Research on Precision Tracking on Fast Steering Mirror and Control Strategy

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Abstract. Fast steering mirror is a device used for controlling the beam direction precisely. Due to the short travel of the push-pull FSM, a compound fast steering mirror system driven by both limited-angle voice coil motor and push-pull FSM together is proposed. In the compound FSM system, limited-angle voice coil motor quickly swings at wide angle, while the push-pull FSM do high frequency movement in a small range, which provides the system with the high bandwidth and long travel. In the control strategy, the method of combining feed-forward control in Kalman filtering with auto-disturbance rejection control is used to improve trajectory tracking accuracy. The simulation result shows that tracking accuracy measured by the compound method can be improved by more than 5 times than that of the conventional PID.

1. Introduction

Precision capture, tracking and targeting systems play a central role in large-size photoelectric measurement equipment, astronomical observation and laser communication. For example, high-accuracy stabilized sighting pod and IRSI have high requirement on stabilization precision of sighting line. Most of the current photoelectric stabilized sighting systems adopt the overall stability mode. Due to the effects of load and various disturbance torque, the overall stabilization precision is usually only 25 ~ 30urad. Therefore, the use of fast steering mirror and compound-axis structure is the effective means for stabilization with large load and high accuracy [1] ~ [6].

At present, drive modes of FSM based on voice coil motor mainly include push-pull, limited-angle, etc., among which push-pull voice coil motor has advantages of fast response rate, high bandwidth, low power consumption, high displacement accuracy, etc., but its travel is short. The bandwidth of limited-angle voice coil motor is lower than that of the piezoelectric ceramic, while its travel is relatively long. The existing FSM is basically driven by independent push-pull voice coil motor or limited-angle voice coil motor, but it does not have the advantages of long travel and high bandwidth at the same time[7].

This paper presents a compound fast steering mirror structure, as shown in Fig. 1, in which first-level steering mirror presents X-Y structure, and is driven by limited-angle voice coil motor, resulting in large range of angle and small shaft coupling. The secondary push-pull FSM has the advantages of high resolving power, fast response rate, etc. Compound fast steering mirror has the advantages of large travel and high bandwidth at the same time. Based on this structure, simulating evaluation and tracking performance on the method of combining ADRC of FSM with compound control with feed-forward compensation are conducted.

2. Principle of Servo Control

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The compound fast steering mirror is composed of quick-swing outer frame driven by voice coil motor and internal push-pull FSM unit. The outer frame has a large range of swing angle, which can realize quick angular positioning. The internal fast steering mirror unit based on piezoelectric ceramic can realize fast image stabilization and beam stabilization in a small angular range. Configuration of limited-angle voice coil motor is as shown in Fig. 2.

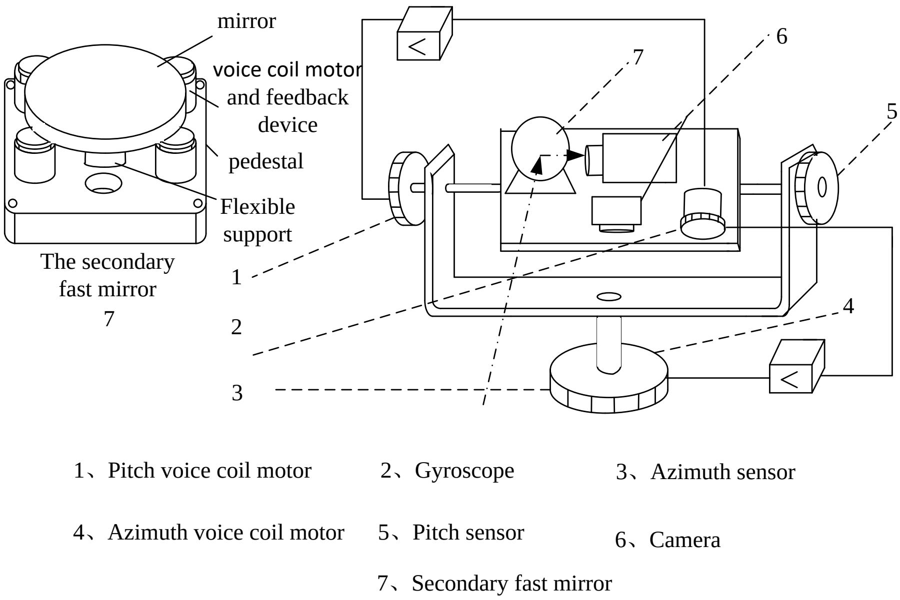

Figure 1. Structure schematic diagram of compound fast steering mirror.

