Improved Active Disturbance Rejection Control based on PSO for a Precise Rotating Servo System

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Abstract. The precise rotating servo system is a nonlinear system and demands on high tracking precision and stabilization, so it is difficult to achieve an ideal control result using PID control strategy. An active disturbance rejection control (ADRC) strategy is presented to guarantee the state variables of the closed loop system to converge to the reference input. After arranging the transient dynamics of the desired attitude, we design an extended state observer (ESO) to estimate the impact from parametric uncertainties and disturbances, and the corresponding compensations can be performed online. Then a nonlinear state error feedback law (NLSEF) is designed to reject the tracking error and nonsingular terminal sliding mode control (NTSM) is an effective error combination form to restrain the chattering effectively and keep the system within finite time. To simply the parameters tuning process of ADRC, particle swarm optimization (PSO) is introduced to optimize the parameters of the controller. Simulation results show that the improved ADRC controller has the advantages of high precision and high disturbance rejection ability, which can meet the requirements of measurement precision and stability of the theodolite.

Keywords: ADRC; ESO; NLSEF; NTSM; PSO.

1. Introduction

Electronic theodolite is widely used in the fields of geodetic surveying, weapon system, and engineering surveying. [1] It has been observed that, in the theodolite surveying systems, full automation has been a predominantly attempted domain due to its explicitly military implication and engineering background. [2,3] Theodolite precision rotating servo control is put forward taking shaft motor drive as the core to improve theodolite measure precision and automation degree by combining theodolite with servo drive technology, which is like other automatic orientation measurement system or automatic target acquisition system. [4,5] So, the rotation controller is a very important part of automatic theodolite which has an important effect on its tactical and technical performance. However, the control of a precise rotating servo system is a formidable problem, because accuracy, stability and speed of response are essential to mission accomplishment. Furthermore, the rotating control system should not only have high tracking precision and good dynamic quality, but also have strong robustness to overcome the parameters perturbation and outside disturbance. It is easy to describe the basic principle of theodolite rotating stability, but it is very difficult to realize as there are parameters perturbation, outside disturbance and many nonlinear factors in the regulator system. In order to overcome these problems, a valid control strategy must be established to guarantee the rotating precision and system stability.

The majority of control systems are operated by PID controllers, well before classical and modern control theory were born. At present, PID controller and its improved forms are used to drive the shaft of electronic theodolite. Combining the advantages of traditional PID control with that of fuzzy control, the rotating controller of north seeker theodolite based on adaptive Fuzzy-PID is designed shown in Ref. [6]. Kunming Wang, et al proposed PIDNN control for theodolite rotating servo system. [7] With the neural network (NN) strong approximation, the adverse control effect of model parameters perturbation is effectively compensated. Meanwhile, many kinds of modern control theories, to a great extent, are not realistic as they demand an accurate mathematical model which is not possible to be obtained in some specific conditions. [8]

The application of ADRC and its actual implementation to electronic theodolite rotating control is, we believe, novel. ADRC is a new nonlinear algorithm used in servo system in recent years. It
maintains the advantages of PID, and is introduced into the motion control system by Ref. [17]. There are four fundamental technical limitations in the existing PID framework, and ADRC is very good to deal with these problems, including the following: (1) a simple differential equation to be used as a transient profile generator; (2) a noise-tolerant tracking differentiator; (3) the power of nonlinear control feedback; and (4) the total disturbance estimation and rejection. [18] The purpose of this paper is to show ADRC control has advantages of high precision and high disturbance rejection ability for rotating system by a reasonable mathematical model and some simulation results.

Based on the parameters tuning analysis of ADRC, we know many parameters are needed to be tuned for ADRC, so the parameters influence mutually and the parameters tuning is relatively difficult. In this paper, PSO algorithm is introduced to optimize the parameters of the controller. Meanwhile, NLSEF law adopts NTSM control method with the reaching law to improve the control performance of system. [19]

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2. Problem Statement

A rotating servo system for automatic electronic theodolite has been designed and built, which can achieve automatic searching and collimation of surveying object, and accomplish automatic measuring with direct and inverted position of telescope, as shown in Figure 1. It consists of the telescope and sighting, the horizontal shaft and vertical shaft, DC motor and transmission device.

