An Position Servo Control of Intelligent Artificial Legs based on Fuzzy-PD Algorithm

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Abstract

Intelligentartificial leg (prosthesis) which is a high precision electromechanical integration device has been a leading-edge research object in the fields of robotics andbiomedical engineering. In this paper, we designed an artificial legs position control strategy based on Fuzzy-PD control, This method of PD control and fuzzy control were combined, in the initial stage of using PD control to improve the response speed, then used the fuzzy control to make the output stably without overshoot. The simulation results show that, the position servo motor of artificial legs can be very good controlled by the Fuzzy-PD control method, the closed loop system step response of output is stable without overshoot, short adjusting time, strong robustness, and has strong interference suppression effect.

Keywords

Artificial Leg; Position Control; Electric Machinery; Fuzzy-PD Control.

1. Introduction

From earliest times to present day, because of the war, disease, injury, traffic and natural disasters, has caused thousands of people lost their lives to the lower limbs, bring a lot of inconvenience, but with the rapid development of industry and traffic, the number per year increased at an alarming rate. Due to the current medical level still cannot regenerate limbs, installing artificial leg amputees (prosthesis) for amputees has become the main means to restore its walking function and therefore it has great social significance of artificial leg [1,2].

The artificial leg is mainly composed of the knee joint, the lower leg and the foot.Among them,the knee joint is the most important parts ,step speed sensor mounted in the knee joint, tail with a small DC linear motor cylinder, microprocessor and battery etc.. Step speed sensor is used to detect artificial leg walking speed.Air compressor cylinderis driven components, which is used to control the bending and stretching of the knee joint. The motor is used to control the opening of a needle valve (flow) in the cylinder, and the opening of the needle valve can be adjusted to changethe speed of bend and stretch,so it can change the artificial legs walking speed. According to the opening of the pace of microprocessor measurement to control the motor to regulate the movement of the needle, so that the artificial leg movement coordination with the other side of the healthy leg. The entire control system is powered by a small lithium battery [3–5].

2. Artificial adjustmentprinciples

The cylinder is the actuator to control the swing speed of the lower leg. There is a piston in the cylinder, and the bending and stretching of the leg will drive the piston to reciprocate. When the leg bent, the piston in the cylinder is moving downward, and then the piston cavity (cavity under the piston) will produces high pressure gas. When the foot of the artificial leg off the ground, generated elastic force by the high-pressure gas of the lower chamber will push the piston upward movement, thereby driving the leg stretching , that is, forward swinging. A needle valve is arranged in the lower cavity of the piston, and the opening of the piston can be controlled to control the amount of air flowing out of the piston cavity and into the upper cavity of the piston, thus controlling the magnitude of the rebound force generated by the piston cavity. The motor components assembled at the rear end of the cylinder are used to control the opening of the needle valve. When the amputee walk faster, motor driving conical needle rod down the valve in the valve, the cylinder rebound increases, the legs swinging speed correspondingly accelerate; on the other hand, when the amputee walking speed slows down when the valve is opened, the cylinder rebound decreases, swinging speed will slow down the leg. The control system based on the measured values of speed, real-time control of motor to change the valve opening, so as to make the speed of artificial leg and on the other side of the healthy leg to matching purposes [6].

3. Position servo motor control requirements

Artificial leg which is a high precision electromechanical integration device, and its movement gait is the same as that the healthy leg, which is divided into the on load and ground swing phase. Study on biological movement mechanics showed that the people normallywalking speed at 90 steps per minute, namely every 0.65 seconds, the gait cycle of oscillation meet 59% of a gait cycle, 41% of the weight meet is a gait cycle, namely for 0.25 seconds. The speed regulation principle of the artificial leg is to adjust the average velocity of the artificial leg back forth in the swing phase by adjusting the velocity of flow (damping) in the air cylinder. Through a linear servo motor to drive the needle valve to adjust the opening of air compressor cylinder circulation way, so as to control the average swing speed of artificial leg, the pace to make artificial leg and on the other side of the healthy leg to keep matching purposes.The speed control of artificial leg has the speed loop and position loop feedback control system, position control according to the given speed controller output value controlling the opening of the needle valve, the position servo must complete in the loading phase this very short period of time, in order to reduce the influence of the speed loop. From the above analysis, the system has higher requirements for position servo, and the performance index of the position loop is as follows: adjusting time $t_s \le 0.08s$ ($\Delta = 5\%$), overshoot $\sigma\% \le 5\%$, steady-state error $e_{ss} = 0$. From thoseperformance index, the system should have very good step response performance [1,7].

The opening of the needle valve in the cylinder is controlled by controlling the position of the needle rod in the valve. The needle valve opening is defined as the flow area of the needle valve. There is a one-to-one relationship between needle bar and the position of needle rod.Changing the position of the needle rod can change the needle valve opening [8].