Figure 2. Limited-angle voice coil motor.

The functional block diagram of compound fast steering mirror is as shown in Fig. 3, in which the main loop is a control loop based on limited-angle voice coil motor, G_0 and G_1 represent the position loop and velocity loop control modules respectively, G_g represents the gyroscope sensor, G_θ represents angular position sensor, G_2 represents secondary stabilization loop control module in push-pull FSM, G_p refers to angular sensor in push-pull FSM[8], and T_{D1} and T_{D2} refer to disturbing terms.

In Fig. 3, rough image stabilization and rough tracking are conducted by first-level platform driven by the limited-angle voice coil motor, secondary image stabilization and precision tracking are performed by fast steering mirror driven by the push-pull voice coil motor.

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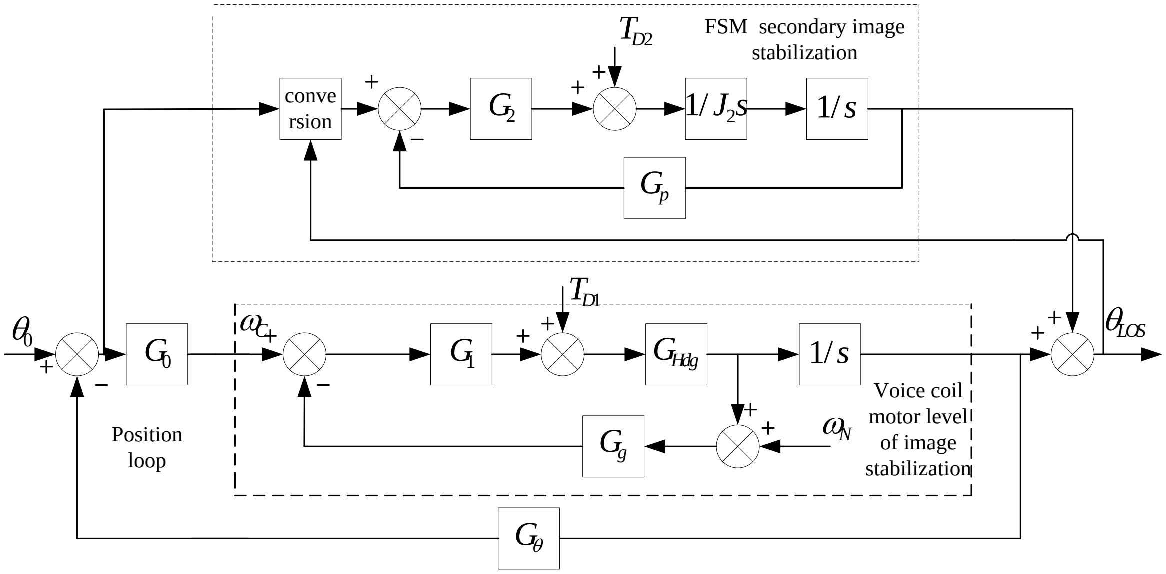


Figure 3. The functional block diagram of compound fast steering mirror.

3. Strategy on Combining ADRC with Feed-forward Control of Closed-Loop System in Compound Fast Steering Mirror

As shown in Fig. 4, the push-pull FSM module in compound fast steering mirror adopts the mode of combining ADRC with feed-forward control. Kalman filtering is used in feed-forward control to filter angular, and to estimate angular velocity and angular acceleration signals so as to form feed-forward compensation control.

