Position Control for the Spherical Joint Driven by PMAs

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Abstract—A spherical joint system driven by pneumatic artificial muscle is constructed. As pneumatic artificial muscle has strong nonlinear characteristics and traditional control methods are hard to overcome the contradictions among control precision, adjusting speed and stability, the 2 order auto-disturbance-rejection controller is introduced. The position control of the spherical joint can be realized by auto-disturbance-rejection controller or PID controller. The experimental results show that auto-disturbance-rejection controller can achieve better control effect than PID controller with steady precision less than 0.4° .

Keywords-PMA;spherical joint; position control;ADRC

I. INTRODUCTION

Joint driving system is an important part of the robot. In order to construct robot joints which have large output torque, simple structure, large sports range and easy control, domestic and foreign experts and scholars have done research, and made a series of achievements. For example, paper [1] designs a new type of three-degree-of freedom vertical fellowship movement decoupling hydraulic servo joint, which has high-energy density and can be applicable to the robot arm operation, paper [2] designs a high-performance robot joint integrated drive system by using directly drive technology for ac servo system.

As a new type of pneumatic actuator, pneumatic artificial muscle responds quickly and moves smoothly. It can achieve very slow motion, which is close to the natural biological movement. As a result, it generates low heat and noise in the operating process [3]. Compared with traditional actuators (motor, air cylinder), it has many advantages, such as simple structure, great flexibility, high output force/weight, etc.[4]. So the pneumatic artificial muscle is suitable as the drive of robot joints.

This paper puts forward a spherical joint system driven by pneumatic artificial muscle. Pneumatic artificial muscle has very strong nonlinear characteristics [5], so the auto-disturbance-rejection controller is introduced to realize control. As the improvement on PID, ADRC eliminates integral link and adds the extended state observer which can realize real-time estimation for the internal model perturbation and external disturbance. It retains the advantages of the PID controller, and overcomes the defects of lower controlling

precision by using nonlinear error state feedback strategy [6]. ADRC can achieve good control effect when it is applied to the system.

II. SPHERICAL JOINT SYSTEM

The spherical joint position control system, which takes industrial PC as the core, is made up of spherical joint mechanical bench, pneumatic circuits, data acquisition and control system. The principle diagram is shown in figure 1.

Figure 1.the principle diagram of spherical joint position control system

The spherical joint mechanical bench consists of orthogonal supports, cylindrical body connection and sphere. Pneumatic artificial muscle is distributed in the body connection, the axis of two angular velocity sensor overlaps the axis of spherical. It is shown in figure 2.

(1)schematic diagram (2)physical figure

Figure 2.spherical joint mechanical bench

Pneumatic circuits consist of the air supply, pneumatic triple, electric proportional valve and pneumatic artificial

muscle. Data acquisition and control system realizes sensor data acquisition and processing as well as the motions of joint control output by using data acquisition card PCI-818, PCI-727.

TABLE I. Components Parameters

	Name	Technology parameters
1	electric proportional valve	ITV0050 0-0.9MPa
2	angular velocity sensor	LCG50-00250-100 0-5V sensitivity 6.4 mV/°/sec
3	data acquisition card	PCI-818 16 road one-port analogue inputs PCI-727 12 road simulated output

III. ADRC DESIGN

It is hard to build up the nonlinear model of the pneumatic artificial muscle, while ADRC can treat the uncertainty of the model as the system disturbance and give compensation by ESO that estimates the real time action, so one ADRC controller is designed to realize control. ADRC consists of tracking differentiator, extended state observer and nonlinear state error feedback^[7]. Its structure is shown in figure 3 below.

Figure 3. ADRC structure chart

Tracking differentiator can quickly track input signals without overshoot or flutter. It can increase the signal-to-noise ratio and give better-quality differential signals. The discrete form is expressed by equation (1) (2) (3), which is formed by the steepest comprehensive function for 2 order discrete system.

$$f_h = fhan(v_1(k) - v(k), v_2(k), r_0, h_0) \quad (1)$$

$$v_2(k+1) = v_2(k) + hf_h \quad (2)$$

$$v_1(k+1) = v_1(k) + hv_2(k) \quad (3)$$

Where, h is sampling time, r_0 is speed factor, h_0 is filter factor.

