A Study on Piezoelectric Ammunition based on Improved Single Neuron Adaptive PID Algorithm

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Abstract. Piezoelectric ceramic as a driver is applied to the deflection of nose, which is a kind of frontier missile control mode. In order to improve the efficiency and reliability of deflection mechanism, a design scheme of the control mechanism that piezoelectric ceramic actuator combined with improved PID algorithm is studied in this paper. Single chip is used to program. We can determine the key design parameters and simulate static characteristics of the control system under the step signal via SIMULINK.The simulation result shows that piezoelectric ceramic actuator based on the improved PID algorithm has advantages of high precision and fast response.

Introduction

Ammunition is an important part of all kinds of damage weapon systems, and the effect of the destruction has always been an important indicator to measure the role of ammunition in the military. The traditional ammunition with many advantages such as simple manufacture, low price, mighty fire and so on, plays a great role in the war. But its shortcomings are also obviously exposed. Smart ammunition [1] developed in the 80's is a new type of ammunition. It uses guidance device to control the flight trajectory, and steers towards targets by the known target location and required accuracy. Compared with conventional ammunition and missiles, smart ammunition obviously improves shooting accuracy and reduces the scope of damage. Terminal sensitive projectile, terminal guidance ammunition, trajectory correction ammunition, etc, are typical representative of smart ammunition [2]. The technique piezoelectric ceramic as actuator [3] utilized to control the deflection of warhead [4] is a trajectory correction technique [5]. This technique combined with a single neuron adaptive PID controller [6,7,8] based on the second-performance learning algorithm is presented in this paper, for the sake of achieving higher precision,faster response of the warhead deflection control technique.

Piezoelectric driving mechanism based on improved PID

It is more convenient for the structure of ammunition to use piezoelectric ceramic as a driver to control warhead deflection. Several piezoelectric ceramic rods are distributed averagely inside the warhead. The warhead connects with missile body by a ball socket. Keep the warhead not turn when the missile rotates quickly during flight. While voltage is applied to the piezoelectric ceramic rods,the length of one side of the ceramic rod elongates due to the reverse piezoelectric effect [9]. At the same time, the anti-voltage is applied to the other side, the ceramic rod becomes shorter. Consequently, the warhead deflects so as to achieve the purpose of modified trajectory. The application of the piezoelectric actuator on the projectile is shown in Figure 1.

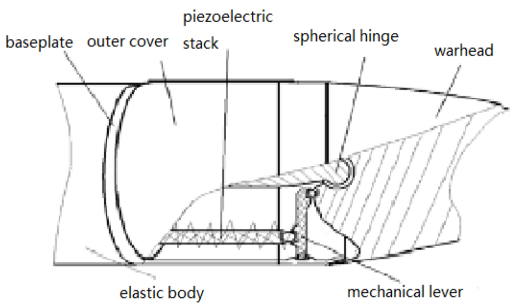

Fig. 1 Piezoelectric Driver Used in Warhead Deflection Ammunition

The position accuracy reduces because of the hysteresis and creep of piezoelectric ceramics [10]. However, using corresponding driving power [11,12,13] and improved PID control algorithm to control the piezoelectric ceramic actuator , can effectively improve the output displacement. Thereby, warhead deflection angle will enlarge. The difference between the input voltage and the feedback voltage is operated by proportion,integral, differential in the single chip microcomputer, and then the calculation result is conveyed to driving mechanism. The structure diagram of the piezoelectric drive mechanism with improved PID is shown in figure 2.

