Pneumatic Actuator Test Stand

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Agenda

Motivation

Hardware

Control Software

Many new actuator designs…

[2]

[1]

[3]

[4]

References listed on last slide

….But lack of unified testing standards

[5] One key issue seen in the literature is incomplete reporting of test methods and testing equipment. This makes it **difficult to fully understand and trust** the reported results, to **replicate** the tests, or to **extend or advance the research**

[6] **Soft robotics lacks standard** benchmarks, metrics, data sets, measurements and characterization workflows, and manufacturing recipes

References listed on last slide

This work: hardware and software for testing pneumatic actuators

Goal: an **open-source**, **easy-to-use** test stand with **repeatable** data collection for **demonstrating** actuator designs decisions

Goal: an open-source, **easy-to-use** test stand with **repeatable** data collection for **demonstrating** actuator designs decisions

Make all aspects publicly available so others may use, modify, and expand upon

Goal: an **open-source**, **easy-to-use** test stand with **repeatable** data collection for **demonstrating** actuator designs decisions

Allows reconfiguration without redesign for new actuators, valves, etc.

In-depth documentation and code commenting makes pneumatic controller customization accessible to non-programmers

Goal: an **open-source**, **easy-to-use** test stand with **repeatable** data collection for **demonstrating** actuator designs decisions

Previous two points grant ability for different labs to recreate the same data

Goal: an **open-source**, **easy-to-use** test stand with **repeatable** data collection for **demonstrating** actuator designs decisions

Setup allows for comparing and validating various actuator design decisions

Prior work

Multiple Outputs to volume

Multiple Solenoid Control Valves

Air inlet

Citation: Clarke Teeple, https://ctrl-p.cbteeple.com/latest/index.html

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Open-source hardware

Schematics of all hardware and electronics used to be publicly available for others to recreate and adapt for their own experiments

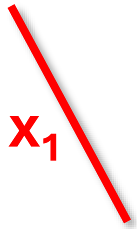
Modularity

All mounting equipment for sample objects and actuators can be fabricated using 3d printing

Allows stand to accommodate any actuator design or desired test set-up in either horizontal or vertical orientation

Easy to work with variables of interest

Flexibility in modularity makes isolating any physical variable between different test conditions simple

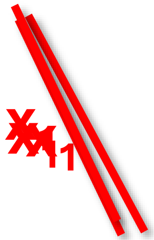


Easy to work with variables of interest cont.

So, if an engineer wants to change actuator design parameters…

Easy to work with variables of interest cont.

…They can easily do so in software, and 3D print alternate mounting hardware



Electronics & Pneumatics

Inlet pressure line

Barrel-jack for power

Output to volume

Agenda

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PID control overview

Where $\boldsymbol{e(t)} = \textbf{reference signal} - \textbf{measured signal}$

An engineer chooses the gain (K) values

Design criteria inform $\tau(t)$

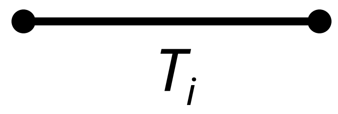
This stand’s pneumatic PID control system

Where z = 1 time step of the control system

Ease of set-up

Zeigler-Nichols Tuning Process

1. Increment K_P until oscillations occur at a steady state
2. Set this K_p as K_u
3. Measure the steady state oscillation period, T_i



*Expanded, pictographic instructions to be included in the documentation

What data looks like

[1]

Zeigler-Nichols & ideal gains

- This controller has the capacity to follow programmed trajectories with high accuracy
- Zeigler-Nichols tuning:

  $K_p = 0.675$

  $K_i = 0.00324$

- Fine manual tuning:

  $K_p = 0.4$

  $K_i = 0.00115$

Adjusting gains

Due to high flow rates, system gains are small in magnitude:

- K_p on the order of 10^{-1}
- K_i on the order of 10^{-3}
- K_d unnecessary given system response speed

Versatile trajectory following

Versatile trajectory following cont.

Versatile trajectory following cont.

Cycle testing for actuator lifetime characterization

- Each dot on the graph represents the average pressure during the ”top” of each step function from one cycle

The “top” of the function

Silpoxy seam burst

- Repeating trajectory cycle functions allows for **infinite test lengths**

Burst testing for actuator limit characterization

- Can also combine with video analysis to determine actuator's $\theta(P)$
- Safe to be around during this testing thanks to clear acrylic shielding

Controller limitations

Zeigler-Nichols tuning can be a time-intensive process

The controller struggles to follow negative slope trajectories near 10-13 PSI/sec. Currently unsure if that is actuator specific

References

[1] Doris et al. – 2024 – *Automated Computational Design of Soft Robots for Functionality and Durability*

[2] Puhlmann et al. – 2022 – *RBO Hand 3: A Platform for Soft Dexterous Manipulation*

[3] Preechayasomboon and Rombokas – 2020 – *Negshell casting: 3D-printed structured and sacrificial cores for soft robot fabrication*

[4] Hawkes et al. – 2021 – *Hard questions for soft robotics*

[5] Case and Marvel – 2024 – *FY24 Soft Robotics Report*

[6] Baines et al. – 2024 – *The need for reproducible research in soft robotics*