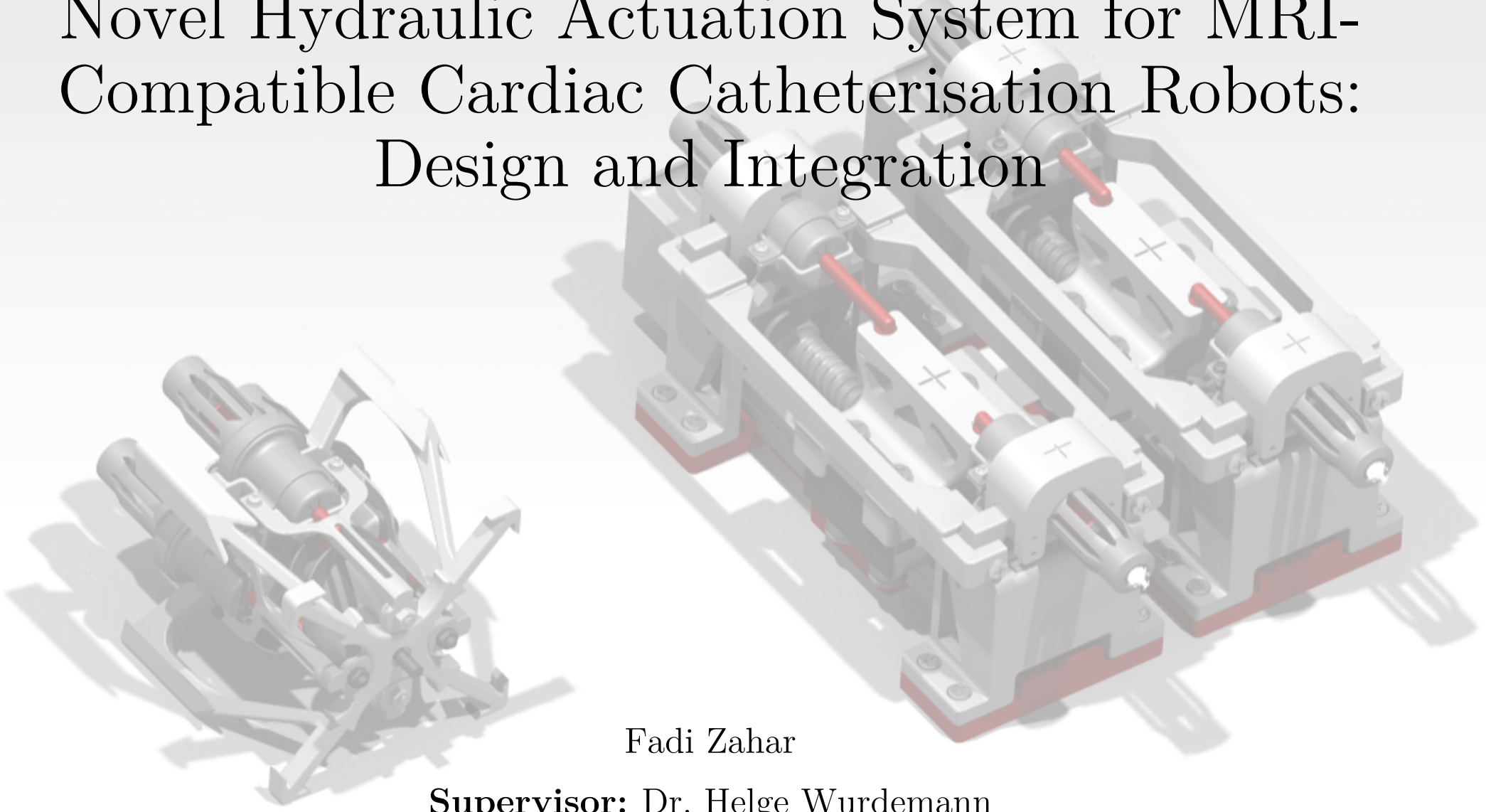
Novel Hydraulic Actuation System for MRI-Compatible Cardiac Catheterisation Robots: Design and Integration



Fadi Zahar

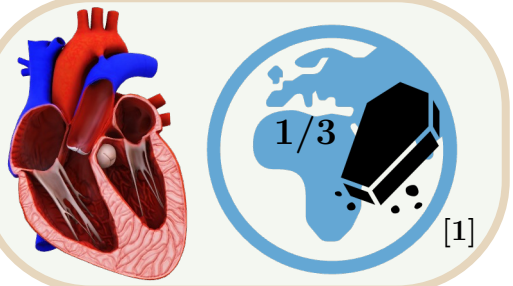
Supervisor: Dr. Helge Wurdemann

June 2023

UCL

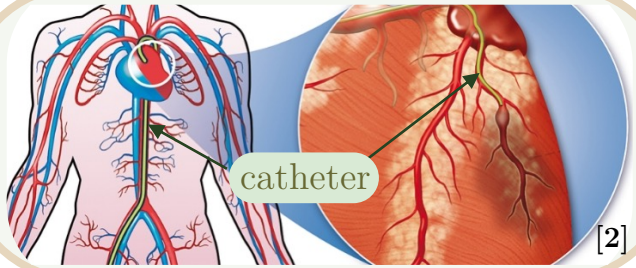
Introduction & Motivation

Cardiovascular Diseases



Diagnosed & Treated with

Cardiac Catheterisation



Current Problems

X-Ray Imaging

To guide the catheter

Harmful to patients and especially clinicians

Solution

MRI

- **Eliminates radiation**
- **More versatile**

BUT

- **Challenging ergonomics**

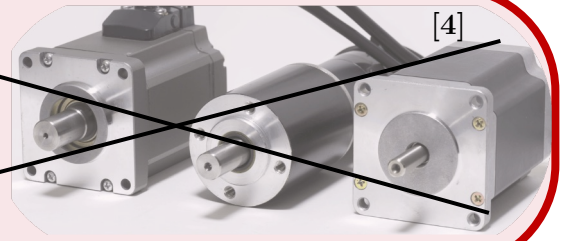
Clinical Need ⇓

Teleoperated MRI-guided Catheterisation

Main Challenge

MRI Compatibility - Actuators

Off-the-shelf motors



Aim

Design, Build, and Test an MRI-compatible actuator for teleoperated MRI-guided cardiac catheterisation.