In order to control the position of the needle rod, the motor must be controlled. According to the literature [1,3,4,9] the linear displacement transfer function of linear motor is:

$$G(s) = \frac{6068}{s^3 + 110s^2 + 6068s} \quad (1)$$

4. Incomplete differential PID control

In this paper, the DC linear motor is controlled by incomplete differential PID, its transfer function is:

$$G(s) = K_P + K_I \frac{1}{s} + K_D \frac{N}{1 + N\frac{1}{s}} \quad (2)$$

According to the Ziegler-Nichols parameter adjustment method, namely to the first pure proportional control, gradually increase the proportion coefficient, until the system produce persistent oscillation, so as to obtain the critical proportion coefficient K_m of the system and the critical oscillation period T_m, according to K_m and T_m can be selected parameters forPID [10]: $K_p = 66$, $K_I = 66/0.0403$, $K_D = 66 * 0.0101$, $N = 100$. In this paper, PID control simulation model is set up as shown in Fig. 1, PID control simulation results are shown in Fig. 2:

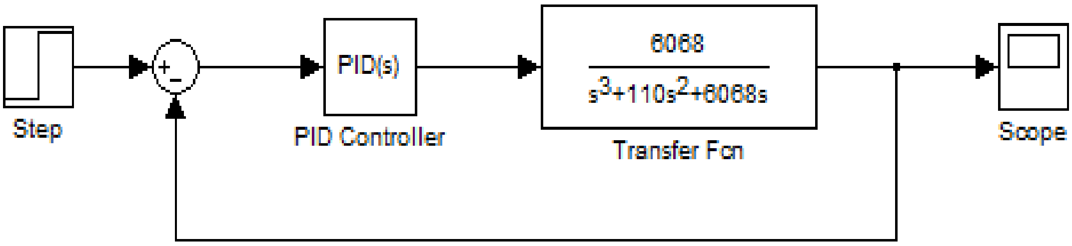

Fig.1 PID control simulation model

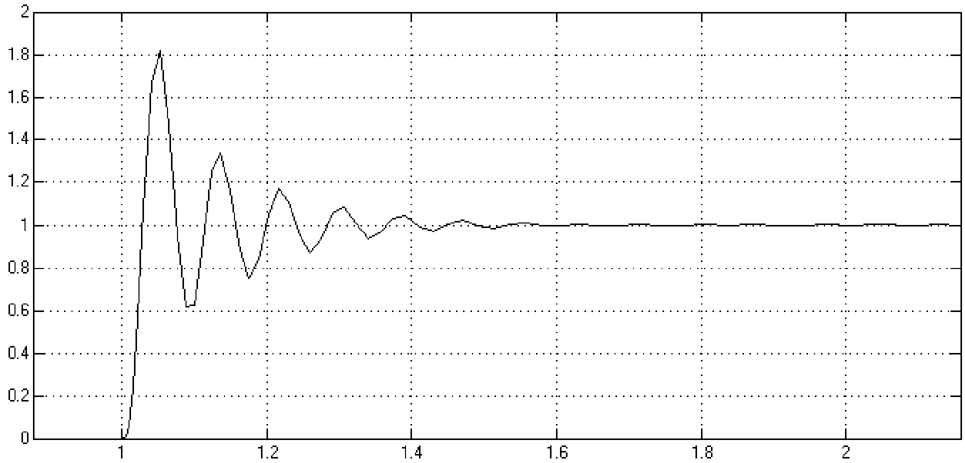

Fig.2 The step response curve of PID control

The position PID control simulation results show that the PID position control, although faster output curve of the system tends to be stable, but the overshoot is heavy, and the oscillations for many times, which will cause the position servo motor to oscillate back and forth, not only consumes energy, more important is easy to damage the motor precision, it does not conform to the actual need [10].

5. Fuzzy control

The biggest advantage is fuzzy control does not need to know the precise mathematical model of the object, but does not require that the parameters of the controller such as PID control, just need to manual control experience control rules can be expressed by fuzzy language, accord with the human thinking habit [8,11-16]. The closed loop system error e and the error change rate de of the position controlas a two-dimensional fuzzy controller of two input variables, the control u input for the output of the controlled variable.By tracking tickets status step signal as control target.The error e range is controlled in [-1,1], the input variables e and fuzzy theory domain de are taken as [-1,1]. The fuzzy domain u of control signal is [-2,2]. According to the actual situation of the physical domain, the scale factor and the quantization factor can be selected. In this paper, are to 1. The input variables e and de the fuzzy subsets of the output variables u in the fuzzy domain are NB, NS, ZE, PS, PB, a total of five, and the membership functions of the fuzzy subsets are selected as Gauss type. According to the experience of manual control,consider different error of the control requirements and the influence of the error rate of change, as shown in table 1 of the fuzzy control rule table.