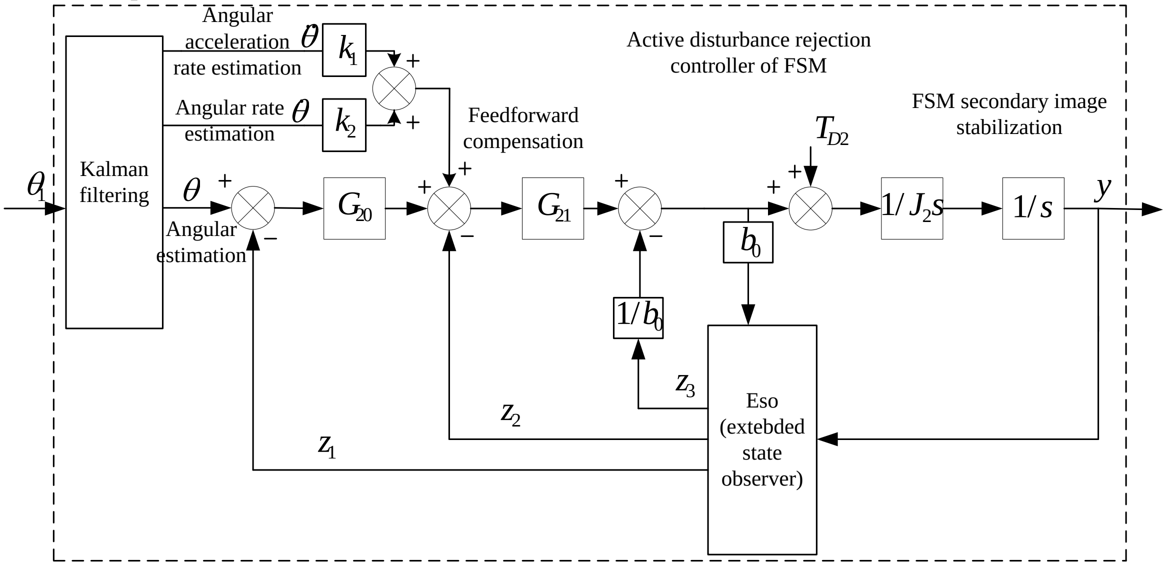


Figure 4. Design on combining ADRC of FSM in tracking mode with feed-forward control.

ADRC is used for observing the external disturbance and providing feed-back compensation, and feed-forward compensation is used for enhancing tracking accuracy of the high-speed galvanometer on fast signal. In ADRC based on piezoelectric ceramic model, as shown in Fig. 4, nonlinear extension state observer designed by Han Jingqing shows [9]:

$$\begin{cases} e = z_1 - y \\ \dot{z}_1 = z_2 - \beta_1 e \\ \dot{z}_2 = z_3 - \beta_2 fal(e, \alpha_1, \delta) + bu \\ \dot{z}_3 = -\beta_3 fal(e, \alpha_2, \delta) \end{cases} \quad (1.1)$$

Where, $\beta_i > 0 (i = 1,2,3)$， $\alpha_1 = 1$， $\alpha_2 = 0.5$。

The function of saturation function $fal(e,\alpha,\delta)$ is to suppress the chattering of signal. It can be expressed as follows:

$$fal(e,\alpha,\delta) = \begin{cases} \dfrac{e}{\delta^{1-\alpha}} & |e| \le \delta \\ |e|^{\alpha} \operatorname{sgn}(e) & |e| > \delta \end{cases} \tag{1. 2}$$