Objectives

1. Develop a fully *MRI-compatible* actuator that allows for *continuous, unlimited, bidirectional rotation.*
2. Test the actuator's *performance.*
3. Integrate the actuator into a *catheter axial motion unit.*
4. Assess the *catheter translation manipulations.*

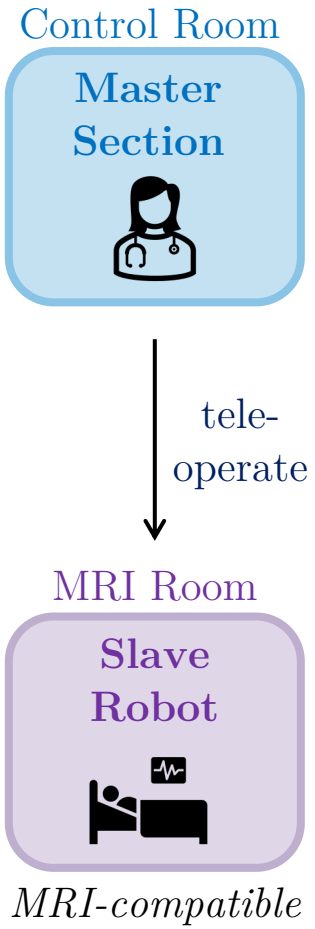
Background

MRI-Compatible Actuators

Ranked by importance		**Piezoelectric**	**Pneumatic**	**Hydraulic**
	Mechanism of Action	Piezoelectric effect: electricity ⇄ mechanical displacement	Uses compressed air to produce motion	Uses liquid (e.g., water or oil) to produce motion
1	*Inherent MRI-Compatibility*	No	Yes	Yes
2	*Dynamics Performance (accuracy, precision, speed, responsiveness)*	Good	Poor (compressible)	Excellent (incompressible)
3	*Maintenance*	Easy	Easy	More demanding

