Tracking Control for Piezoelectric Actuators with Advanced Feed-forward Compensation Combined with PI Control

Cristian Napole, Oscar Barambones, Mohamed Derbeli, Mohammed Yousri Silaa, Isidro Calvo and Javier Velasco.
Piezoelectric Actuators: State of art

- Active Vibration Systems.
- Sensing.
- Energy Recovery.
- Stick-slip motors.

Nonlinearities
- Hysteresis
- Creep.
- Vibration dynamics.

Common controllers
- SMC.
- SMC w/ PID.
In this research:

- Feedback-Feedforward control architecture for PEA tracking.
- FF compared: Artificial Neural Networks (ANN) & Hammerstein Wiener (HW).
- Feedback controller: Proportional-Integral (PI).
- Performance metrics: error analysis, control signal and integral of absolute error (IAE).
Hardware involved

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Dimensions</td>
<td>7.3x7.3x36</td>
<td>mm</td>
</tr>
<tr>
<td>Max displacement</td>
<td>38.5</td>
<td>µm</td>
</tr>
<tr>
<td>Max force</td>
<td>1000</td>
<td>N</td>
</tr>
<tr>
<td>Drive voltage range</td>
<td>0-150</td>
<td>V</td>
</tr>
<tr>
<td>Error due to hysteresis</td>
<td>15</td>
<td>%</td>
</tr>
</tbody>
</table>
Hysteresis description

- Triangular input signal.
- Amplitude: 145V.
- Period: 1s.
- Sampling time: 1kHz.
ANN Settings

• TDNN
• Training set: Input voltage & displacement along 10s.
• 70/15/15 data split.
• Levenberg-Marquardt training algorithm.
• 22 neurons.
• 5 delays.
• Metric: mean squared error (MSE).
HW settings

Input/Output Polynomial.

Training set: Input voltage & displacement along 10s.

Metric: fit percent.
Results: Hysteresis fitting

- **Hysteresis Fitting**
  - Displacement [μm] vs Voltage [V]
  - Graph showing displacement versus voltage with different lines representing ANN, HW, and PEA.

- **Error**
  - Voltage [V] vs Time [s]
  - Graph showing error with lines for ANN and HW.
Results: Hysteresis fitting
Results: Tracking performance

- $K_p = 10.$
- $K_i = 1000.$
Results: Tracking performance

- $\text{IAE}_{\text{ANN}} = 0.0384$.
- $\text{IAE}_{\text{HW}} = 0.0486$.
Conclusions

- Experiments with a commercial PEA were carried.
- The hysteresis plot was obtained.
- ANN & HW was used for mapping and feed-forward.
- A PI controller was implemented in the feedback loop.
- HW has a good performance in terms of control action.
- ANN behaves better in terms of tracking (Lowest IAE).
- Future research: Comparison with advance PI controllers (FPID, neural), other ANNs configurations (LSTM), different HW configuration or optimisation, etc.
Acknowledgements

• Basque Government.
• Diputación foral de Álava.
• Basque Country University.