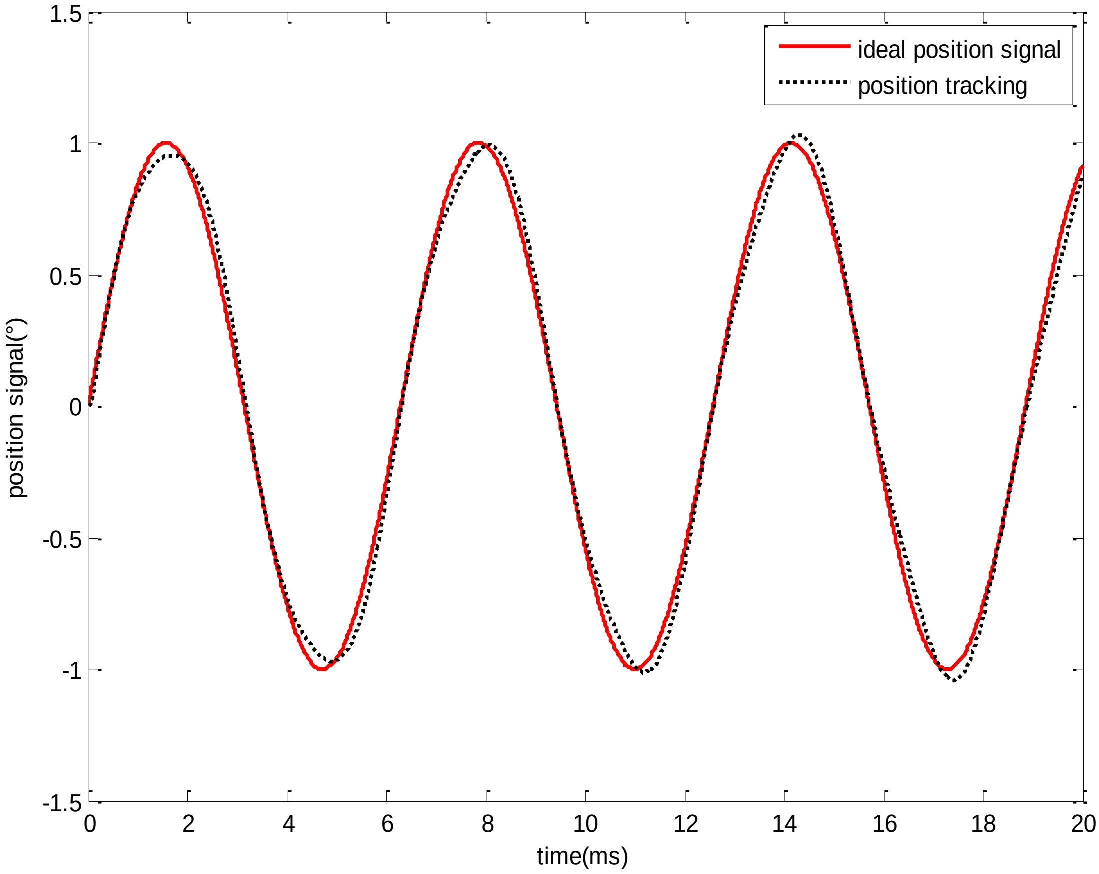
Simplifying the transfer function of FSM and converting it into a differential equation, we can get the solution:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -6849 x_2 + 6849 u + f(x_1, x_2) \\ y = x_1 \end{cases} \tag{1. 3}$$

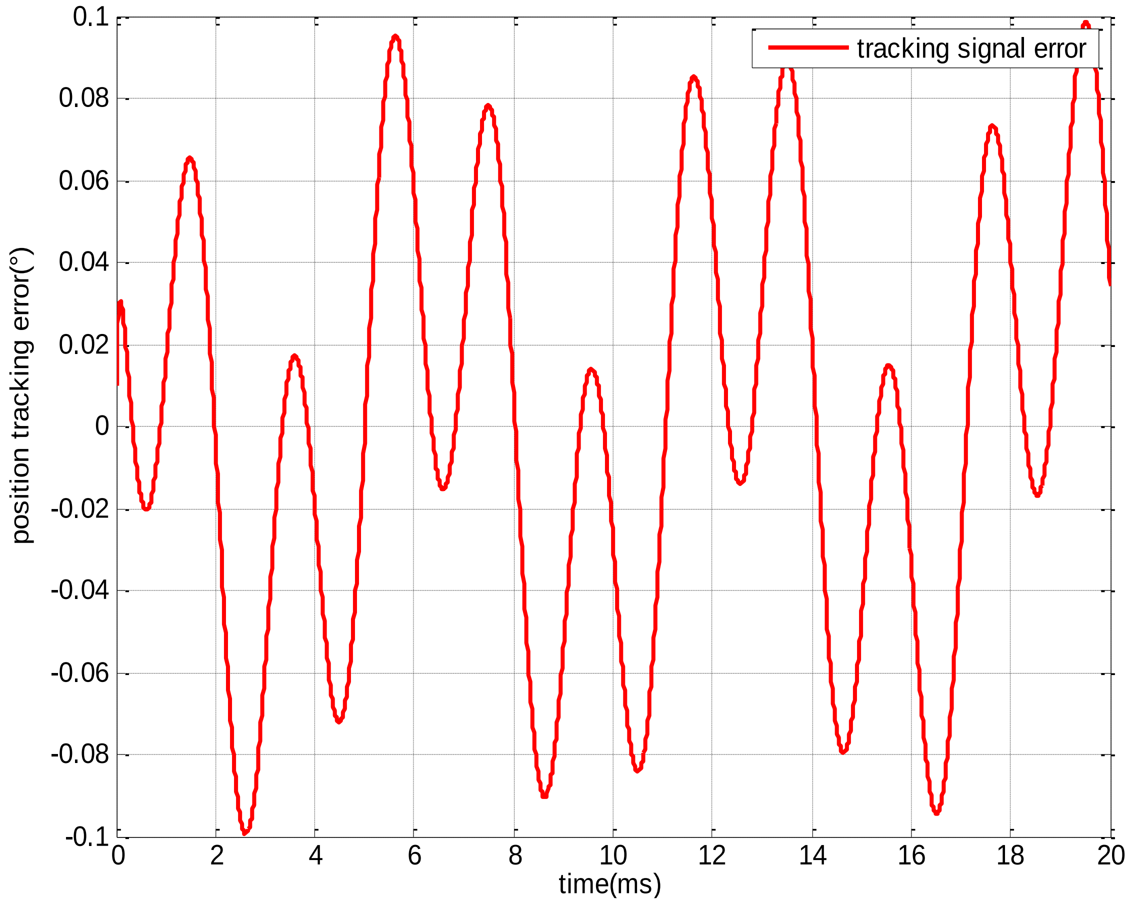
Where, $f(x_1, x_2)$ remains unknown.

