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ROBUST CONTROLLER FOR DC SERVO MOTOR

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Abstract

This paper highlights a robust contrller for DC servo motor. The controllers is proposed to control the DC motor actuator as a power source, the robust controller is designed using an active disturbance rejection controller (ADRC) based on extended state observer (ESO). This controller can accurately estimate the disturbance of the DC motor actuator is achieved. So controller make the DC motor actuator movement for tracking a reference one in the presence of the modeling uncertainty and the external disturbances during its process. The simulation and experimental results show that the proposed controller ensures good robustness and adaptability under modeling uncertainty and external disturbance.

Nomenclature:

$\dot{x}$: Linear velocities of sliders [m/s]
$\omega, \dot{\theta}$: Angular velocities of slider's motors [rad/s]
ν_r : Reference movement of linear velocity of slider [0.007 m/s].
θ General rotational angle of DC motor's rotor [rad].
$f()$: Modeling uncertainty and unknown disturbance of the actuator.

1. Introduction

Nowadays, the robotic systems become widely used in many applications which are harmful and dangerous for the human being. Furthermore, a robotic welding is very practical and useful in the industrial applications in the views of

Key words: active disturbance rejection controller (ADRC), extended state observer (ESO), DC motor actuator

increasing the quality, productivity and the labour-saving. To control the movement of motor actuator as a power source is the most importance in the robotic system [4]. The DC motor actuator is combinated by DC motor and slider system. The accurate of the mathematical model of DC motor actuator which requires accurate DC motor and slider parameters cannot be completely achieved due to significant plant uncertainties. These uncertainties include external disturbances, unpredictable parameter variations, and unmodeled plant nonlinear dynamics. Consequently, this will deteriorate the dynamic tracking performance of speed and position performance significantly [3].

This paper introduces a new configuration called auto-disturbance rejection controller (ADRC) for control of DC motor actuator. The auto-disturbance rejection controller, which is inherently suitable for dealing with the system uncertainties, generates very good static and dynamic performance, even in the presence of a large and fast variation of motor parameters and load disturbances. The core of ADRC is the extended state observer (ESO), which is based on the concept of generalized derivatives and generalized functions. Using the extended state observer, the ADRC can realize accurate disturbance of the system. In addition, the impact of external disturbances and parameter variations could also be estimated and compensated by the ADRC. Therefore, the accurate knowledge of the DC motor combine with slider model is not required. As a result, the design of ADRC is inherently independent of the controlled system model and its parameters. Therefore, this controller has the advantage of good adaptability and robustness. This paper presents a detailed comparison of the ADRC controller under different operating conditions based on simulation and experimental results. It is shown that the proposed controller can provide excellent speed dynamic performance under large variations of system parameters and load conditions.

2. Control Strategy

2.1 Modeling of DC motor actuator using DC motor combine with slider.

To design a robust servo controller for DC motor actuator using auto-disturbance rejection controller as shown in Fig.1. The auto-disturbance rejection controller, which is inherently suitable for dealing with the system uncertainties, so the dynamic equation of each system's actuator can be expressed as follows:

$$\ddot{\theta} = \left[-a\dot{\theta} - \frac{\tau_l}{J} + (b - b_0)u\right] + b_0u = f() + b_0u \tag{1}$$

where, $a = B/J; b_0 = k/J; b$ is the best estimation of the nominal value b_0 and $d = (b_0 - b)u$ is the disturbance control input. u is the motor's current; b_0 is the constant parameter of DC motor; the time-varying function $f()$ represents for the modeling uncertainty and the disturbance of the actuator. The $f()$ function is estimated by ESO method.