![Fig.1. The rotating system of electronic theodolite.](image)

![Fig.2. The configuration of the ADRC for theodolite rotating servo system.](image)

A DC torque motor is used for the vertical shaft driving device of theodolite rotating servo system. Considering the disturbances, the motor model can be composed by mechanical equation and electrical equation as follows,

\[ J\ddot{\theta} = T_e - k_v\omega_v - T_i \]

\[ u = r_a i + L_a \frac{di}{dt} + k_v\omega_v \]

\[ T_e = k_r i \]

where ra, La, i represent the armature resistance, inductance and current respectively; kT is the motor torque coefficient, kv is the viscous friction coefficient, and ke is the counter voltage factor; J denotes the total moment of inertia of motor Jm and load Jl; TI is the comprehensive disturbance
including motor friction torque, motor torque fluctuation, system parameter uncertainty and other disturbance; Te is the motor output torque; u is the controller output, which is also regarded as the input control voltage of motor; θ is the actual angular position of motor; ωs is the actual angular velocity of motor.

With the small La, the theodolite rotating servo system can be simplified and expressed in the state space form based on the transfer function, as follows,

\[
\begin{align*}
\dot{\theta} &= \omega_s \\
\dot{\omega}_s &= a\omega_s + bu(t) - T_f(t) / J - T_w(t) / J + d(t)
\end{align*}
\]

where \( a = -(k/raJ + k_v/J) \), \( b = kT / (raJ) \). \( d(t) \) denotes the external kinematic disturbance; \( T_f(t) \) denotes the friction torque and \( T_w(t) \) is the motor torque fluctuation, which can be described as follows,

\[
T_f = \left[ f_c + (f_s - f_c) \exp\left(-\frac{\omega_0}{\omega_0^c}\right) \right] \text{sgn}(\omega_s)
\]

where \( \omega_0 \) is the Stribeck velocity; \( f_c \) and \( f_s \) represent the levels of Coulomb friction and stiction, respectively.

\[
T_w = A_{ripple} \sin(2\pi ft + \phi),
\]

where \( f = Nos/360 \), \( A_{ripple} \) is the amplitude value of torque fluctuation. \( N \) is the tooth-slot number, and \( \phi \) is the phase angle which is relative with initial position of motor.

The angular position and angular velocity are two important variables of the system. Defining the angular position and angular velocity as the system state variables, i.e., \( [x_1,x_2]^T = [\theta, \omega_s]^T \), so the mathematic model of theodolite rotating control system can be expressed as the following second-order system,

\[
\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= f(x_1, x_2, d(t), t) + bu(t) \\
y &= x_1
\end{align*}
\]

where \( x_1 = y = 0 \) is the output variable, \( x_2 \) is magnification factor and \( d(t) \) is the external disturbance. \( f(x_1,x_2,d(t),t) \) is the total external and internal disturbances function. Define the error \( er = yr - y \), where \( yr \) is reference angular position input.

3. Active Disturbance Rejection Control

Theodolite rotating controller can be designed by classical control theory, such as PID, so the controller design depends heavily on the models. As the plant’s parameters vary largely, it is difficult to keep the original good dynamic and static performances.

In this paper, ADRC is employed to control the precise rotating servo system by dealing with modeling errors and structural uncertainties. The structure of control system based on ADRC with 2th order is shown in Fig. 2, in which three components: (1) Tracking Differentiator (TD), (2) Extended State Observer (ESO), and (3) Nonlinear State Error Feedback (NLSEF) are included. A transitional process and differential signal can be obtained with TD; estimations of the states of plant and disturbances from inside and outside can be obtained with ESO; state errors are combined in nonlinear form with NLSEF.

3.1 TD

In the transition design, both the transition signal \( v_1 \) and its derivative \( v_2 \) are simultaneously presented. The differential signal is usually obtained by the backward difference of the given signal, but it will get unstable and inaccurate results in the presence of noise. However, TD has the ability to
resolve the problem of differential signal extraction via integration to avoid unnecessary noise and make the system performance more effective and robust in some situations.\textsuperscript{[20]} One feasible second-order TD can be designed as follows,

\[
\begin{align*}
\dot{v}_1 &= v_2 \\
\dot{v}_2 &= f\text{han}(v_1 - v(t), v_2, r, h_0)
\end{align*}
\]  

where \( v(t) \) denotes the control objective, \( v_1 \) is the desired trajectory and \( v_2 \) is its derivative. \( r \) and \( h_0 \) are the controller’s parameters. \( r \) is the speed factor and it will decide tracking speed. \( h_0 \) is the filtering factor, which makes an effort of filter. These parameters can be adjusted individually according to the desired speed and smoothness. \( f\text{han}(v_1-v(t),v_2,r,h_0) \) is defined as follows.(9)

