Fast and Accurate
Force and Motion Control of
Shape Memory Alloy (SMA) Actuators

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What is SMA?

an alloy which

1. has an \textit{austenite} crystal phase, which is stable at higher temperatures,

2. has a \textit{martensite} crystal phase, which is stable at lower temperatures, and

3. exhibits the \textit{shape memory effect}.

Austenite crystals are cubic: \_

Martensite crystals are monoclinic: \\

or \\[opened_square]
The Shape Memory Effect

hot

cooling

cold

warming

deform
SMA Actuators

- Convert heat into mechanical work
- Are usually heated electrically
- Need an external force to stretch them
- Are made of straight or coiled SMA wire

SMA wires are easily stretched when cool

but recover their original shape when heated
Advantages
- mechanically simple
- large force outputs
- high force-to-weight ratio
- cheap
- clean
- silent
- spark-free
- easily miniaturized

Disadvantages
- inefficient
- slow
- hard to control

but we can fix these
Control Challenges:

- nonlinear
- hysteresis
- nonrepeatable
- hard to model
- limit cycles

antagonistic pairs help but we can model the high-frequency dynamics force feedback seems to solve this problem
Making SMA Faster

- our *rapid heating algorithm* allows faster electrical heating without risk of overheating
- doubles actuator velocity
Why Focus on Heating?

Excerpt from Flexinol (tm) data sheet:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Current (mA)</th>
<th>Contraction Time (sec)</th>
<th>Off Time 70C</th>
<th>Off Time 90C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050</td>
<td>50</td>
<td>1</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>0.075</td>
<td>100</td>
<td>1</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>0.100</td>
<td>180</td>
<td>1</td>
<td>0.8</td>
<td>0.4</td>
</tr>
</tbody>
</table>

If we use the recommended safe heating currents then, for a thin wire, heating takes longer than cooling.
How it Works

1. measure SMA wire resistance

2. limit heating power to a value computed from the resistance
Tracking Response

- rapid heating off
- rapid heating on

Tracking response of SMA actuator

Output shaft angle (degrees)

Time (s)
Power to Each Actuator

- **rapid heating off**
- **rapid heating on**

![Graph showing heating power over time](image-url)