**ACE$^{\pi}$** Group – **Artificial, Collective, Embodied, & Physical intelligence**

**Dr. S.M.Hadi Sadati**
Lecturer in Robotics & Mechatronics
School of Engineering and Materials Science
Queen Mary University of London

# "Towards Intelligent Endoluminal Navigation & Intervention:
## *Analytical, Artificial, and Embodied/Physical Intelligence in Action*"

**Analytical Methods & Classical Control**

**Artificial Intelligence**

**Collective Intelligence**

**Embodied/Physical Intelligence**

**Evolutionary structural response design**

Hardware design
Low-level control

Low/High-level control

**Social control (conformity to goals and rules)**

**Decision making (response mode control)**

Emerging behaviour

Structural response, outsource computation

**Co-pilot autonomy, task specialization**

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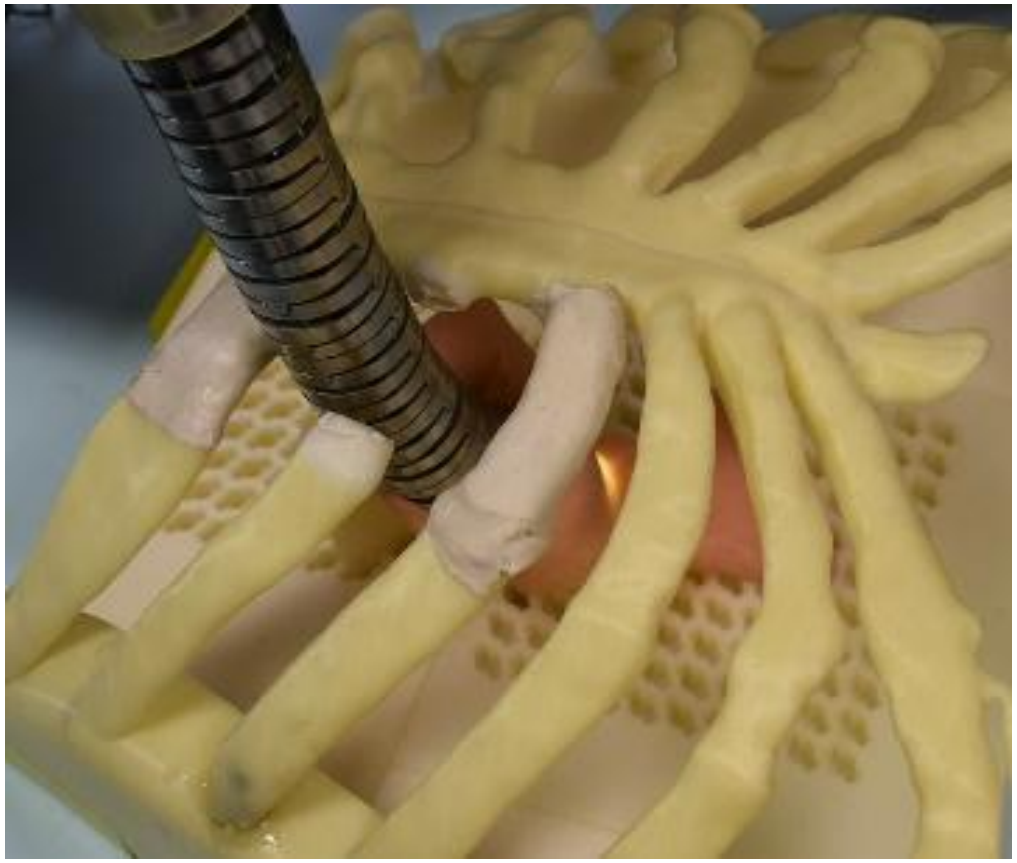
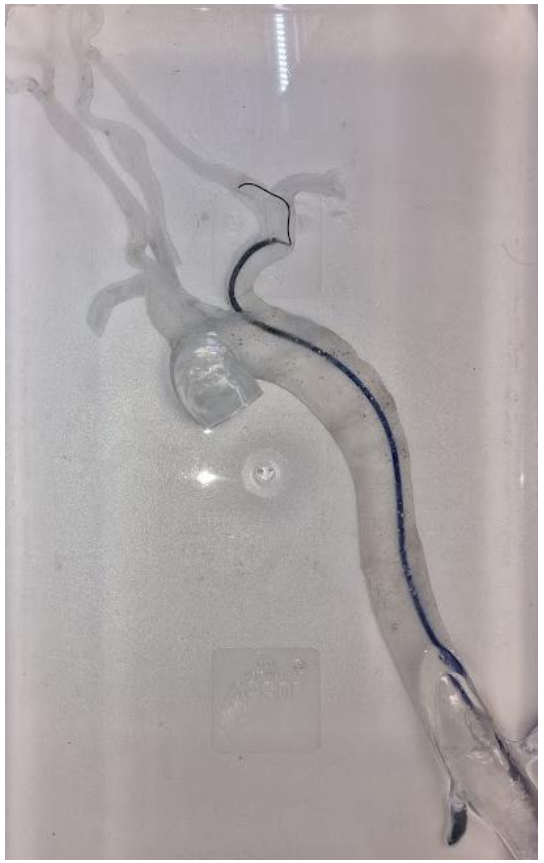
# "Towards Intelligent Endoluminal Navigation & Intervention:
## *Analytical, Artificial, and Embodied Intelligence in Action*"

