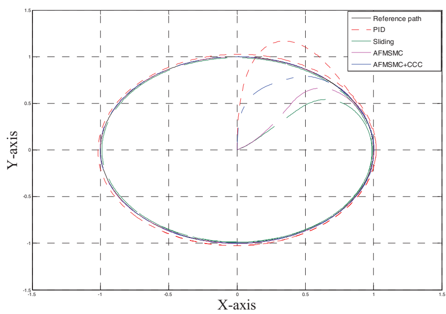

Fig. 3. Comparision of circular trajectory for different controller design

Fig. 4 shows the simulation results of each individual axis for different controller design for a circular trajectory. We obviously realize that the proposed AFMSMC with CCC approach can quickly track the reference input, and there is no exceeding. It means that the proposed AFMSMC with CCC approach has change superior by better or than by to the other methods' performance.

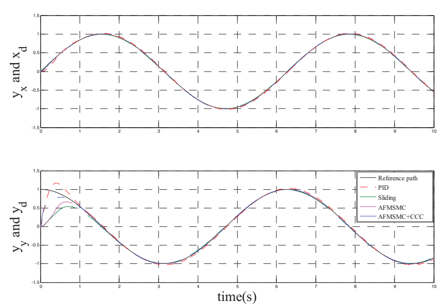

Fig. 4. Comparision of single axis position for different controller design in a circular motion

It can be obvious in Fig. 3 and Fig. 4 that the advantage of our proposed controller is its ability to eliminate the effect of transient response, and then contouring accuracy for multiple axis motion to be improved.

A. Indirect

In Fig. 5 and Fig. 6 show the results of indirect adaptive fuzzy time-varying sliding mode on X-axis and Y-axis, and the circular trajectory is shown in Fig. 7.

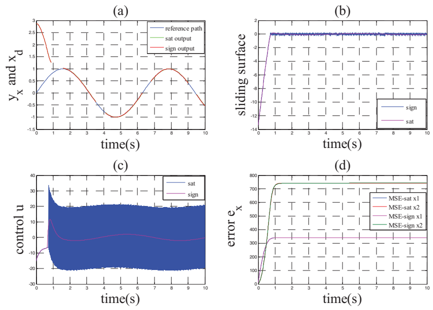

Fig. 5. Indirect adaptive fuzzy time-varying sliding mode on X-axis: (a) system output y_x and desired intput x_d, (b) sliding surface, (c) control force, (d) tracking error (MSE)

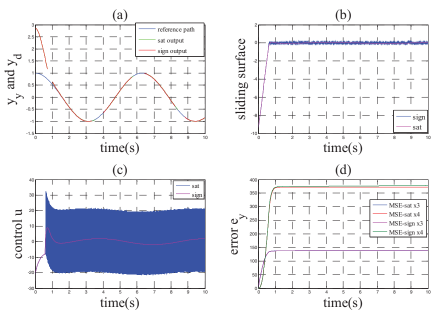

Fig. 6. Indirect adaptive fuzzy time-varying sliding mode on Y-axis: (a) system output y_y and desired intput y_d, (b) sliding surface, (c) control force, (d) tracking error (MSE)

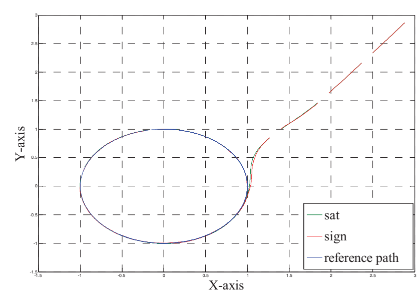

Fig. 7. Circular trajectory with indirect adaptive fuzzy time-varying sliding mode on biaxial

B. Direct

In Fig. 8 and Fig. 9 show the results of direct adaptive fuzzy time-varying sliding mode on X-axis and Y-axis, and the circular trajectory is shown in Fig. 10.

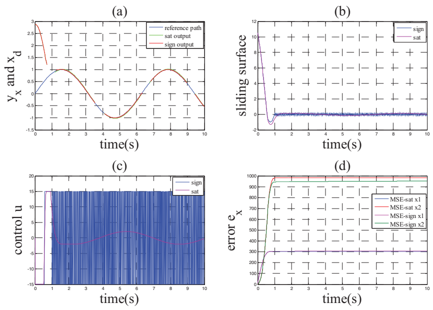

Fig. 8. Direct adaptive fuzzy time-varying sliding mode on X-axis: (a) system output y_x and desired intput x_d, (b) sliding surface, (c) control force, (d) tracking error (MSE)

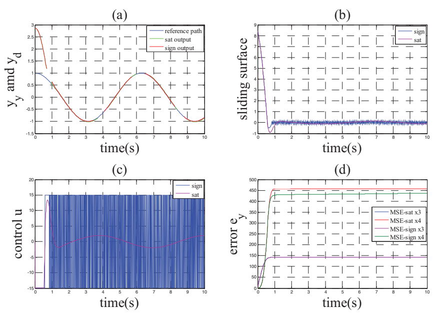

Fig. 9. Direct adaptive fuzzy time-varying sliding mode on Y-axis: (a) system output y_y and desired intput y_d, (b) sliding surface, (c) control force, (d) tracking error (MSE)

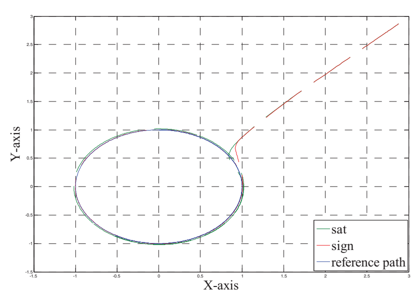

Fig. 10. Circular trajectory with direct adaptive fuzzy time-varying sliding mode on biaxial

VI. Conclusions

In this paper, the tracking problem for a class of the gantry stage system and internal uncertainties is investigated during two axis. Based on a cross-coupled control architecture incorporating adaptive fuzzy moving sliding mode control design method for improving the tracking performance and enhancing the contouring accuracy of gantry stage, simultaneously. The proposed adaptive fuzzy moving sliding mode control algorithm does not require accurate dynamic model for each feed drive system into the controller design, and therefore, is easy to implement in practice. Compared with the conventional control schemes, the experimental results show that the proposed control approach is effective to maintain the synchronization motion for different reference signals by eliminating contour error. Based on the Lyapunov stability theory, the proposed controller guarantees asymptotic stability of the closed-loop gantry position system. All the theoretical results are verified by numerical simulations to demonstrate the effectiveness of the proposed synchronization schemes.

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