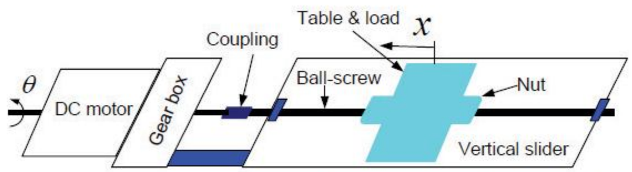

Fig.1 DC motor actuator using DC motor combine with slider

2.2 ADRC control method

As we know, the modeling uncertainty and the disturbance of the DC motor actuator is represented by $f()$ function. So the problem is to design a servo controller for system's actuator which can estimate the modeling uncertainty and the disturbance of the DC motor actuator and then compensate itself. To overcome this problem, the servo controller based on the active disturbance rejection control (ADRC) method is proposed to control the output of the actuator via the input of DC motor [3]. The servo controller consists of an estimated extended state observer (ESO), a profile generator and a nonlinear PD controller as shown in Figure 2.

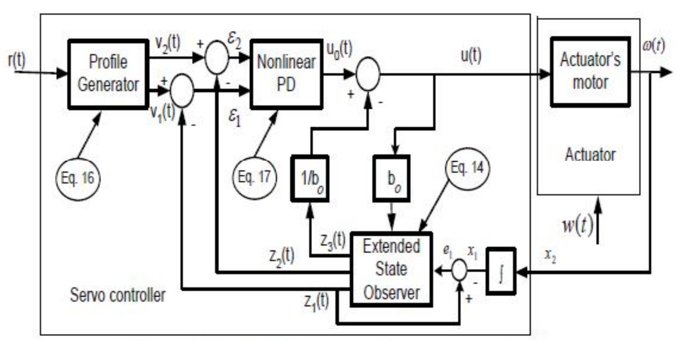

Fig. 2 Block diagram of servo controller

where $r(t)$ is the angular velocity reference input of an actuator's motor which is given by the main controller, $u(t)$ is the controlled current of the actuator's motor, $w(t)$ is the external disturbance, $\omega(t)$ is an angular velocity output of the actuator's motor which implies the output of the actuator.

The modeling uncertainty and the disturbances of the actuator are estimated by ESO and compensated during each sampling time simply using only the measured angular velocity output of the actuator's motor. So the servo controller is designed without an explicit mathematical model of the actuator. This is the reason why the simple dynamic model of the actuator in Eq. (1) is used.

2.3 Extended state observer (ESO)

The state space form of Eq. (1) can be rewritten as follows:

$$\begin{cases} x_1 & = 0 \\ \dot{x}_1 & = x_2 = \theta \\ \dot{x}_2 & = x_3 + b_0 u, \quad x_3(t) \underline{\underline{\Delta}} f(t, x_1, x_2, w) \\ \dot{x}_3 & = -D(t) = \dot{f}(0) \end{cases} \tag{2}$$

where both $f()$ and its derivative $D(t)$ are assumed to be unknown. By taking $f() = f(t, x_1, x_2, w)$ as an extended state, x_3, it is now possible to estimate $f()$ by an ESO [2]. The ESO is a unique nonlinear observer designed to estimate $f()$ which is augmented as a state for the system as follows:

$$\begin{cases} \dot{z}_1 & = z_2 - \beta_{01} f_{c1}(e_1) \\ \dot{z}_2 & = z_3 - \beta_{02} f_{c2}(e_1) + b_0 u \\ \dot{z}_3 & = -\beta_{03} f_{c3}(e_1) \end{cases} \tag{3}$$

where $e_1 = z_1 - x_1$, z_1, z_2 and z_3 are the estimates of x_1, x_2 and $x_3 = f()$, respectively. β_{01}, β_{02} and β_{03}, are observer gains, and $f_{ci}(e_1), i = 1, 2, 3$, are the nonlinear continuous function as follows:

$$\begin{aligned} f_{ci}(e_1) & = fal(e_1, \alpha_i, \delta_i) \\ & = \begin{cases} |e_1|^{\alpha_i} \mathrm{sign}(e_1).\ |e_1| > \delta_i \\ \frac{e_1}{\delta_i^{1-\alpha_1}}\ otherwise \end{cases} \quad for\ \delta_i > 0 \end{aligned} \tag{4}$$

By the extended state observer for the system, the system (4) is the ESO of the system (3). It has the properties $z_i(t) \to x_i(t), i = 1, 2, 3$, as $t \to \infty$. The demonstration of ESO convergence is proven by [Huang and Han (2000)].