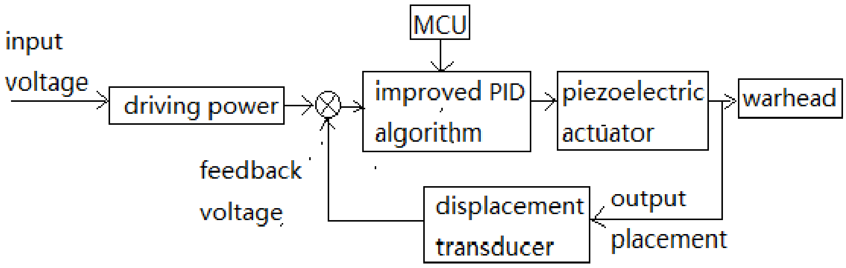

Fig. 2 Structure of Piezoelectric drive mechanism based on improved PID

Single chip microcomputer module uses the type of C8051F410 SCM [14] which is a bridge to realize the transformation of digital signal and analog signal. And it also can process the received signal and generate input voltage signal. The flow chart of software design of single chip microcomputer is shown in figure 3. The drive power from [15], makes voltage linearly amplify. It has characteristics of high precision,strong driving ability,simple structure and good stability. In addition, it also can work under different signals. The displacement transducer from [16] obtains the dynamic displacement of measured voltage by using the inverse piezoelectric effect of piezoelectric ceramic materials.Afterwards, the dynamic displacement generated by inverse piezoelectric effect is measured by the reflex light displacement sensor, in order to get measurement of voltage parameters.

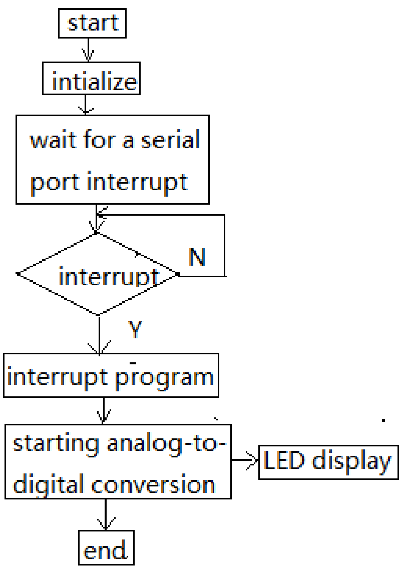

Fig. 3 Flow chart of software design

In the optimal control theory, we can get the desired effect by the quadratic performance index calculating the control rate.Similarly, we can employ the idea of the quadratic performance index in the neuron learning algorithm. Quadratic performance index are introduced in the adjustment of weighting coefficients. The weighted coefficients are adjusted through making the weighted sum-squared output error and control increment the least.Sequentially, we can realize indirectly constraint control to the output error and control incremental weighted.

Set performance indicators as follow:

$$E(k)=\frac{1}{2}\left(P\left(y_d(k)-y(k)\right)^2+Q\Delta^2u(k)\right) \tag{1}$$

In the above formula, P and Q are respectively the output error and control increment of the weighted coefficient. $y_d(k)$ and $y(k)$ are respectively the time reference input and output.

Neuron output is as follow:

$$u(k)=u(k-1)+K\sum_{i=1}^{3}w_i^{'}(k)x_i(k)$$

$$w_i^{'}=w_i(k)/\sum_{i=1}^{3}\left|w_i(k)\right| \qquad (i=1,2,3)$$

$$w_1(k)=w_1(k-1)+\eta_I K\left[Pb_0z(k)x_1(k)-QK\sum_{i=1}^{3}\left(w_i(k)x_i(k)\right)x_1(k)\right]$$

$$w_2(k)=w_2(k-1)+\eta_P K\left[Pb_0z(k)x_2(k)-QK\sum_{i=1}^{3}\left(w_i(k)x_i(k)\right)x_2(k)\right]$$

$$w_3(k)=w_3(k-1)+\eta_D K\left[Pb_0z(k)x_3(k)-QK\sum_{i=1}^{3}\left(w_i(k)x_i(k)\right)x_3(k)\right] \tag{2}$$

In the above formula, b_0 is the first value of the output response, and

$$x_1(k)=e(k)$$

$$x_2(k)=e(k)-e(k-1)$$

$$x_3(k)=\Delta^2e(k)=e(k)-2e(k-1)+e(k-2)$$

$$z(k)=e(k) \tag{3}$$

Simulation Analysis

Simulation [17] research begins with the optimal quadratic performance index learning algorithm. The input step response signal is $yd(k)=100$, sampling time is 0.001s, and the external interference is $\xi(100)=3$ in the 100th sampling time. The position tracking results are shown in figure 4 and figure 5 before and after the introduction of the modified PID algorithm.