TD with nonlinear feedback combination can provides transition process for expected input \( v \), that is, \( v_1 \) and its differential \( v_2 \). Meanwhile, TD has the ability to track the given input reference signal with quick response and no overshoot.

\[
\begin{align*}
d &= rh_0^2, \quad a_0 = h_0 v_2, \quad y = (v_1 - v(t)) + a_0 \\
a_1 &= \sqrt{d(d + 8y)} \\
a_2 &= a_0 + \text{sign}(y)(a_1 - d) / 2 \\
s_y &= (\text{sign}(y + d) - \text{sign}(y - d)) / 2 \\
a &= (a_0 + y - a_1)s_y + a_2 \\
s_a &= (\text{sign}(a + d) - \text{sign}(a - d)) / 2 \\
f\text{han} &= -r(a - \text{sign}(a))s_a - rs\text{sign}(a)
\end{align*}
\]  

3.2 ESO

For the nonlinear system

\[
\begin{align*}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= f(x_1, x_2, t) + bu(t) \\
y &= x_1
\end{align*}
\]  

in order to track the system states \( x_1(t), x_2(t) \) well, the following nonlinear states observer can be designed, [21]

\[
\begin{align*}
\dot{e}_0 &= z_{01} - y \\
\dot{z}_{01} &= z_{02} - \beta_{01}e_0 \\
\dot{z}_{02} &= -\beta_{02}f\text{al}(e_0, \alpha, \delta) + b_0u
\end{align*}
\]  

where \( z_{01}, z_{02} \) are the states observer outputs and \( \beta_{01}, \beta_{02} \) are the observer gains. \( f\text{al}(x, \alpha, \delta) \) is a nonlinear function described by

\[
f\text{al}(x, \alpha, \delta) = \begin{cases} 
\frac{x}{\delta^{1 - \alpha}}, & |x| \leq \delta \\
\text{sign}(x)|x|^\alpha, & |x| > \delta
\end{cases}
\]

The acceleration \( f(x_1(t), x_2(t)) \) is extended to the new variable \( x_3 \), named,

\[
x_3(t) = f(x_1(t), x_2(t))
\]  

Furthermore, we define \( \dot{x}_3(t) = a(t) \). The new extended system from the system (10) can be now rewritten as follows,
Now, for the above extended system, we construct a state observer in the form as follows,

\[
\begin{align*}
\dot{e} &= z_1 - y \\
\dot{z}_1 &= z_2 - \beta_1 e \\
\dot{z}_2 &= z_3 - \beta_2 f(e, \alpha_1, \delta) + b_0 u \\
\dot{z}_3 &= -\beta_3 f(e, \alpha_2, \delta)
\end{align*}
\]  

(15)

where \(z_1, z_2,\) and \(z_3\) are the observer outputs and \(\beta_1, \beta_2, \beta_3\) are the observer gains. By selecting rationally \(\beta_1, \beta_2, \beta_3\), which is a particular problem, this system can estimate the states variables \(x_1\) and \(x_2\) of the system (10) and the real-time action of the extended state \(x_3(t) = f(x_1(t), x_2(t))\), that is, \(z_1\) is used to estimate \(x_1\), \(z_2\) is used to estimate \(x_2\), and \(z_3\) is the extended state variable to estimate the nonlinear part \(f(x_1(t), x_2(t))\).

\[x_3(t) = f(x_1(t), x_2(t), t, d(t))\]  

(16)

If the function \(f(x_1, x_2)\) include the time variable \(t\) and the unbeknown disturbance \(d(t)\), similarly, supposing that, the observer can also obtain the estimates \(z_1(t), z_2(t)\) of the system state variables \(x_1(t), x_2(t)\), and the estimate \(z_3\) of the extended state variable \(a(t) = f(x_1(t), x_2(t), d(t), t)\). The state observer of the extended system (15) is called the extended state observer (ESO), and the variable \(x_3(t)\) is called the extended state.