2.4 Profile generator

From the reference angular velocity input for the servo controller, $r(t)$, and the sampling time of the system, the profile generator generates the signals $\nu_1(t)$ and $\nu_2(t)$. The $\nu_1(t)$ is the rotational angle and $\nu_2(t)$ is the angular velocity. The relationship of the output of the profile generator ν_1, ν_2 and its input reference $r(t)$ is as follows:

$$\begin{cases} \nu_1(t_n) & = \nu_2(t_n)dt + \nu_1(t_{n-1}) \\ \nu_2(t_n) & = r(t_n) \end{cases} \tag{5}$$

2.5 Nonlinear PD controller

The nonlinear PD controller makes the errors ε_1 and ε_2 converge to zero

$$u_0(t) = k_P f_1(\varepsilon_1) + k_D f_2(\varepsilon_2) \tag{6}$$

where u_0 is the output of the nonlinear PD controller, k_1 and k_2 are the gains of the PD controller, $\varepsilon_1 = \nu_1 - z_1$ and $\varepsilon_2 = \nu_2 - z_2$ are the position error and the angular velocity error, respectively. $f_1()$ and $f_2()$ are appropriate nonlinear functions such as follows:

$$f_i(\varepsilon_i) = fal(\varepsilon_i, \alpha_{0i}, \delta_{0i} = \tag{7}$$

where α_{0i} and $\delta_{0i}, (i = 1, 2)$ are constant parameters to be determined.

2.6 Servo controller design

The output of the total servo controller is proposed as follows:

$$u(t) = u_0(t) - z_3(t)/b_0 \tag{8}$$

where $z_3(t)/b_0$ is used to compensate the actuator's disturbance.

3. Simulation and Experimental Results

3.1 Simulation results For simulation, in this paper the Matlab is used. firstly, a general dynamic model of an actuator which uses a DC motor as a power source is used to describe the dynamic model of the sliding actuator as shown in Fig. 1.

$$\ddot{\theta} = \left[-a\dot{\theta} - \frac{\tau_l}{J} + (b - b_0)u\right] + b_0 u = f() + b_0 u \tag{9}$$

where τ_l is the actuator motor's torque disturbance, $a = B/J$ and $b = k/J$. J is the actuator's friction coefficient, k is the torque constant of the actuator's motor, J is the inertial moment of the actuator's motor. The simulation results based on known modeling uncertainty and known disturbance of the actuator are compared with the experimental results in the same sliding actuator and conditions as shown in Photo 4. The parameters of the sliding actuator are shown in Table 2.

with $b_0 = 80$ chosen in experiment, $a = B/L = 1.1235$ and $b = k/J = 74$,, from Eq. 9, the function $f() = -0.1235\dot{\theta} - \frac{\tau_l}{0.0081} - 6u$ is obtained. Furthermore, the weight 3.2kg which is putting off from the slider' table makes the disturbance torque τ_l from the following relationship:

$$m = \frac{k\tau_l 2\pi}{gp + 2\pi r g f_{ms}} \approx 5.855\tau_l \tag{10}$$

where $g = 9.81[m/s^2]$, $f_{ms} = 0.005$, is the coefficient of friction, $k = 6$ is the ratio of geared box of DC motor, $r = 5mm$ is the radius and $p = 0.5mm$ is the pitch of the screw. The weight $m = 3.2$kg makes the disturbance torque $\tau_l = 0.546$ kg cm.

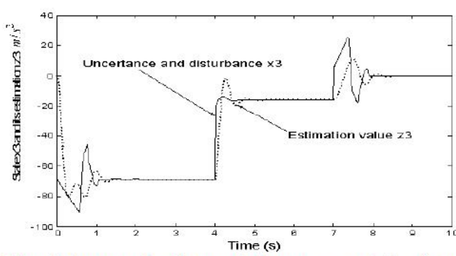

Fig. 3 Simulation result of extended state x_3 and its observer z_3.