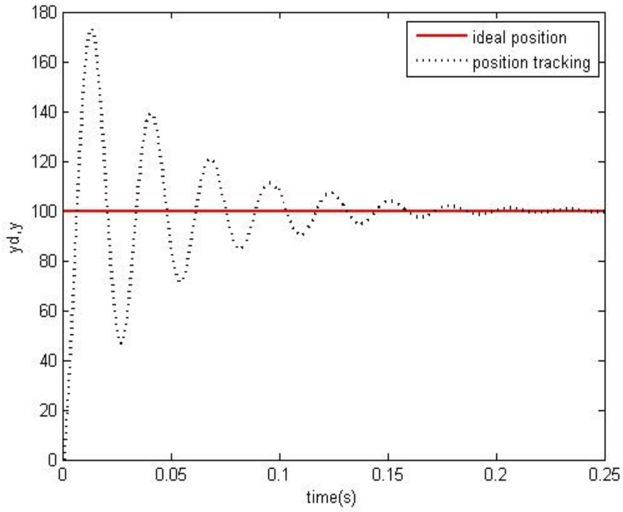

Fig. 4 Simulation of piezoelectric ammunition base on the unmodified PID algorithm

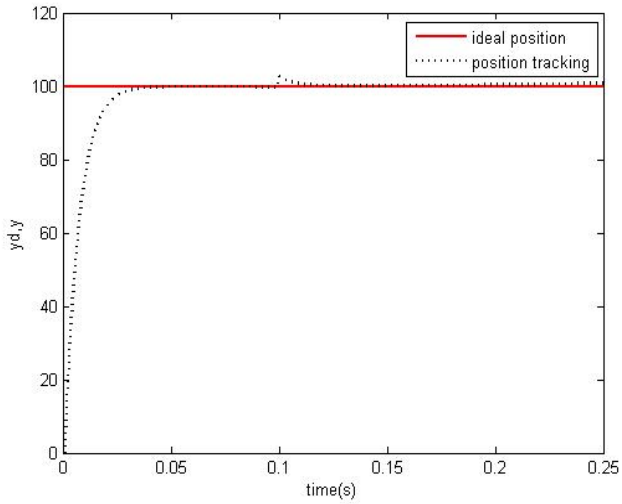

Fig. 5 Simulation of piezoelectric ammunition based on modified PID algorithm

When the system input step signal amplitude is 100, it can be seen that location tracking result is ideal after the PID control with the optional quadratic performance index of learning algorithm compensating. At the same time,the system is better to deal with external interference. Therefore, it is proved that the single neuron adaptive PID control based on the quadratic performance index learning algorithm is effective for the control mechanism. What’s more,the design itself that deflection warhead ammunition based on piezoelectric ceramic is more lightweight compared with other modified ammunition. Coupling with the modified PID algorithm makes its control better. And this mechanism can work in different forms of signal.Accordingly, it is more suitable for application in missile.

Conclusions

The improved PID algorithm combined with piezoelectric ceramic actuator forming a new control mechanism is fully inside the warhead, which will nor affect the body shape. The system has high precision, fast response and other advantages. We complete the theoretical verification through the analysis of simulation results. Nonetheless, the piezoelectric ceramic ammunition is different from conventional ammunition, since the hysteresis and creep of piezoelectric ceramics will change with the change of temperature in practical application. The static simulation is studied in this paper, while the dynamic simulation is still worth to be further studied.

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