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Neuron PSD Control for Piezoelectric Micro-Displacement System

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Abstract. In order to eliminate the influence of the hysteresis, creep and nonlinear of the piezoelectric ceramic and other influence of the outside factors, the adaptive neural PSD control algorithm is proposed to implement the real-time control of the micro-positioning workpiece table. The experiment result verifies the validity of the close-loop control. The displacement precision is 0.01 μm, and response time is less than 0.1s.

1. Introduction
Piezoelectric ceramic actuator has a great advantage over other kinds of actuators. So it is widely used in the application fields of precision positioning [1]. However, the hysteresis, creep and non-linearity characteristic of piezoelectric ceramic depress its positioning accuracy [2], and bring some difficulties to control it for piezoelectric ceramic micro-positioning systems. So the effective and new control methods should be exploited to improve the positioning accuracy. No matter what kinds of control pattern, open-loop or close-loop, voltage drive or charge drive, if the piezoelectric ceramic actuator is asked to reach the wanted positioning accuracy and dynamic character [3], we must combine it with the certain control algorithm. In order to eliminate the influence of the hysteresis, creep and non-linearity of the piezoelectric ceramic and other influence of the outside factors, the single neuron PSD control algorithm is proposed to implement the real-time control of the micro-positioning worktable. This algorithm features self-learning, self-adapting, easy calculation and simple structure. It is needless to identify the system model for the single neuron PSD control algorithm [4]. This is just suitable for piezoelectric ceramic actuator. Because the differences of material, structure and work condition of actuator lead to difficulty of establishing a standard mathematic model to describe the dynamic non-linearity characteristic precisely. In this paper, flexure hinge mechanism, piezoelectric ceramic actuator and driving power, all are self-made. The close-loop control system of piezoelectric ceramic actuator is built up, and all tests are finished on it. The experiment result verifies the validity of the close-loop control system.

2. Piezoelectric micro-displacement close-loop system theory
This system is composed of piezoelectric ceramic actuator, piezoelectric ceramic driving power, inductance sensor, A/ D conversion card and computer. The system structure diagram is shown by figure 1. The computer is chosen to control this system and flexure hinge mechanism is chosen as a micro-displacement platform. The parallel displacement is brought on platform when the driving power drives the piezoelectric ceramic piles. The movement scope is asked from 0 to 3.5 μm, and the
displacement resolution is 0.01 μm. The computer outputs the control signal (0-5V electric voltage) by D/A port on data collecting card, and control the driving power to output the 0-200V continuous voltage to drive the micro-displacement platform. The displacement signal is detected by inductance sensor, and is input to the computer after the A/D conversion. The computer judges and processes the feedback signal, then changes the control electric voltage, further adjusts to the displacement output, and so the close-loop control is realized.

3. Single neuron PSD control

Although the single neuron self-adaptive PID controller has the function to on-line self-study and self-adjustment the PID parameter, with the ability to fit the time-vary process parameter, when the gain changes, it does not have the function on-line study and adjust the gain automatically. However, the gain can be modified in self-adaptive PSD algorithm. Therefore the self-adaptive PSD control algorithm with the gain self-adjusted is formed by leading the recursive calculation and gain modification in it. General self-adaptive control algorithm need to identify the process, and then the control law is designed. So some complicated calculation must be carried on in each sample period, and it is difficult to assure the accuracy of mathematical model. As a result, its application is limited. Self-adaptive PSD control algorithm establishes function index according to the geometrical features of the process error, and so shapes the PSD (proportion, sum, differential) control regulation [5]. This method did not need to identify the process parameter, and have the obvious simplicity and realization.

Aim at the piezoelectric ceramic micro-displacement drive system, the single neuron self-adaptive PSD controller is designed and shown by figure 2. The input of converter reflects the controlled process output and given state. For example, the expected displacement output is \( X_d(n) \), and the actual output is \( X(n) \). So we have \( z(n) = X_d(n) - X(n) \); \( z(n) \) is function index. The state of \( x_1, x_2 \) and \( x_3 \) is what the neuron study needs after conversion. Here, \( x_1 = e(n) = z(n) \), \( x_2 = e(n) - e(n-1) \), \( x_3 = e(n) - 2e(n-1) + e(n-2) \), \( w_i(n) \) is the weight coefficient corresponding to \( x_i(n) \), and \( K \) is the proportional coefficient. The control signal is produced by the association scan of neuron. The weight coefficient needs to be normalized in order to ensure the convergence and robustness of self-adaptive neuron PSD algorithm. In engineering application, people summary that the on-line study and modification of \( P, S, D \) three parameters is associated with \( e(n) \) and \( \Delta e(n) \). According to this, the weight coefficient study in PSD control algorithm needs to be modified; i.e., \( x_i \) is changed into \( e(n) + \Delta e(n) \). After modification like this, and lead in the correction method of gain in PSD control, the neuron self-adaptive PSD control algorithm is gained.

\[
\Delta u(n) = K(n) \sum_{j=1}^{3} w'_i(n)x_j(n)
\]

\[
w'_i(n) = \frac{w_i(n)}{\sum_{j=1}^{3} |w_j(n)|}
\]
\[ w_i(n+1) = w_i(n) + \eta_p z(n)u(n)[e(n) + \Delta e(n)] \]
\[ w_j(n+1) = w_j(n) + \eta_p z(n)u(n)[e(n) + \Delta e(n)] \]
\[ w_j(n+1) = w_j(n) + \eta_p z(n)u(n)[e(n) + \Delta e(n)] \]
\[ K(n) = \begin{cases} 
  K(n-1) + \frac{CK(n-1)}{T_x(n-1)} & \text{sign} e(n) = \text{sign} e(n-1) \\
  0.75K(n-1) & \text{sign} e(n) \neq \text{sign} e(n-1) 
\end{cases} \]
\[ \Delta T_x(n) = L^*\text{sign}[\Delta e(n)]T_x(n-1)[\Delta e(n)] \]