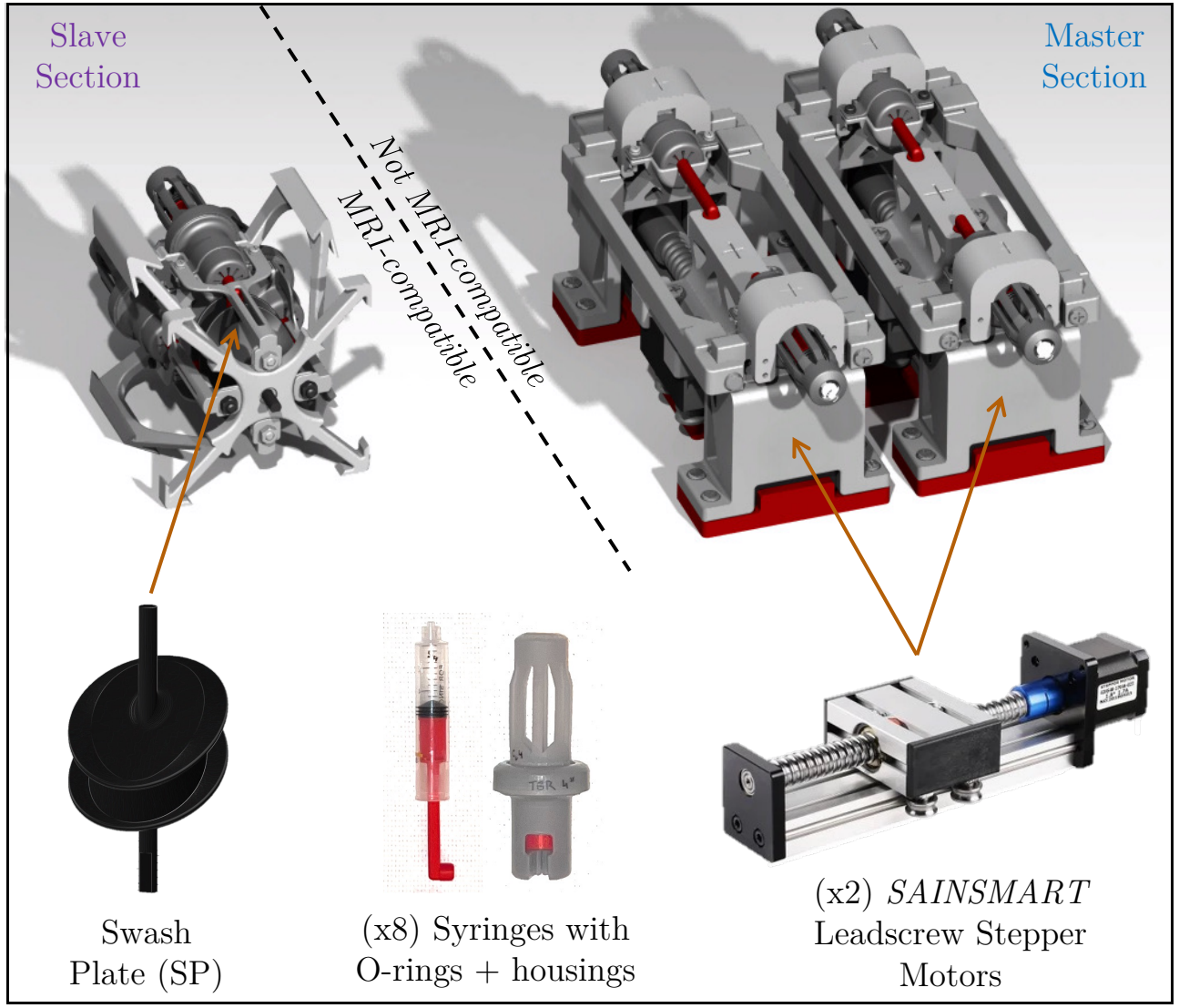
worst intermediate best

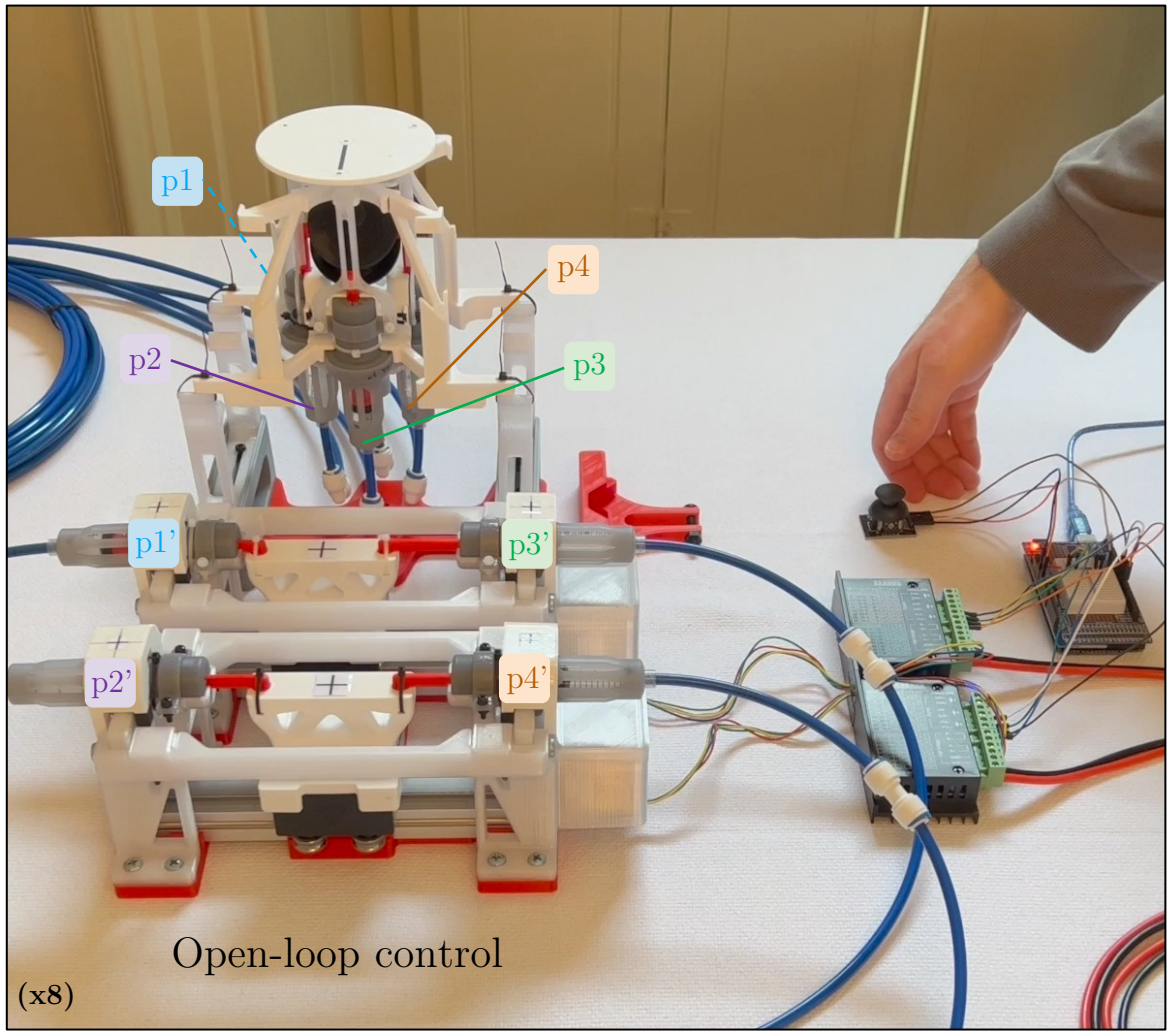
Master-Slave Configuration



Design 1: Novel Hydraulic Motor

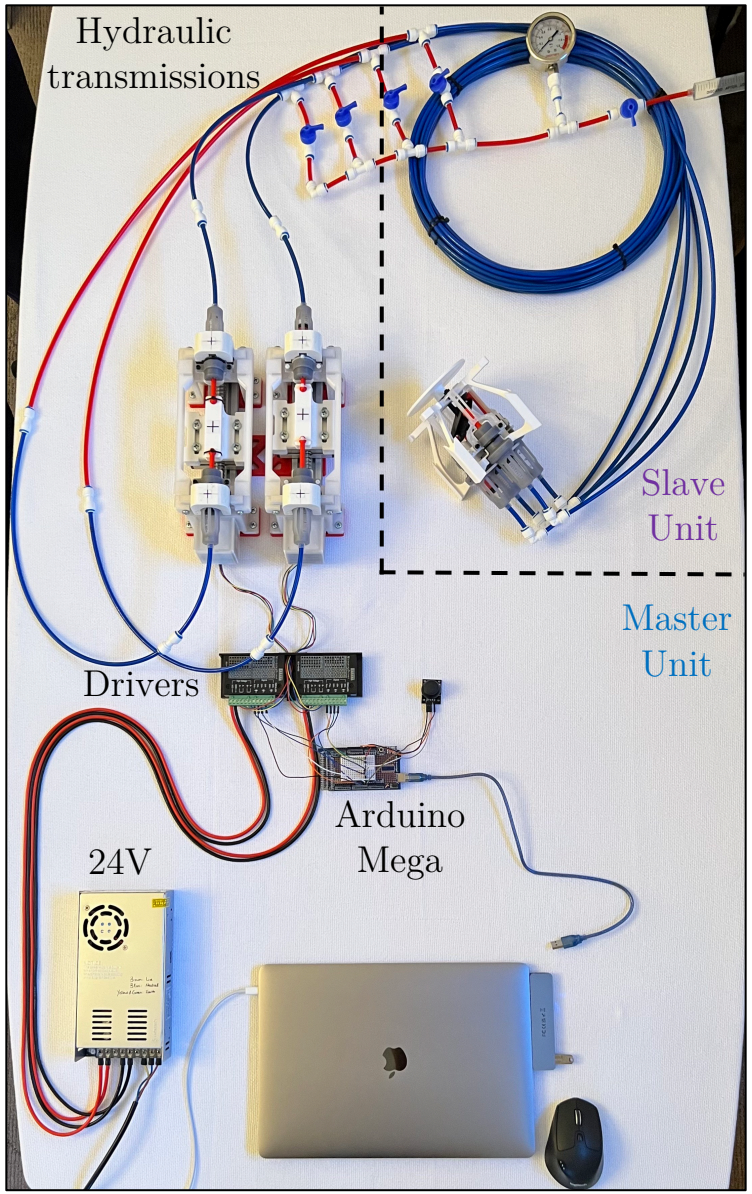
Swash Plate Mechanism: finite piston strokes → continuous, unlimited, bidirectional rotation