The structure diagram of ESO is given in Fig. 3,

![Fig. 3. The structure diagram of ESO.](image)

3.3 Nonlinear Feedback Combination

Based on the system state errors from ESO and TD, feedback control law \(u\) can be gotten. A nonlinear combination of error signal and its differential can be constructed as follows,

\[u_0 = k_p f(e_1, \alpha_1, \delta) + k_d f(e_2, \alpha_2, \delta)\]  

(17)

where \(k_p\) and \(k_d\) are two coefficients of \(u_0\), respectively. \(e_1 = x_1 - z_1\), and \(e_2 = x_2 - z_2\).

Generally, the nonlinear coefficient \(\alpha_1\) and \(\alpha_2\) are selected as \(0 < \alpha_1 < 1 < \alpha_2\).

At last, the control law can be represented as follows,

\[u = u_0 - \frac{z_1}{b_0}\]  

(18)

where \(b_0\) is the control compensation coefficient, it requires \(b_0 < b\), but the different value is small.
4. Simulation Analysis

Aimed at the theodolite rotating system, in this section some simulation researches are accomplished to illustrate the feasibility and effectiveness of ADRC and to find some rules of ADRC. The values of the system main parameters are listed in Tab. 1.

<table>
<thead>
<tr>
<th>System Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated motor voltage /V</td>
<td>$U_0$ 9</td>
</tr>
<tr>
<td>Motor armature resistance /Ω</td>
<td>$r_a$ 2.76</td>
</tr>
<tr>
<td>Motor torque coefficient /Nm/A</td>
<td>$k_T$ 1.2</td>
</tr>
<tr>
<td>Viscous friction coefficient</td>
<td>$k_v$ 0.2</td>
</tr>
<tr>
<td>Counter voltage factor</td>
<td>$k_e$ 0.7</td>
</tr>
<tr>
<td>System moment of inertia /Kgm²</td>
<td>$J$ 0.2</td>
</tr>
<tr>
<td>Coulomb friction/Nm</td>
<td>$f_c$ 2.0</td>
</tr>
<tr>
<td>Coulomb stiction/Nm</td>
<td>$f_s$ 2.6</td>
</tr>
<tr>
<td>Striebeck velocity</td>
<td>$\omega_0$ 0.06</td>
</tr>
<tr>
<td>Number of pole pairs</td>
<td>$P$ 4</td>
</tr>
<tr>
<td>Motor EMF coefficient /V/(rad/s)</td>
<td>$k_e$ 0.7</td>
</tr>
<tr>
<td>Torque fluctuation amplitude/Nm</td>
<td>$A_{ripple}$ 0.154</td>
</tr>
<tr>
<td>Tooth-slot number</td>
<td>$N$ 79</td>
</tr>
<tr>
<td>Phase angle /°</td>
<td>$\varphi$ 0</td>
</tr>
<tr>
<td>Sampling time/sec</td>
<td>$T$ 0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADRC Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonlinear coefficient of $f_a l$</td>
<td>$\alpha_1$ 0.75</td>
</tr>
<tr>
<td>Nonlinear coefficient of $f_a l$</td>
<td>$\alpha_2$ 1.25</td>
</tr>
<tr>
<td>Control compensation coefficient</td>
<td>$b_0$ 1.7</td>
</tr>
<tr>
<td>Linear area of $f_a l$</td>
<td>$\delta$ 0.2</td>
</tr>
</tbody>
</table>

(a) $\omega_0=5$

(b) $\omega_0=10$
Fig. 4. The system responses of theodolite angular position tracking with different $\omega_0$.

(a) Angular position.  
(b) Angular position tracking error.  
(c) Driving voltage.  
(d) Angular velocity.  

Fig. 5. The system responses of theodolite angular position tracking with different $\omega_c$. 

ADRC Parameters Tuning

ADRC parameters are closely related to the control performance of the whole system. The main ADRC parameters to be tuned are as follows,

1) ESO: $\beta_1, \beta_2, \beta_3$;
2) NLSEF: $k_p, k_d$;
3) TD: $r$

$L = [\beta_1, \beta_2, \beta_3]^T$ is the observer gain vector. Using the bandwidth-parameterization method given by Ref. [22], all of the observer eigenvalues are $-\omega_0$, whose absolute value is the observer bandwidth, we obtain

$$L = [3\omega_0, 3\omega_0^2, \omega_0^3]$$

A properly tuned $\omega_0$ must be larger than the state frequency to estimate effectively the state and disturbance. By adopting a designed ESO, outputs $y$ and $\dot{y}$ and disturbance $f$ can be estimated precisely. Parameters $r$, $k_p$, and $k_d$ are fixed for 16, 25, 10 and $\omega_0$ is set as 5, 10 and 20. The system responses of theodolite angular position tracking with different $\omega_0$ are shown in Fig. 4. In this part, being different from the rigid step input signal, motion trajectory planning with maximum speed of $0.3^\circ/s$ is used to obtain a smooth climbing curve of angular position to improve tracking performance under ADRC law.