Extended state observer that estimates the real time action can give compensation to simplify control object. 3 order extended state observer is expressed by equation (4) (5) (6) (7) (8) (9).

$$e = z_1(k) - y(k) \quad (4)$$

$$f_e = fal(e, 0.5, h_1) \quad (5)$$

$$f_{e1} = fal(e, 0.25, h_1) \quad (6)$$

$$z_1(k+1) = z_1(k) + h(z_2(k) - \beta_{01}e) \quad (7)$$

$$\begin{aligned} z_2(k+1) = & z_2(k) + h(z_3(k) - \beta_{02}f_e \\ & + f_0(z_1(k)) + b_0(z_1(k))\Delta u(k))) \end{aligned} \quad (8)$$

$$z_3(k+1) = z_3(k) + h(-\beta_{03}f_{e1}) \quad (9)$$

Where, z_1, z_2, z_3 track x_1, x_2 , disturbance, h_1 is interval length of linear period, $\beta_{01}, \beta_{02}, \beta_{03}$ are observer parameters, $f_0=0, b_0=5000$.

Nonlinear state error feedback uses the smooth feedback to make the steady-state error diminish in index form and so accelerate response speed. It is expressed by equation (10) (11) (12) (13).

$$e_0(k) = e_0(k-1) + e_1(k) \quad (10)$$

$$e_1(k) = v_1(k) - z_1(k) \quad (11)$$

$$e_2(k) = v_2(k) - z_2(k) \quad (12)$$

$$u(k) = \beta_0 e_0(k) + \beta_1 \text{fal}(e_1(k), 0.5, h_2) + \beta_2 \text{fal}(e_2(k), 1.5, h_2) \quad (13)$$

Where, h_2 is estimated coefficient of linear period, β_0 、 β_1 、 β_2 respectively are integral, scale, differential coefficient.

Finally z_3 is compensated to control quantity to improve the control performance. It is expressed by equation (14).

$$\Delta u = \frac{u(k) - z_3(k) - f_0(z_1(k))}{b_0(z_1(k))} \quad (14)$$

IV. SINGLE FREEDOM DEGREE POSITION CONTROL

The initial pressure of pneumatic artificial muscle is 0.25 MPa. The spherical joint system turns 20°, 40°, 60° in single freedom degree by using ADRC and PID controllers. The step response is shown in figure 4. Controller parameters are as follows:

$$\begin{aligned} \text{ADRC : } h &= 0.01, \quad h_0 = 0.02, \quad r_0 = 5800, \quad h_1 = \\ &0.07, \beta_{01} = 80, \beta_{02} = 1400, \beta_{03} = 2800, h_2 = 0.11, \beta_0 = 0.2, \beta_1 \\ &= 130, \beta_2 = 2, \end{aligned}$$

PID: $k_p=1.1, k_i=0.05, k_d=0$, (20°)

$$k_p=1.1, k_i=0.05, k_d=0, (40^\circ)$$

$$k_p=1.1, k_i=0.05, k_d=0, (60^\circ)$$

Figure 4. The step response comparison between ADRC and PID

As shown in Figure 4, the average steady-state error is less than 0.3° , and the average transition process time is about 0.6 s under the control of ADRC, while the average steady-state error is less than 0.4° , and the average transition process time is about 1 s under the control of PID. Compared with PID, the average steady-state error reduces by 25% and the response time reduces by 40% adopting ADRC.

V. TWO FREEDOM DEGREE COMPOUND POSITION CONTROL

The spherical joint position control target is represented by attitude matrix T . The included angles between corresponding coordinate system axis X, Y, Z and fixed coordinate system are α, β, λ . The included angles α, β, λ only determine attitude matrix T . The system realizes the control target by ADRC. The control targets are $\alpha=8^\circ, \beta=6^\circ, \lambda=6^\circ$ and $\alpha=24^\circ, \beta=17^\circ, \lambda=17^\circ$. Controller parameters are as follows:

ADRC 1 : $h = 0.05, h_0 = 0.025, r_0 = 6200, h_1 = 0.08, \beta_{01} = 70, \beta_{02} = 1350, \beta_{03} = 2650, h_2 = 0.14, \beta_0 = 0.34, \beta_1 = 190, \beta_2 = 3.4,$

ADRC 2 : $h = 0.05, h_0 = 0.023, r_0 = 6100, h_1 = 0.075, \beta_{01} = 80, \beta_{02} = 1450, \beta_{03} = 2700, h_2 = 0.13, \beta_0 = 0.3, \beta_1 = 170, \beta_2 = 2.5,$

Figure 5. included angle of coordinate system axis x

Figure 6. included angle of coordinate system axis y

Figure 7. included angle of coordinate system axis z

As shown in Figure 5, 6 and 7, the steady-state time which reaches the target location is about 2 s, the steady-state error is less than 0.5° . It is shown that ADRC can achieve good spherical joint position control.

VI. CONCLUSIONS

As a new type of pneumatic actuator, pneumatic artificial muscle is taken seriously with good flexibility, but it has some disadvantages, such as linearity error, slow response speed and low repetition accuracy. In order to overcome the above shortcomings, this study adopts ADRC on spherical joint control experimental research and obtains ideal control effect that lays the foundation for multiple joint control.

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