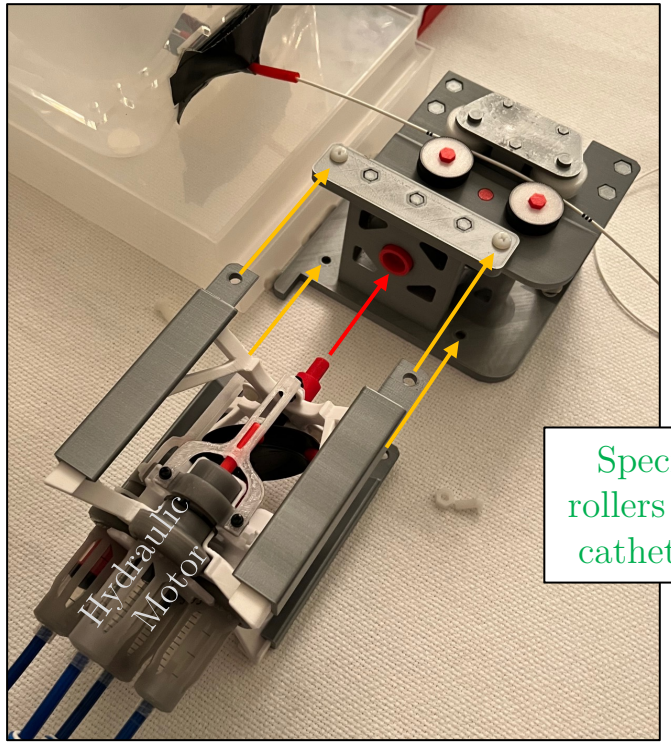




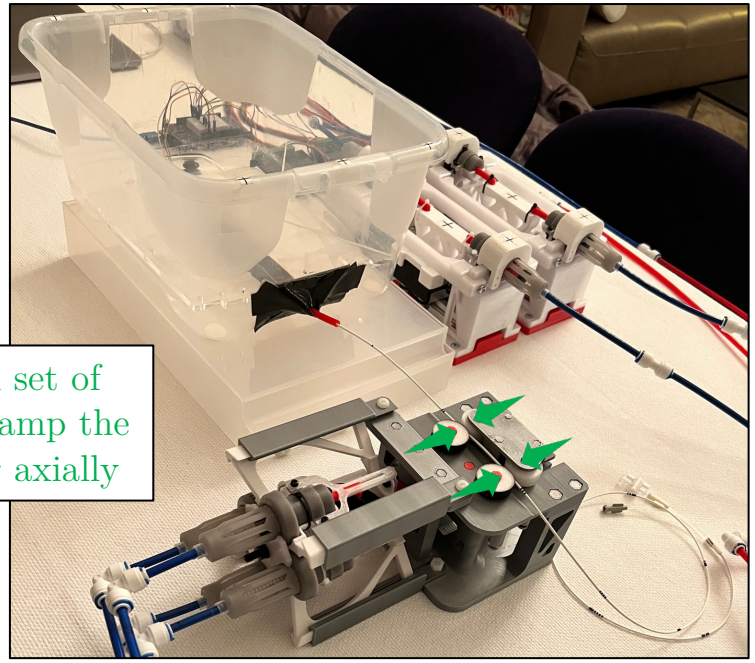
Four closed fluid lines: p1-p1', p2-p2', p3-p3', and p4-p4'

Design 2: Integration





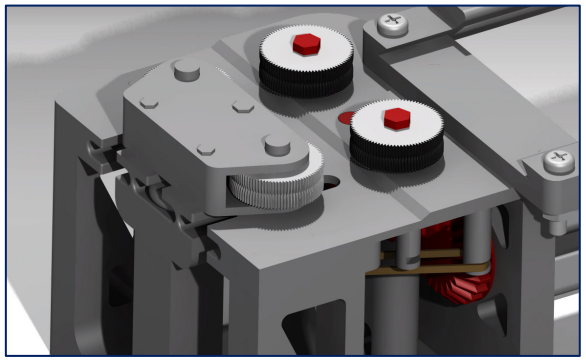
Catheter Axial Motion Unit



Special set of rollers clamp the catheter axially

Slave Unit

- Made entirely of MRI-compatible materials
- Use of 3D printing (FDM & SLA)
- Plastic bearings and nuts & bolts

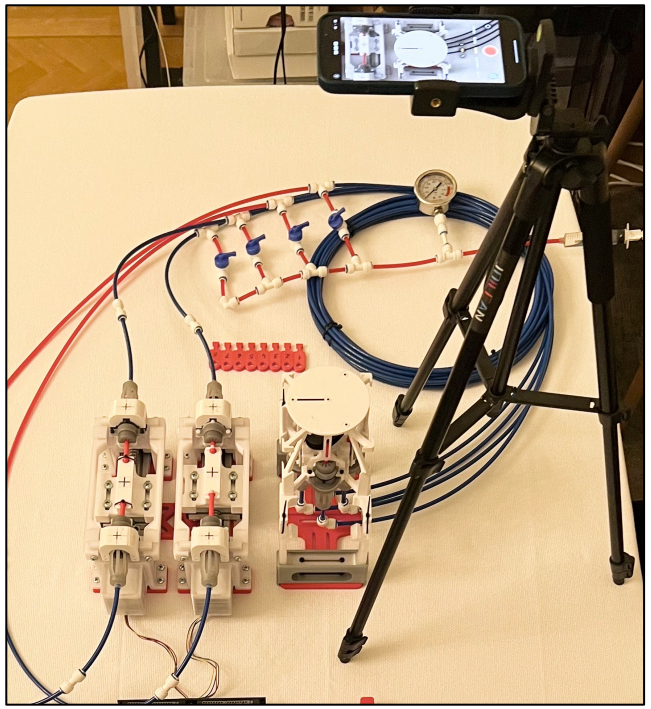


Experimental Setups

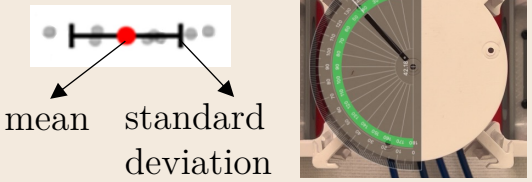
Experiments (A-B)
Hydraulic Motor Rotation