From the Fig. 4, we can know that the bigger $\omega_0$ improves the system tracking speed. When $\omega_0$ is 20, the time of system convergence is about 28s, but $\omega_0$ for 5 or 10 cannot realize it. Meanwhile, we can find the big $\omega_0$ amplifies the noise to make driving voltage chattering. So the parameter $\omega_0$ is chosen through considering both the system convergence time and the controller chattering.

As proportional and differential coefficients of NLSEF, $k_p$ and $k_d$ are selected as $k_p=2\omega_c$ and $k_d=\omega_c^2$ based on the bandwidth-parameterization method, where $\omega_c$ is the controller bandwidth. While $r$ and $\omega_0$ are fixed for 16 and 15, $\omega_c$ is set as 1,2,5,10, and 20, respectively. The system responses of the theodolite angular position tracking with different $\omega_c$ are shown in Fig. 5.

From Fig. 5, a large $\omega_c$ has a good position tracking performance. The better response speed can be gotten with a larger $\omega_c$. For instance, the convergence time is about 12.5s, when $\omega_c$ is for 20. Comparatively, the convergence time for the others is increased greatly. Besides, a large $\omega_c$ can decrease the system overshoot and angular velocity undulation. When $\omega_c$ is 1, the system overshoot
as maximum value can reach 33%. Angular velocity undulation is also important character for theodolite rotating servo system. However, a large $\omega_c$ can breach the stability of the control signal. When $\omega_c$ is 20, the maximum value of driving voltage is about 18.2V, which is difficult to bear for the rated motor voltage 9V. According to the experience, the observer bandwidth $\omega_0$ should be larger than the controller bandwidth $\omega_c$ so that the observer can follow the controller rationally considering different impacts: system response speed, position tracking overshoot, angular velocity undulation, and control voltage.

$r$ is the parameter of TD, which influences the convergence speed of system response directly. To explain the impact principle of $r$, contrast experiments are carried out. While $\omega_c$ and $\omega_0$ are fixed for 20 and 15, $r$ is set as 0.2, 1, 5, 10 and 20, respectively. The system responses of theodolite angular position tracking with different $r$ are shown in Fig. 6.

Some main performance parameters comparison of different $r$ experimental results is listed in the Tab.2. Thought reading it, we can know the performance change with different $r$ clearly.

<table>
<thead>
<tr>
<th>$r$</th>
<th>Max. velocity (°/s)</th>
<th>Convergence time (s)</th>
<th>Max. position tracking error (°)</th>
<th>Max. control value (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.548</td>
<td>16.5</td>
<td>1.18</td>
<td>7.37</td>
</tr>
<tr>
<td>1</td>
<td>1.091</td>
<td>14</td>
<td>0.66</td>
<td>8.85</td>
</tr>
<tr>
<td>5</td>
<td>1.802</td>
<td>5</td>
<td>0.446</td>
<td>12.16</td>
</tr>
<tr>
<td>10</td>
<td>2.342</td>
<td>5</td>
<td>0.423</td>
<td>15.32</td>
</tr>
<tr>
<td>20</td>
<td>3.133</td>
<td>5</td>
<td>0.405</td>
<td>19.705</td>
</tr>
</tbody>
</table>

Generally speaking, parameters tuning of ADRC is very important to obtain a good control performance of system, and it is also a litter difficult. In the process of experimental simulation, we can find some rules to choose the parameters of ADRC. Parameters tuning procedure of ADRC can be given in the Fig. 7.

![Fig. 7. The parameters tuning procedure of ADRC.](image)

To be brief, $\omega_c$, $\omega_0$, and $r$ are choosen respectively. Then, fine adjustment for some parameters to improve the whole control performance of the system.

5. Design of NTSM-ADRC based on PSO

In order to improve the control performances of the rotating servo system furthermore, NLSEF of ADRC adopts NTSM control method to enhance the system robustness and to shorten the convergence time of the system states. For system (7), the conventional NTSM is described by the following terminal sliding mode surface function, [23]

$$s = x_t + \frac{1}{\beta} x_t^{p/q} \tag{20}$$
where $\beta > 0$, and $p$ and $q$ are the positive odd integers satisfying $q < p < 2q$.