\( \eta_p, \eta_s \) and \( \eta_d \) is learning rate of proportion, sum and differential respectively. Here, different learning rate is adopted, so that each weight coefficient is adjusted respectively according to need. The choice of the weight coefficient initial value has the very big influence to the quality of the control function, and must be chosen rightly. According to the experience, it is generally an average allotment between -0.5 and 0.5. The choice of the \( K \) value is also count for much. If the \( K \) is big, the system is fast but has an overshoot, and even the system is unsteady. When the delay of controlled process is enlarging, the \( K \) value must let up, in order to assure that the system is stable. If the \( K \) value is chosen too small, it will make the rapidity of system become worse. The neuron self-adaptive PSD control algorithm makes the gain \( K \) has the ability of on-line study and automatic adjustment, so it strengthens the self-adaptive ability of system.

4. Experiment test

4.1. Open-loop test
First, we test the exportation of actuator, i.e., exert electric voltage on the micro-displacement. The interval is 5 V. The variety scope is from the 0 to 200 V, and then returns the 0 V. The relationship between the electric voltage of piezoelectric ceramic actuator and output displacement is shown by figure 3. From the figure 3, there exists the slow in open-loop, and the biggest slow is 0.48 μm. The main cause results from piezoelectric ceramic.

![Figure 3. The relationship between driving voltage and output displacement.](image)

4.2. Close-loop test
The sample time of close-loop control system is chosen as 15 ms, i.e. the feedback signal of output displacement is collected by inductance sensor every 15 ms. The computer processes the feedback signal according to the single neuron self-adaptive PSD control algorithm. So the control voltage is attained to control the output displacement. Figure 4 is the step response curve of system. From the step response curve, it can be seen that the accuracy of output displacement is high, the rising curve is
smooth, the error margin is ±0.01 μm, and response time is about 65 ms. Under this control method, the system have a good control results. But the response with PID control presents the certain vibration process. Table 1 and table 2 are actuarial measurement data, when the target displacement range is 0μm–3μm–0μm, and the interval of target displacement is 0.04μm. From the error data in the table, the single neuron PSD control can attain within ±0.01 μm in accuracy. Actually, the precision of which single neuron PSD control can reach is closely related with a resolution and accuracy of displacement sensor. Raising the resolution and accuracy of displacement sensor can correspondingly improve the positioning accuracy.

<table>
<thead>
<tr>
<th>target (μm)</th>
<th>0.02</th>
<th>0.06</th>
<th>0.48</th>
<th>0.52</th>
<th>1.00</th>
<th>1.04</th>
<th>1.52</th>
<th>1.56</th>
<th>1.60</th>
<th>1.64</th>
</tr>
</thead>
<tbody>
<tr>
<td>actual (μm)</td>
<td>0.01</td>
<td>0.06</td>
<td>0.48</td>
<td>0.53</td>
<td>1.00</td>
<td>1.04</td>
<td>1.51</td>
<td>1.56</td>
<td>1.60</td>
<td>1.65</td>
</tr>
<tr>
<td>error (μm)</td>
<td>0.01</td>
<td>0.06</td>
<td>0.48</td>
<td>0.53</td>
<td>1.00</td>
<td>1.04</td>
<td>1.51</td>
<td>1.56</td>
<td>1.60</td>
<td>1.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>target (μm)</th>
<th>1.80</th>
<th>1.84</th>
<th>2.00</th>
<th>2.04</th>
<th>2.08</th>
<th>2.12</th>
<th>2.52</th>
<th>2.56</th>
<th>2.88</th>
<th>2.92</th>
</tr>
</thead>
<tbody>
<tr>
<td>actual (μm)</td>
<td>1.80</td>
<td>1.84</td>
<td>2.00</td>
<td>2.03</td>
<td>2.08</td>
<td>2.12</td>
<td>2.53</td>
<td>2.56</td>
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<td>2.92</td>
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<td>0.01</td>
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<td>1.00</td>
<td>1.04</td>
<td>1.51</td>
<td>1.56</td>
<td>1.60</td>
<td>1.65</td>
</tr>
</tbody>
</table>

4.3. Anti disturbance analysis
By detecting the input port of displacement signal on data collecting card, there exists disturbance signal whose amplitude is about 0.06v, showed by figure 5, and the biggest disturbance formed by it to the displacement feedback signal is 0.12 μm. (0.06/5×10=0.12). But from the step response curve on figure 4, we can see that the actual output displacement error margin only have 0.01 μm. So the single neuron PSD control represses the disturbance effectively, and has the very strong adaptability to outward environment. Meanwhile, it surely can reach the very high positioning accuracy.

5. Conclusion
This paper aim at hysteresis, non-linearity of piezoelectric ceramic actuator and uncertainty influenced by many factors, so the single neuron PSD control algorithm is adopted to control and test the micro- displacement system based on one-way flexure hinge. The experiment results show that the
single neuron PSD control system has the high accuracy, quick response and the strong ability of anti disturbance etc. It can be well satisfied with the displacement request of micro-displacement platform.

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References
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