Positional Accuracy

Continuous Tracking



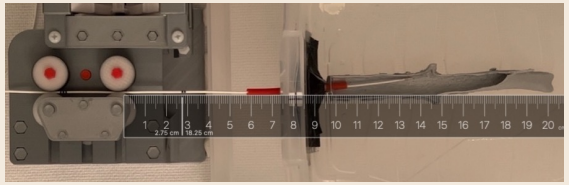
Positional Accuracy (PA)



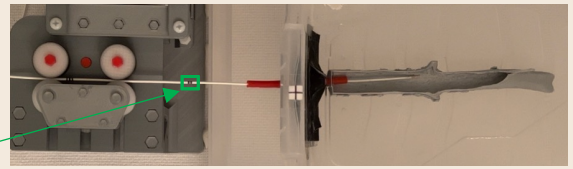
mean

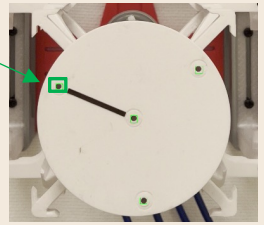
standard deviation

- Manual Measurement



- OpenCV Python
- Track selected landmarks coordinates at 30fps (iPhone)





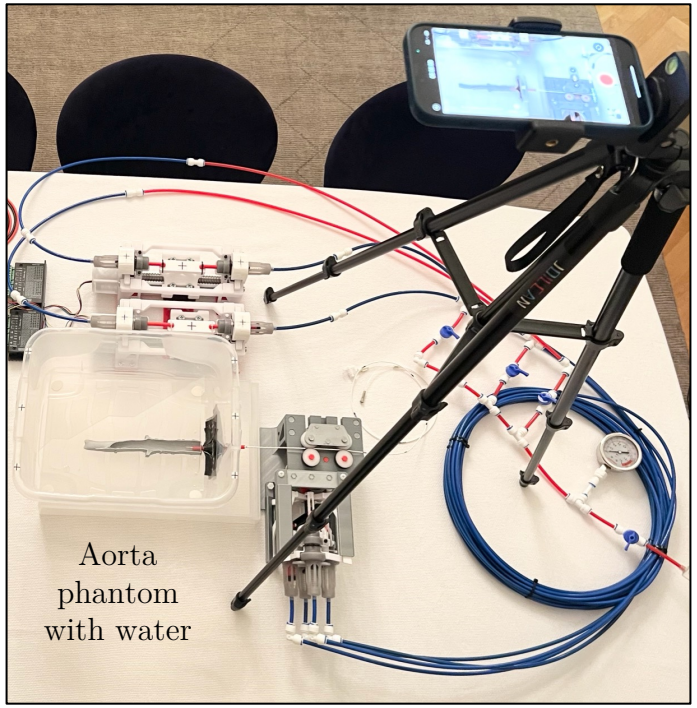
Continuous Tracking (CT)