When $f(x_1,x_2) = 33\sin(1000\pi t)$ and $b = 6849$, extension state observer is used for observing the unknown part to conduct simulation of control system.

Simulation efficiency and errors of trajectory tracking by the conventional PID control are as shown in Fig. 5. Trajectory tracking and error simulation efficiency from combining ADRC with feed-forward control are as shown in Fig. 6.

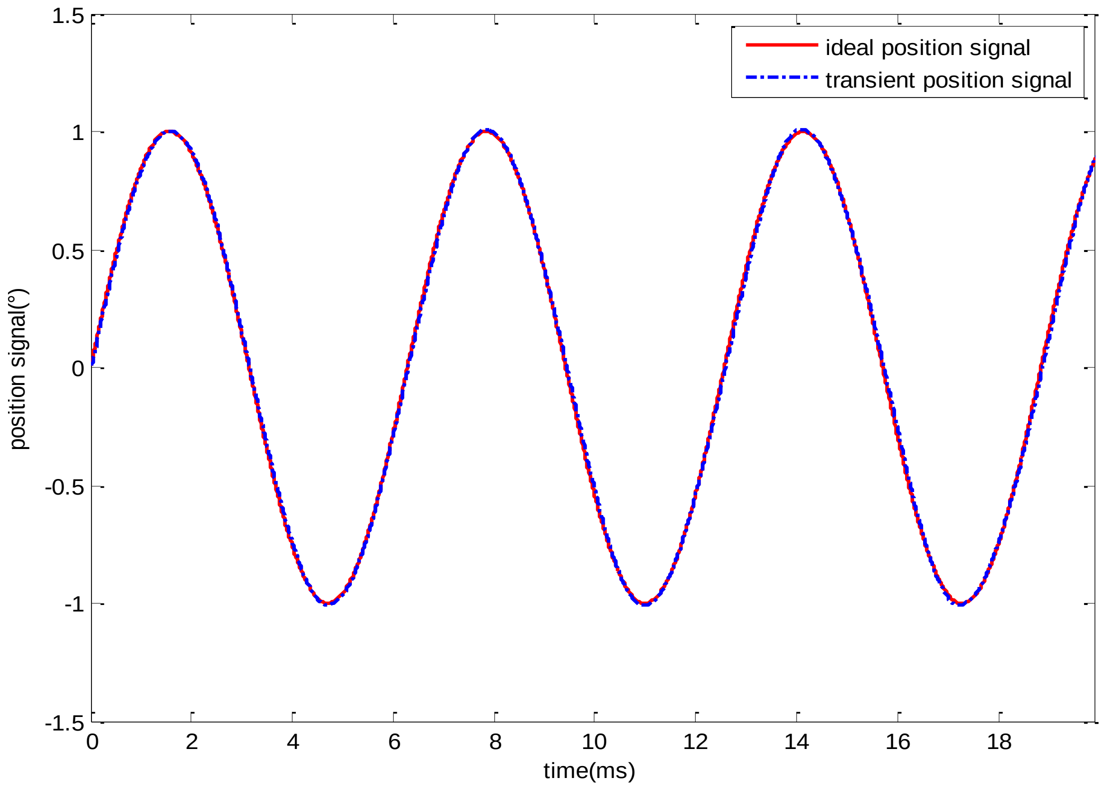


(a)



(b)

Figure 5. Continuous trajectory tracking and tracking error from conventional PID control.