Based on the sliding mode surface function (20), an improved NTSM controller based the reaching law is designed as follows, [24]

$$u_0 = -h^{-1}[f(x) + \beta \frac{q}{p} x_2^{2-pq} + ks + (l_k + \eta) \text{sgn}(\delta)]$$  \hspace{1cm} (21)

where $\eta > 0$, is a constant. $d(x,t)$ is the uncertainty and disturbance satisfying $|d(x,t)| < l_g$, and $l_g > 0$.

The controller can ensure the NTSM occurs. Analyzing the NTSM surface function (20), we can know that both the system states $x_1$ and $x_2$ converge to the target signals in the finite time.

Here, we choose the integral time absolute error (ITAE) performance index as the minimal target function of parameters optimization. The particle position, the particle velocity and the target function can be expressed as follows,

$$v_{i+1} = \omega v_i + c_1 r_1 (P_i - l_i) + c_2 r_2 (G_i - l_i)$$  \hspace{1cm} (22)

$$l_{i+1} = l_i + v_{i+1}$$  \hspace{1cm} (23)

$$W = k \int_0^\infty t |e(t)| dt$$  \hspace{1cm} (24)

where $l$ and $v$ represent the particle position and the particle velocity; $\omega$ is the inertia factor; $c_1$ and $c_2$ are the acceleration constants; $r_1$ and $r_2$ are the random numbers from [0,1]; $P_i$ is the optimization position of the single particle before now; $G_i$ is the optimization position of the whole particle swarm before now; $W$ is the fitness value, that is ITAE value; is the gain coefficient; $e(t)$ is the system error.

The optimization process of NTSM-ADRC method by PSO can be seen in Fig. 8.

To explain the superiority of NTSM-ADRC with PSO, we carry out the system tracking experiment comparing with the convention ADRC method. The tracking target is set for $y_r = 0.4^\circ$. The same parameters of TD and ESO are the same as those of the above rigid step input signal: $T=0.001$, $r=16$, $h_0=0.001$, $\delta=0.2$, $\alpha_1=0.75$ and $\alpha_2=1.25$; The ESO parameters of the convention ADRC method are given as follows: $\beta_1=40, \beta_2=1000, \beta_3=8000$; The NELSF parameters of the convention ADRC method are set as follows: $k_p=25, k_d=10, b_0=1.7$. The NTSM parameters of the proposed ADRC method are set as follows: iteration number $G=250$, swarm size $m=30$, dimension number $D=3$, inertia factor $\omega=0.6$ and acceleration constants $c_1=c_2=1.5$. After 250 steps iteration, the curves of the fitness $W$ can be displayed in Fig. 9; The angular tracking performance comparisons under proposed ADRC method and convention ADRC method are shown in Fig. 10a.
From Fig. 9, the performance index ITAE reduces unceasingly in the process of the controller optimization to find the better parameters. The parameters after tuning based on PSO are gotten as follows: $\beta_1=31.2358$, $\beta_2=141.5187$, $\beta_3=6579.2368$.

As shown by Fig. 10b, the proposed NTSM-ADRC obtains satisfying dynamic and static performance in the presence of both load variation and strongly nonlinear friction torque. In the beginning stage of the state tracking, the response curves are similar. Although the overshoot value using the proposed method is larger than that using the convention ADRC, it reduces rapidly to achieve the system states convergence about 0.5s. The total convergence time is about 0.92s, which is much less than the convergence time of the convention ADRC. Enlarging the simulation time for 50s of the convention ADRC method, the overshoot time is about 1.72s and the states convergence time is about 26s. From simulation results, we can also know that the steady error with the designed control method is reduced to $1.2 \times 10^{-4}$ from $5.7 \times 10^{-3}$ with the convention ADRC method due to NTSM and PSO.

6. Conclusions and Further Remarks

This paper has presented a practical application of ADRC for precision rotating servo system of electronic theodolite with the internal nonlinear dynamics and external disturbance. To account for system dynamics variations, the ADRC is thus employed to estimate and compensate for them. Considering the different reference input signals and the different perturbation conditions of the system parameters, the tracking performance of the system is analyzed. PSO and NTSM control are introduced into ADRC to optimize the controller parameters and to improve the performances of the theodolite rotating system. Simulation results have demonstrated the effectiveness of ADRC.

References