All experiments were repeated *10 times each*

Experiments (C)
Catheter Translation

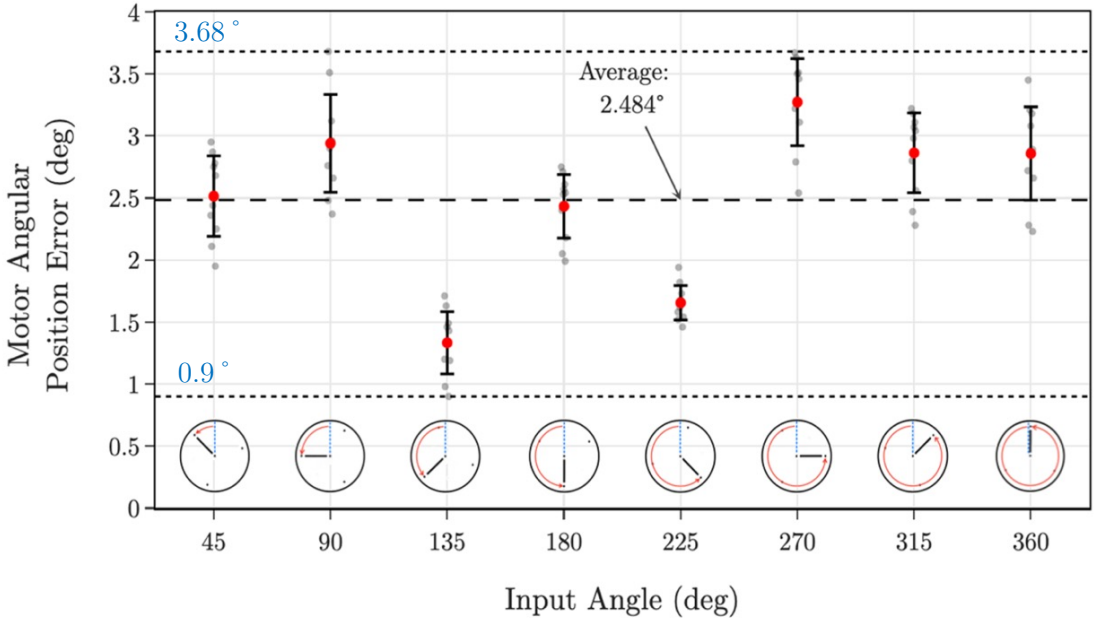
Positional Accuracy

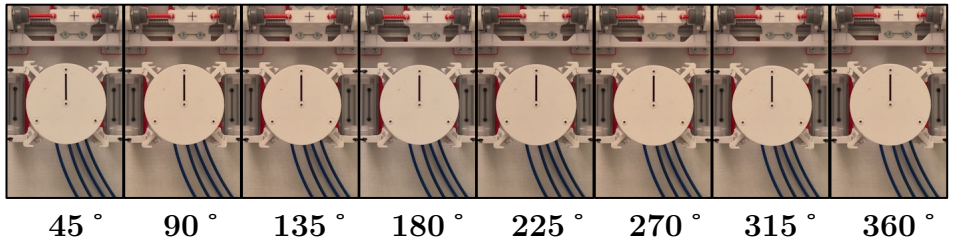
Continuous Tracking



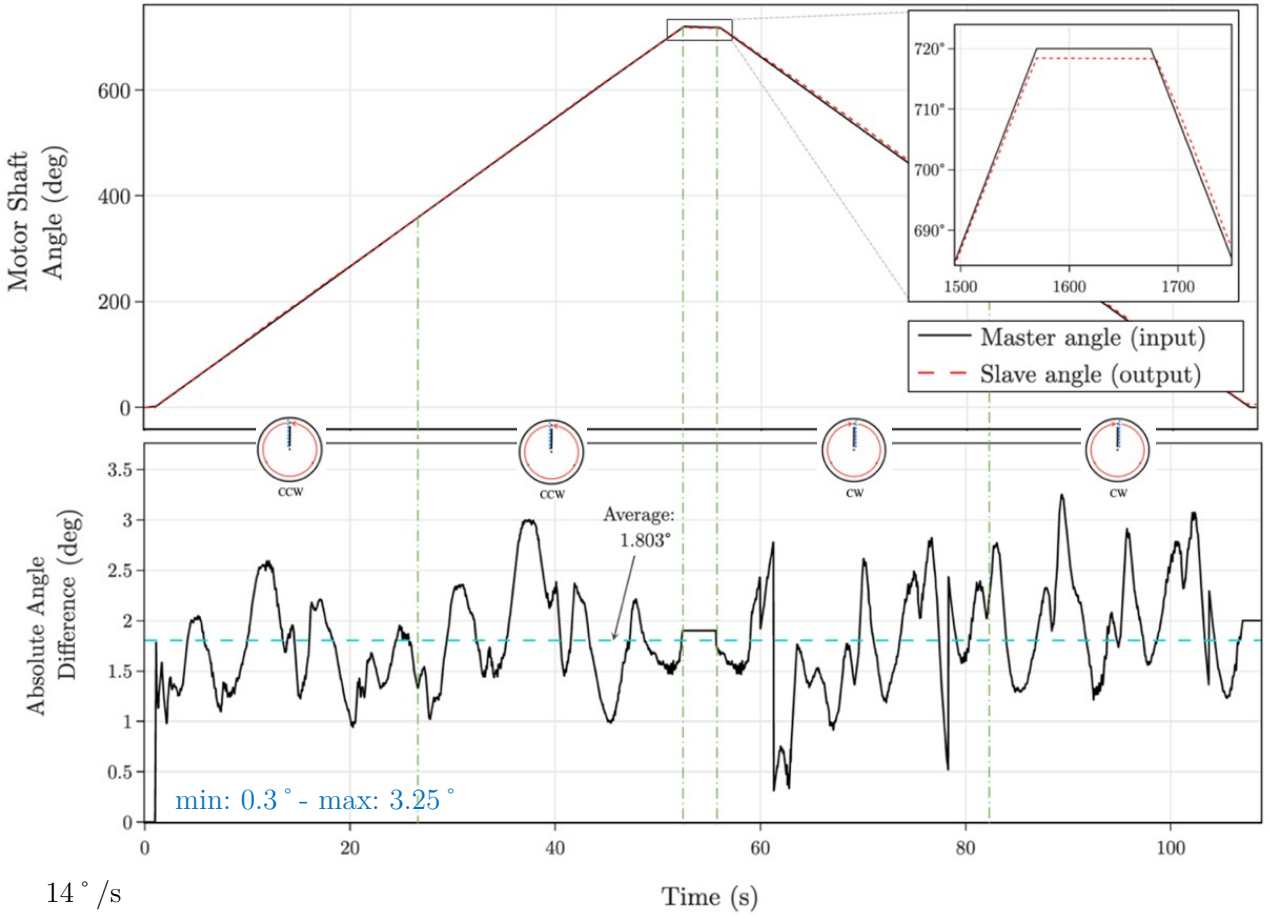
Experiments (A-B): Hydraulic Motor Rotation