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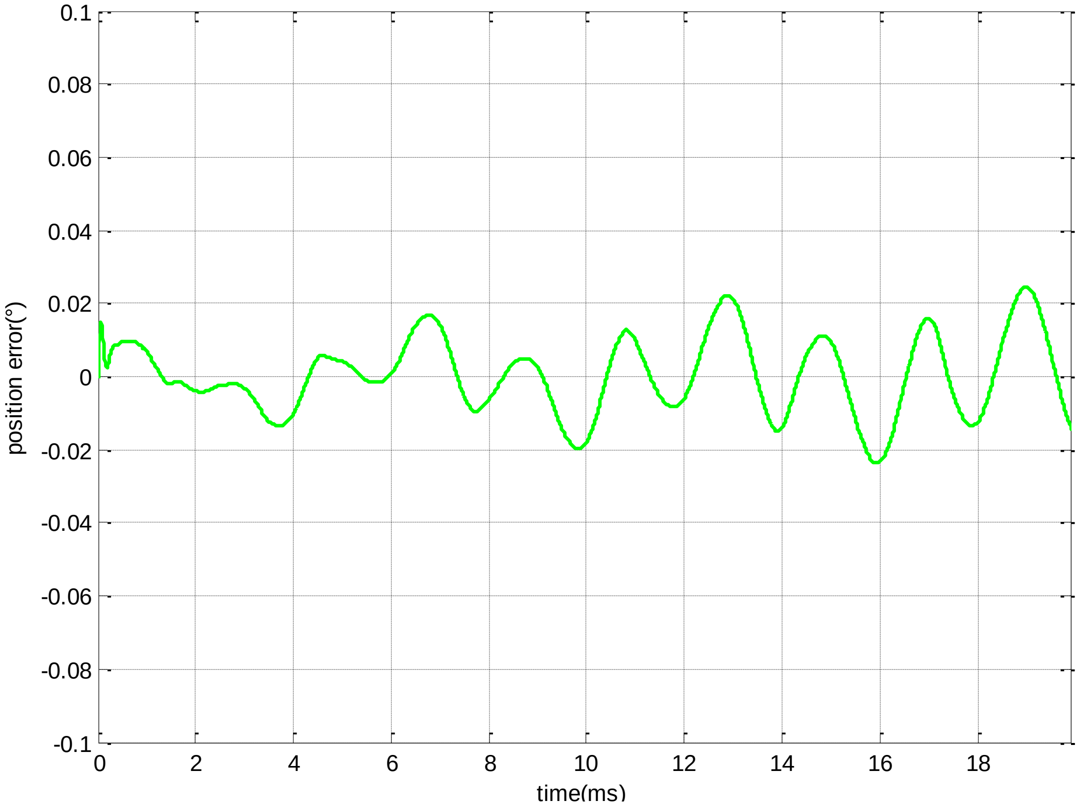
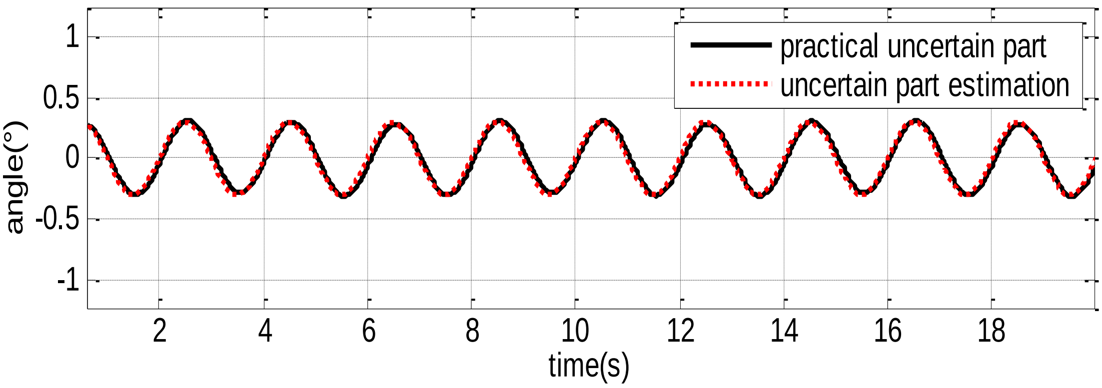