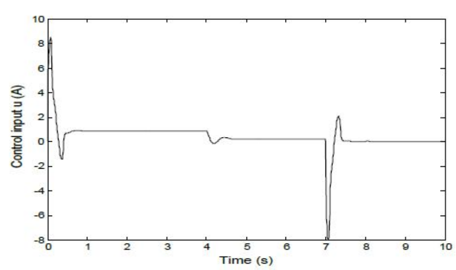

Fig. 4 simulation result of current control input u

Figures 3 shows that the estimation value z_3 track the uncertanti x_3 of the system very well. The efficiency of ESO which is used to estimate the modeling uncertainty and unknown disturbance. State x_3 and its estimation $z_3 = f()$ is very sensitive with internal and external disturbances. However, z_3 converges to x_3 just after fluctuating. In Fig. 4 the control in put u is very sensitive with noise which based on z_3 of the system.

3.2 Experimental results

The dynamic model in Eq. (1) is applied to the DC motor actuator which uses a DC motor as a power source as shown in Photo 4. In this experiment, an external disturbance is made by putting up or putting off the weight on the slider's table of the actuator. The actuator's reference input $r(t)$ is a step function which has a period of seven seconds. The angular velocity $\omega(t)$, the output of the actuator's motor is measured by the optical encoder. The microprocessor PIC16F877 and a DC motor driver LMD 18200 are used in the control board

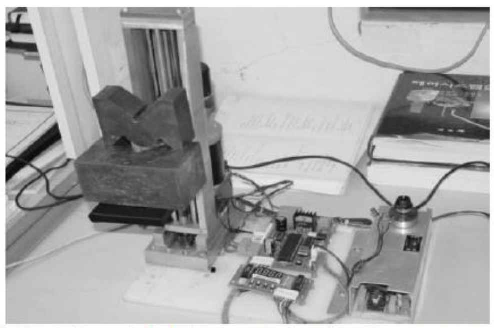

Photo 4 Experimental sliding actuator for the servo controller

Table 1 Parameters used for the servo controller

Eq. (1)	$b_0 = 80$; sampling time is 10 ms
Eq. (3)	$\beta_{01} = 75$; $\beta_{02} = 530$; $\beta_{03} = 40$;
Eq. (4)	$\alpha_1 = 0.7$; $\alpha_2 = 0.22$; $\alpha_3 = 0.8$; $\delta_{1,2,3} = 0.03$;
Eq. (6)	$k_P = 1.7$; $k_D = 5.3$;
Eq. (7)	$\alpha_{01} = 0.5$; $\alpha_{02} = 0.$; $\delta_{01,02} = 0.03$;

Figures 5 show that the output of the experimental results for rotational angle and angular velocity of DC motor is bounded around the simulation results. Furthermore, the outputs track the reference input very well. State x_3 and its estimation $z_3 = f()$ is very sensitive with internal and external disturbances. Finally, the simulation and experimental results show that the servo controller is very powerful and useful for the actuator which uses a DC motor as a power source by using the simple dynamics in Eq. (1).

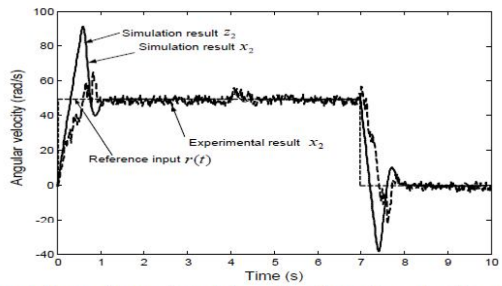

Fig. 5 Simulation and experimental results of angular velocities of DC motor

4 Conclusion

In this paper robust controller for DC motor actuator is represented. The auto-disturbance rejection controller is shown in simulation and experimental results, which is inherently suitable for dealing with the system uncertainties. In addition, the impact of external disturbances and parameter variations could also be estimated and compensated by the controller u under different operating conditions. The simulation and experimental results show that proposed control system has good performance.

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