(A) Positional Accuracy

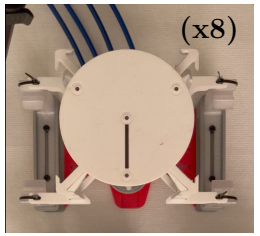


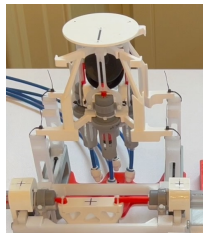


(B) Continuous Tracking



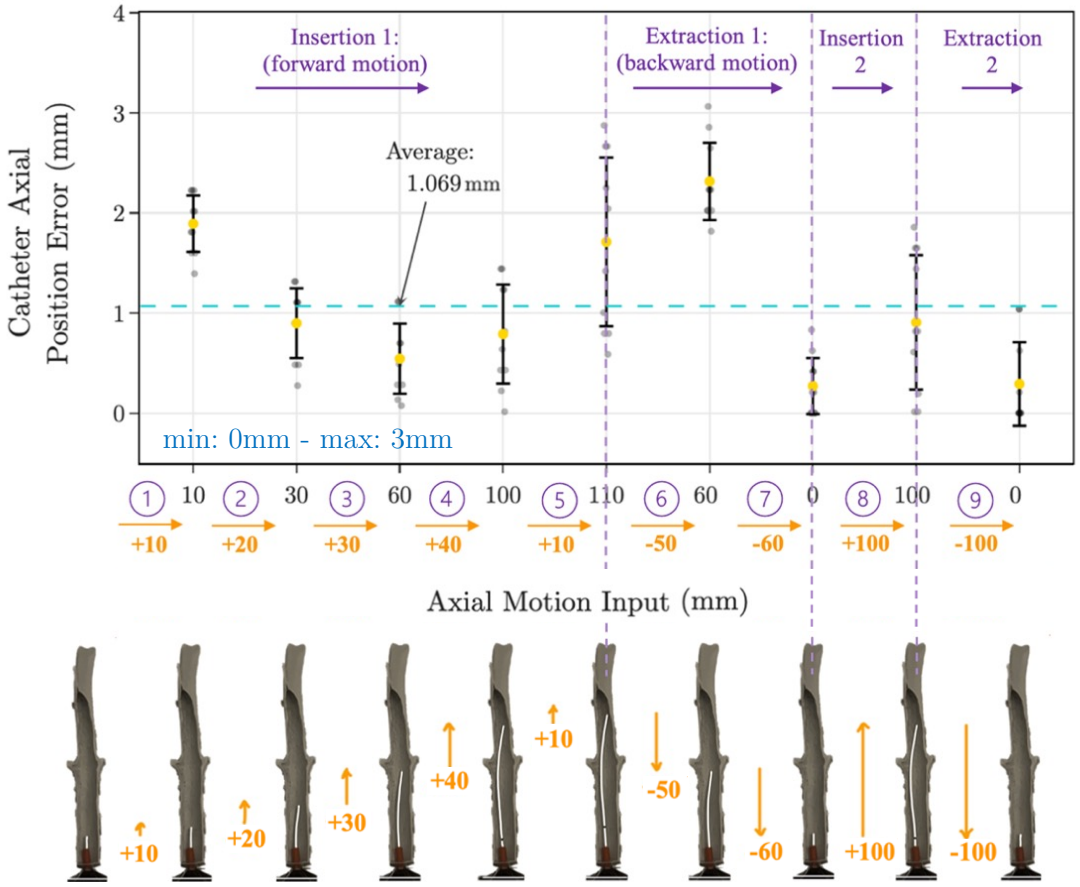
14 ° /s



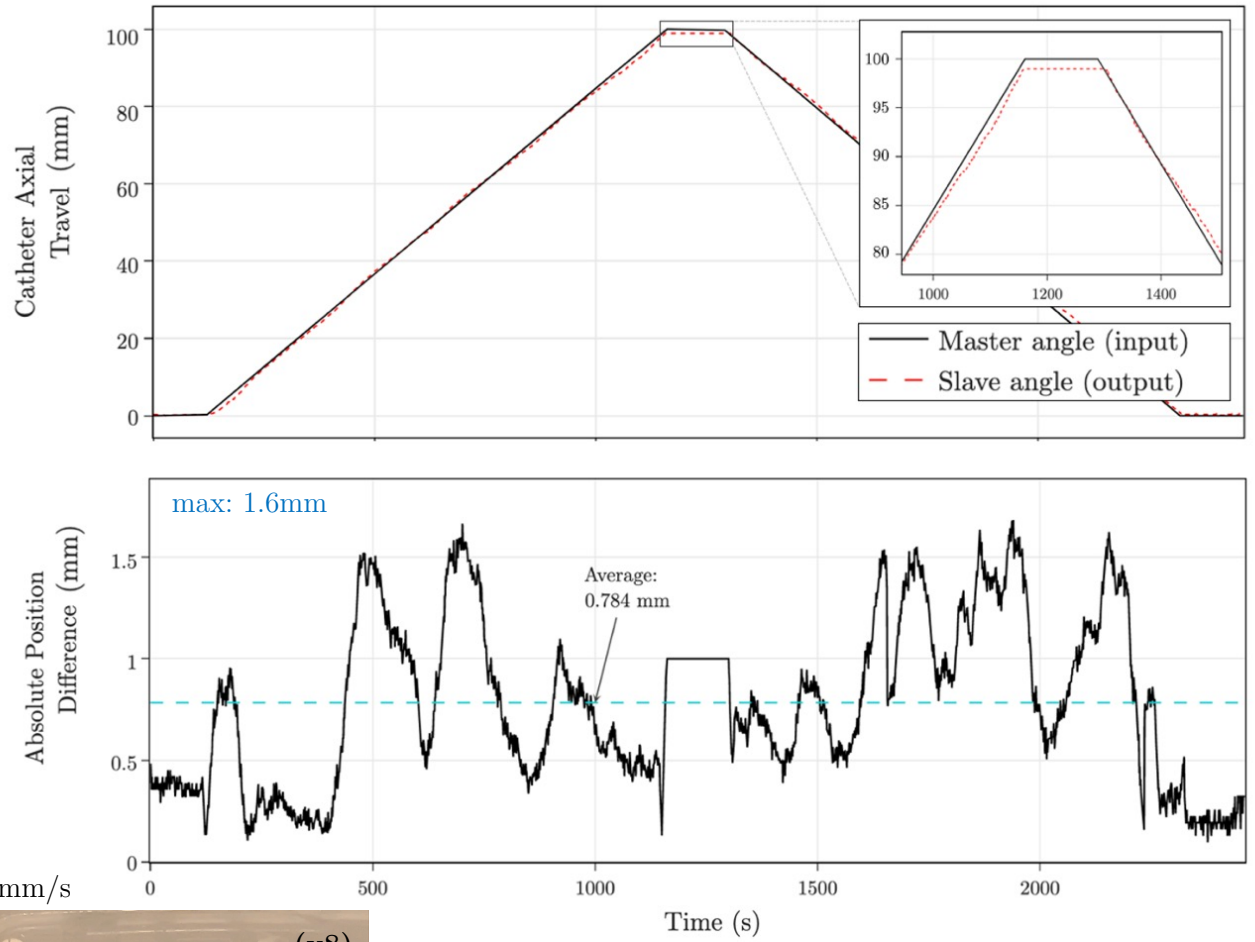


Experiments (C): Catheter Translation

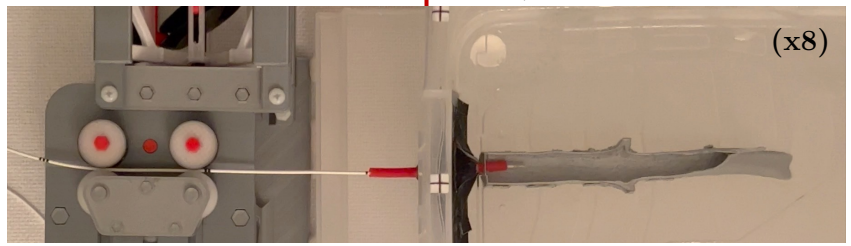
(C.1) Positional Accuracy



(C.2) Continuous Tracking



2.9mm/s



Conclusion, Limitations, Future Work

Conclusion

- Aim & Objectives accomplished. ✓
- PA & CT show promising results:
- Matches typical 1mm error for the catheter translation [5] .
- 0.64 ° tracking error for hydraulic motor in [6] compared to 1.8 ° in this study: friction