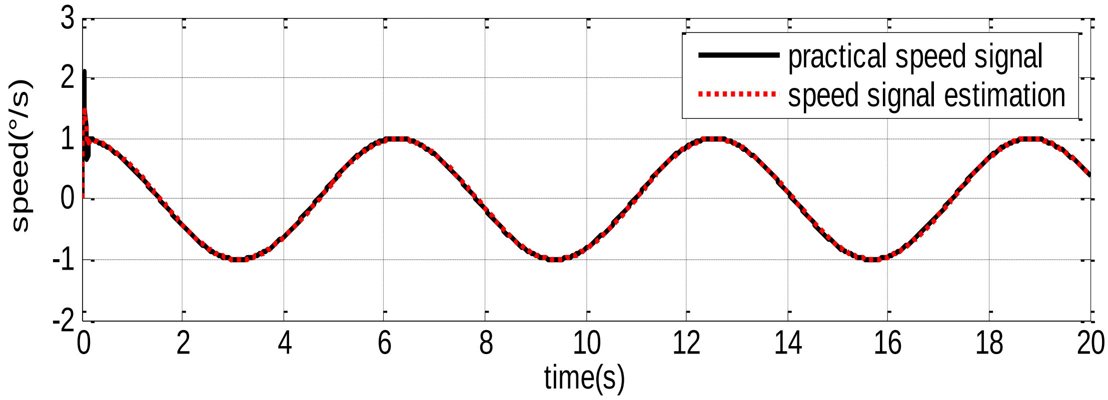
(b)

Figure 6. Trajectory tracking and tracking error of combining ADRC with feed-forward control.

Compared Fig. 5 with Fig. 6, we can see that the conventional PID control produces relatively large tracking error due to the presence of external disturbance signal and control delay. Combining ADRC with feed-forward control can estimate the external disturbance and provide compensation, on the other hand, its estimated velocity and acceleration can be used as feed-forward control to improve trajectory tracking accuracy. From the simulation results, we can see that in the case of the same external disturbance, the algorithm in this paper reduces the comprehensive control error of the system by a factor of 5, with strong capacity of resisting disturbance and good control performance. Integrated position, velocity and disturbance estimation of ADRC are as shown in Fig. 7, in which the expansion state observer can accurately estimate the feedback velocity signal and the disturbance signal, and correct velocity loop and provide disturbance compensation in the control loop.



(a)



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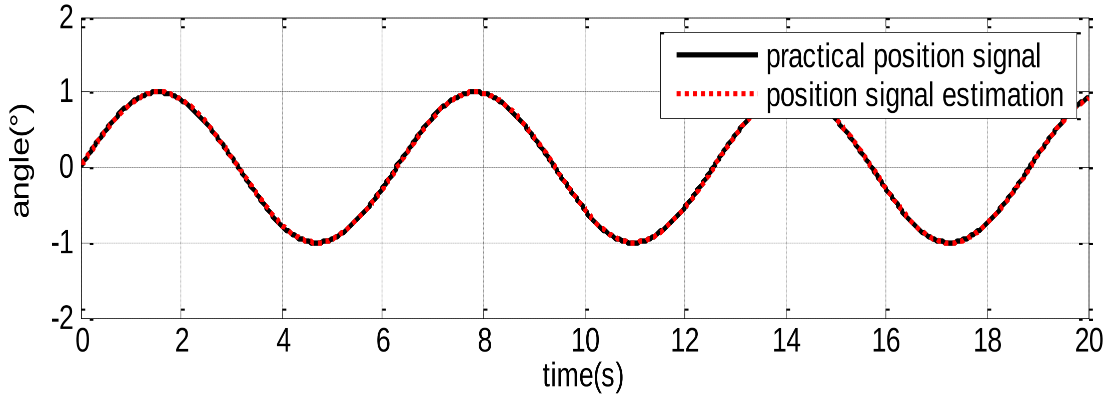

(c)

Figure 7. Observed results from expansion state observer.

4. Conclusion

In order to compensate for the shortcoming of short travel of piezoelectric ceramic galvanometer, limited-angle voice coil motor is introduced to drive the galvanometer frame of piezoelectric ceramic to swing quickly at large angle, which constitutes compound fast steering mirror with a large travel, high bandwidth and high accuracy. In the control strategy, the method of combining ADRC with feed-forward compound controller is introduced so that velocity loop control, feed-forward control and disturbance compensation control are added on the basis of positioning control in the conventional piezoelectric ceramic. From the simulation results, we can see that its trajectory tracking accuracy get greatly improved than that of the conventional PID control.

5. References and Citations

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