Table.1 fuzzy control rule table

ude / e	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NB	NB
NS	NB	NB	NS	NS	ZE

ZE	PS	ZE	ZE	ZE	NS
PS	ZE	PS	PS	PB	PB
PB	PB	PB	PB	PB	PB

Establish the simulation model of position fuzzy control as shown in Fig. 3 in the SIMULINK, run the simulation model, the fuzzy control of the closed-loop system under the step response curve is shown in Fig. 4, Fig. 4 shows that the simulation waveform in the closed loop control system of fuzzy controller under the step response curve is very table, no overshoot,no oscillation, has been greatly improved compared with PID control, so the control performance has been very good, but the longadjust regulation time, will need about 2S, does not meet the requirements of real-time.

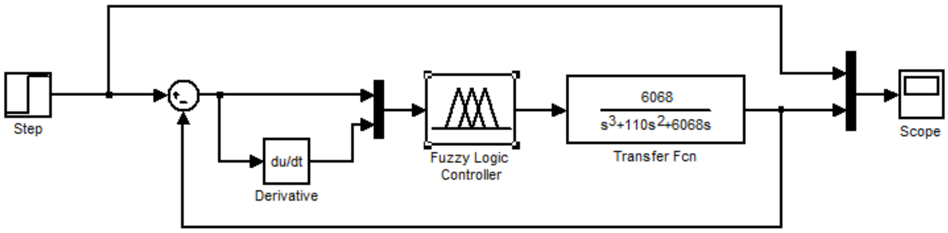

Fig.3 Fuzzy control simulation model

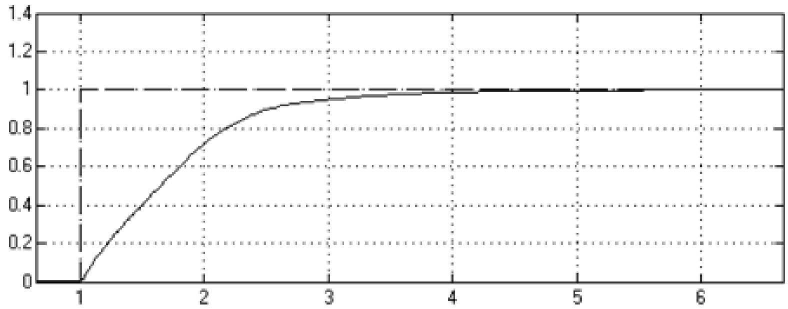

Fig.4 Fuzzy control response curve

6. Improved Fuzzy PD control

According to the analysis result of the front, the intelligent artificial leg position actuating motor PID control regulation time is fast, but the output of the system with the overshoot and oscillation times; While performing the motor of the fuzzy control response curve is very smooth and no overshoot, but to adjust for a long time, both of them do not meet the requirements of the actual performance index. In order to control the intelligent artificial leg position servo motor can quickly adjust and no oscillation on the smooth output, this paper proposes a PID control and fuzzy control combined with fuzzy PD controller to control the intelligent artificial leg position servo motor, by use of the advantages of both, and mutually make up their own shortcomings. By the simulation results of PID control and fuzzy control in front of the analysis, found that the response speed of the PID control, and the output of the fuzzy control is stable and no overshoot, so the choice of fuzzy PD control in the beginning stages of large deviation when using PID control to improve the response speed of the system, because the integral used in PID control in order to eliminate the steady-state error and improve control precision ,at the same time can increase the amount of overshoot, not suitable for use in large deviation control state, this paper adopts PD control and remove integral effect; when the deviation is small fuzzy PD controller using fuzzy control to make the closed-loop system stable output without overshoot. Fig. 5 is a simulation model of fuzzy PD control based on the combination of PD control and fuzzy control. As long as the selection of a suitable switching threshold of PD control and fuzzy control, the unit step response curve of the closed-loop system is obtained.

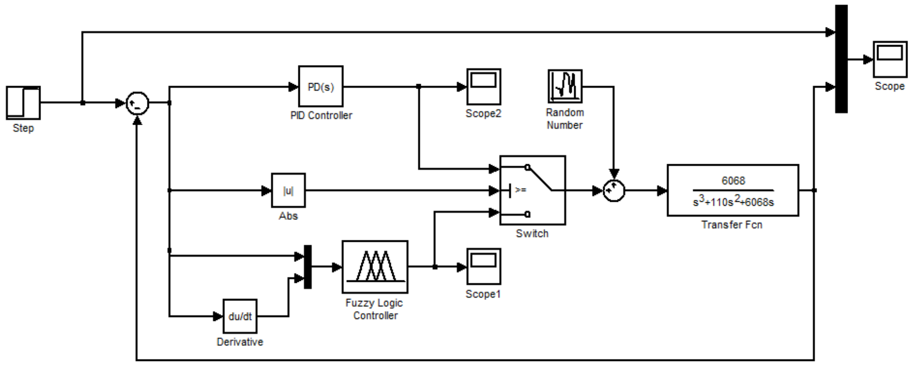

Fig.5 Fuzzy-PD control simulation model

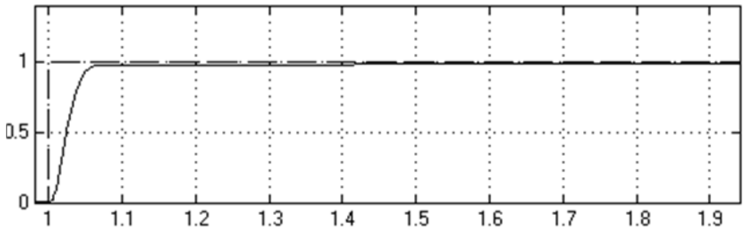

Fig.6 Fuzzy PD control response curve

Fuzzy PD control simulation waveform is shown in figure 6, the simulation curves show that the fuzzy PD control of the step response curve of fast response, short rise time, and the output is very stable, no oscillation and overshoot and adjusting time of the whole transition process $t_s \le 0.06s$ ($\Delta = 5\%$), steady state error $e_{ss} = 0$, has good control performance.

7. Conclusion

Intelligent artificial leg has a very important practical significance for the disabled people and the society, but artificial legposition servo control of the traditional control mode of the output oscillation of large amount of overshoot, slow adjustment or response time is long. In this paper, the fuzzy PD control, fuzzy control and PD control can be combined to improve the performance of intelligent artificial leg position servo control. The analysis of the above results proved that the fuzzy PD control, this design can not only achieve the system output without oscillation and overshoot, fast response, short adjusting time, strong robustness and has strong interference suppression effect, has good control effect and practical significance.

References

[1] Xiao Hongfeng Tan Guanzheng and Chen Yongqi: Simulation and design of linear motor position servo system for artificial legs. Micro motor (servo technology),2001 (03),p.21-24.

[2] ChenQiou et al:Research and design of knee joint follow-up control system of artificial limb. Computer measurement and control, 2010 (08),p.1771-1773.

[3] TanGuanzheng, Fuzzy_GA_ _ omitted the controller has the incomplete differential and its application in intelligent bionic artificial legs _ Tan Guanzheng. Robot, 2002.

[4] XiaoHongfeng, Liang Feng and Tan Guanzheng,Optimization and Simulation of a new fuzzy PID controller. Computer simulation, 2003 (04),p.32-35.

[5] Ma Shaoxing, the research progress of artificial limb dynamic knee joint, in sixth Beijing International Rehabilitation Forum - amputation and Rehabilitation Engineering Forum 2011: Beijing, China, p.6.

[6] LiuGuolian, Tan Guanzheng and He Yan:The design speed of intelligent artificial leg control system CIP-I. Journal of Nantong Vocational College, 2008 (02),p.62-66.

[7] WangBinrui and Xu Xin:Intelligent bionic legs. Control and decision making, 2004 (02), p. 121-127+133.

[8] LiuGuolian, Tan Guanzheng and He Yan:The application of fuzzy sliding mode control in intelligent artificial control. Science technology and engineering, 2008 (15),p.4361-4365.
[9] TanGuanzheng:The optimal with incomplete derivation fuzzy PID control _ _ omitted can be used in the simulation of artificial leg _ English _ Tan Guanzheng. Control theory and applications, 2002.
[10] Shi Liang Chen: MATLAB/Simulink system simulation super learning manual. Edition first. 2014 edition, Beijing: People's Posts and Telecommunications Publishing House.
[11] LiJinxin, Zhang was loose and He Yong:The research of motion control robot based on fuzzy PID. Control engineering, 2014 (S1),p.41-44.
[12] LiHongwei: Simplified fuzzy control and Simulation of single inverted pendulum. Control engineering, 2010 (06),p. 769-773.
[13] Tube Ping et al: Predictive control of hypersonic vehicle based on fuzzy system. Control engineering, 2014 (06), p.823-828.
[14] LiuHuibo, and Wu Yanhe ;Research and Simulation of fuzzy adaptive PID control for brushless DC motor. Control engineering, 2014.21 (4), p.583-587.
[15] Li Jun, sun Yong: Application of fuzzy control in BALL&PLATE device. Experimental technology and management, 2001 (01), p. 23-28.
[16] ZhangJia: Photoelectric tracking system based on fuzzy adaptive PID control experiment. Experimental technology and management, 2014 (08), p. 59-63+86.