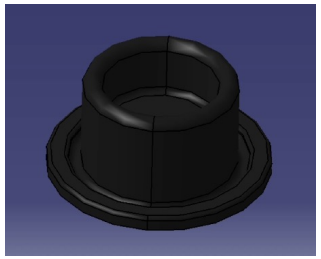
Limitations

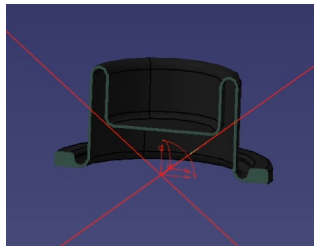
- PA: Manual (Random) Errors.
- CT: OpenCV errors and limited resolution + catheter bending → introduce inaccuracies.
- Experiments at very low speeds due to the stepper motors' limitations → switch to servo motors

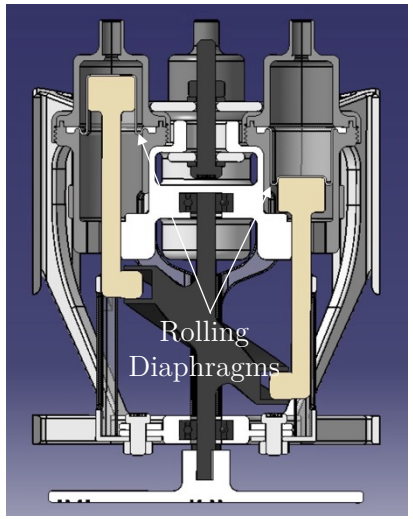
Future Work

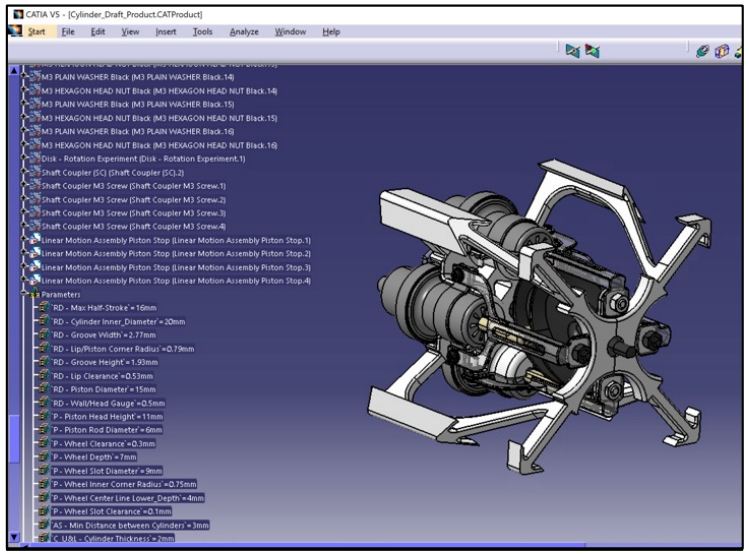
- Test under MRI (evaluate compatibility).
- Further tests: step responses 1-1 fluid line, force/torque weightlifting, sinusoidal positional tracking, positional frequency response: *responsiveness & time delays.*
- Bi-plane tracking, better cameras, higher resolutions.
- Dynamics simulations to optimise the design parameters.
- Construct Lower-friction components + reduce clearances
- Replace O-rings with Rolling diaphragms (RD) to reduce friction.

⇒ *The model is **already** fully parametric with 80+ RD-related parameters**









*

References & More...

I, Fadi Zahar, confirm that the work presented in this presentation is my own. Where information has been derived from other sources, I confirm that this has been indicated in the presentation.

[1] Cardiovascular diseases (CVDs). World Health Organization | WHO 2021. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds) (accessed May 7, 2023).

[2] What Is Cardiac Catheterization. National Heart Lung and Blood Institute | NHLBI 2022. https://www.nhlbi.nih.gov/health/cardiac-catheterization# (accessed May 17, 2023).

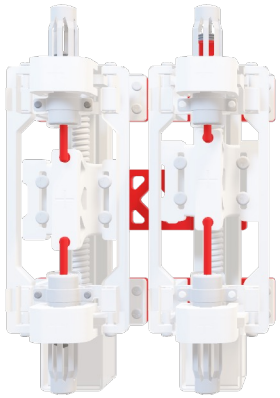
[3] MRI (Magnetic Resonance Imaging): What It Is, Types & Results. Cleveland Clinic 2022. https://my.clevelandclinic.org/health/diagnostics/4876-magnetic-resonance-imaging-mri (accessed May 29, 2023).

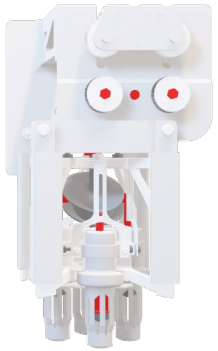
[4] Peterson Z. How to Drive a Servo Motor and the Components You Need. Octopart 2021. https://octopart.com/blog/archives/2021/07/how-to-drive-a-servo-motor-and-the-components-you-need (accessed May 30, 2023).

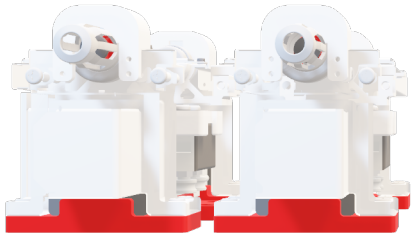
[5] Thakur Y, Holdsworth DW, Drangova M. Characterization of Catheter Dynamics During Percutaneous Transluminal Catheter Procedures. IEEE Trans Biomed Eng 2009;56:2140–3.

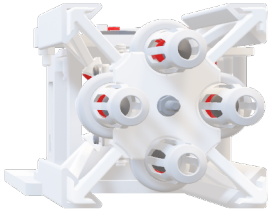
[6] Dong Z, Guo Z, Lee KH, Fang G, Tang WL, Chang HC, et al. High-Performance Continuous Hydraulic Motor for MR Safe Robotic Teleoperation. IEEE Robot Autom Lett 2019;4:1964–71. https://doi.org/10.1109/LRA.2019.2899189.

AUGMENT









Scan to view in AR: