Introduction to Control Theory

PID and Fuzzy Controllers

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Motivation

“...hark, now hear the sailors cry,
smell the sea, and feel the sky ...”
State of the system

Structure of the system

- **System:** Something that changes over time
- **Control:** Influence that changes system behavior
- **State:** control variable (e.g. percentage)
- **Reference:** what we want the system to do
- **Output:** Measuring some aspects of the system
- **Feedback:** Mapping from output to input
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Control Theory: How to pick a proper Input signal while achieving

- Stability
- Tracking
- Robustness
- Disturbance rejection
- Optimality
PID Control Design

Maintaining Speed

- State: velocity (v)
- Input: Pedal on/off (u)

\[ F = cu \] (1)

- Relating Input to State:

\[ F = ma, \quad ma = cu, \quad \frac{dv}{dx} = a, \quad \dot{v} = \frac{c}{m} u \] (2)
Control signal should handle errors \( (e = \text{control Input} - \text{Output}) \)

Error handling criteria:
- Small error = small Input
- Control Input should not be jerky
- Control Input should be dynamic

Brainstorming!
\[ u(t) = K_P e(t) + K_I \int_0^t e(t)\,dt + K_D \frac{\delta e(t)}{\delta t} \]

- **P**: Reduce rising time (stability), doesn’t eliminate S-S error
- **I**: slow response, S-S eliminated, overshoots
- **D**: stabilize system, eliminates overshooting, noise sensitivity

<table>
<thead>
<tr>
<th></th>
<th>Rise time</th>
<th>Overshooting</th>
<th>settling time</th>
<th>S-S error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P</strong></td>
<td>decreases</td>
<td>increases</td>
<td>small change</td>
<td>decreases</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>decreases</td>
<td>increases</td>
<td>increases</td>
<td>eliminates</td>
</tr>
<tr>
<td><strong>D</strong></td>
<td>small change</td>
<td>decreases</td>
<td>decreases</td>
<td>no-change</td>
</tr>
</tbody>
</table>
**Trail and Error**

- Increase P until it oscillates "the push"
- Increase I to decrease rise time and eliminate S-S
- Increase D to decrease overshoots, after testing with noise
- Calibration may take days
- Not Reusable/Practical
Ziegler–Nichols method

- Heuristic tuning method
- Only P is set "Simple"
- Creates quarter Wave Decay
- Works perfectly in a sluggish, laggy environment
- May cause vigorous overshoots

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Kp</th>
<th>Ki</th>
<th>Kd</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.5Kc</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>0.45Kc</td>
<td>1.2Kp/Tu</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>0.6Kc</td>
<td>2Kp/Tu</td>
<td>KpTu/8</td>
</tr>
</tbody>
</table>

- Kp is increased until it oscillates with constant amplitude
- At constant oscillations, Kp = Kc and Tu is oscillation period
Computerized Software
- Collects Data, Builds a model and suggest Gains
- Robustness issues.

Neuro-PID Controlling
- Output is feedback to the neural network in a recurrent way.
- Adaptive to changes.

Others: Fuzzy PID controller, Neuro-Fuzzy PID controller
Limitations

▶ PID can be represented as an observer
▶ Linearity
▶ Noise in D (Filtering)
▶ Windup: Large change of setpoints occurs, I accumulates error during rise, thus overshoots. (Limit it)
▶ Not useful in a system with fragile actuators
Fuzzy Logic Controller

"Fuzzy theory is wrong, wrong, and pernicious. What we need is more logical thinking, not less. The danger of fuzzy logic is that it will encourage the sort of imprecise thinking that has brought us so much trouble. Fuzzy logic is the cocaine of science."

- Prof. Kahan, University of California, Berkeley
Where are the Fuzzy systems?

- Shifting gears in automatic transmissions in cars
- Focussing your camera and camcorder
- Running the cruise controls
- Controlling dishwashers and washing machines
- Heaters and many more.

The plan?

- Design a fuzzy controller using:
  - Fuzzification ... Membership functions for our controlled variable,
  - A Rule Base
  - Defuzzification ... Get a control signal
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To be or not to be

- A statement is either True or False
- A thing is either living or dead
- A person is either funny or not

- This Statement is False
- A virus is neither living or dead
- Fun is relative non measurable feature
- Robert is tall
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- Robert is tall
Fuzzy logic permits degrees of truth.
We can’t accept the sharp classification
Our concept of tallness is Fuzzy.

50 shades of truth
Robert can be tall by 0.9 truth value
The sky is a member of the set of cloudy skies by a truth value of 0.7
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Fuzzification

Tip: smooth ⇔ expensive
Temperature is 80

- It’s 0.67 room is okay
- 0.33 room is hot
Rule Base

- If room is Cold, set the Heater on High mode
- If room is Okay, set the Heater on medium mode
- If room is Warm, set the Heater on Low mode
- Centroid
- Max-membership principal
- Center of sums
- Center of Largest area and More
Centroid (center of gravity)

\[ Z^* = \frac{\int c(z) \cdot zdz}{\int c(z)dz} \]
Weighted Average

\[
\mu = \frac{(0.3 \times 2.5) + (0.5 \times 5) + (1 \times 6.5)}{0.3 + 0.5 + 1} = \frac{5.41}{1.8} = 5.41 \text{ meters}
\]
Mean Max

\[ Z^* = \frac{a + b}{2} \]
Center of Sums

\[ z^* = \frac{\int_Z z \sum_{k=1}^{n} \mu_{C_k}(z) \, dz}{\int_Z \sum_{k=1}^{n} \mu_{C_k}(z) \, dz} \]
Conditions

- Each membership function overlaps only the nearest neighbouring membership functions.
- Membership values in all relevant fuzzy sets should sum up to 1 (approximately)
- Dis-ambiguity, Computational-Complexity should be considered when choosing a defuzzification method.
Pros:

▶ Behavior based (not Model based)
▶ Simple, intuitive for starters
▶ Can work as a nonlinear controller (without the need for linearization)

Cons:

▶ May not scale well to large rulesets
▶ Difficult to estimate the membership function
Conclusion

- Structure of the feedback system
- How to mitigate errors
- PID design and components
- Gains’ tuning
- Fuzzy logic
- (De)fuzzification & fuzzy rules
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