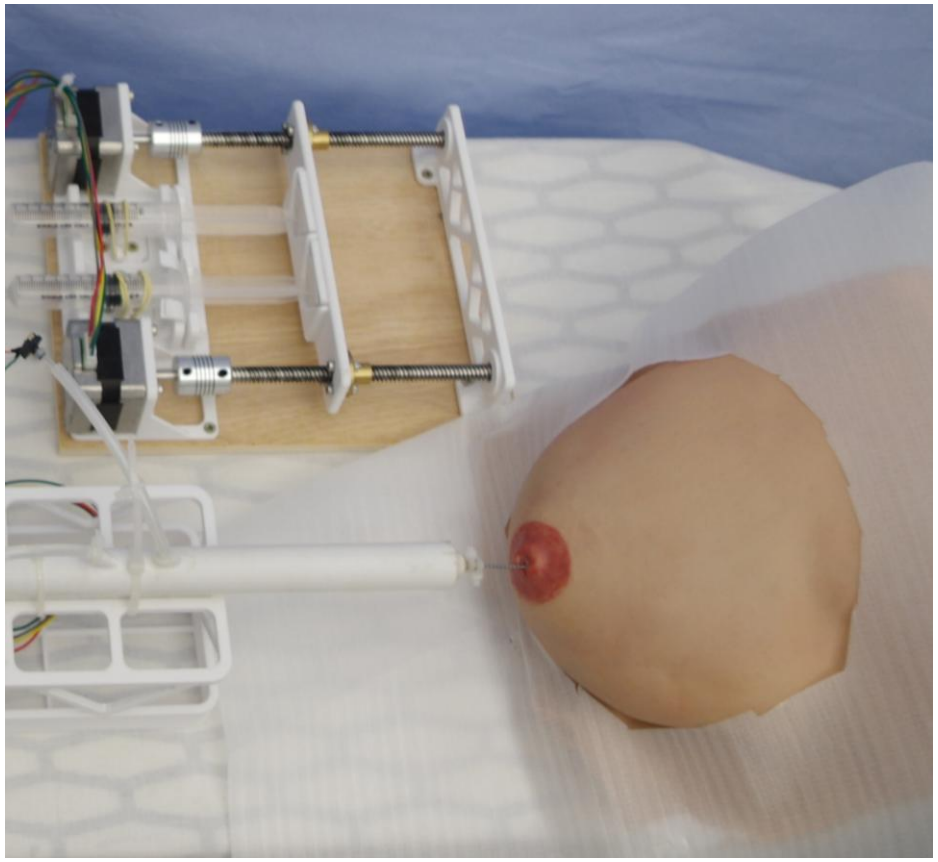
**Analytical Autonomy-** Surgical Aortic Valve Replacement (SAVR)



**AI Autonomy-** Mechanical Thrombectomy in Acute Stroke

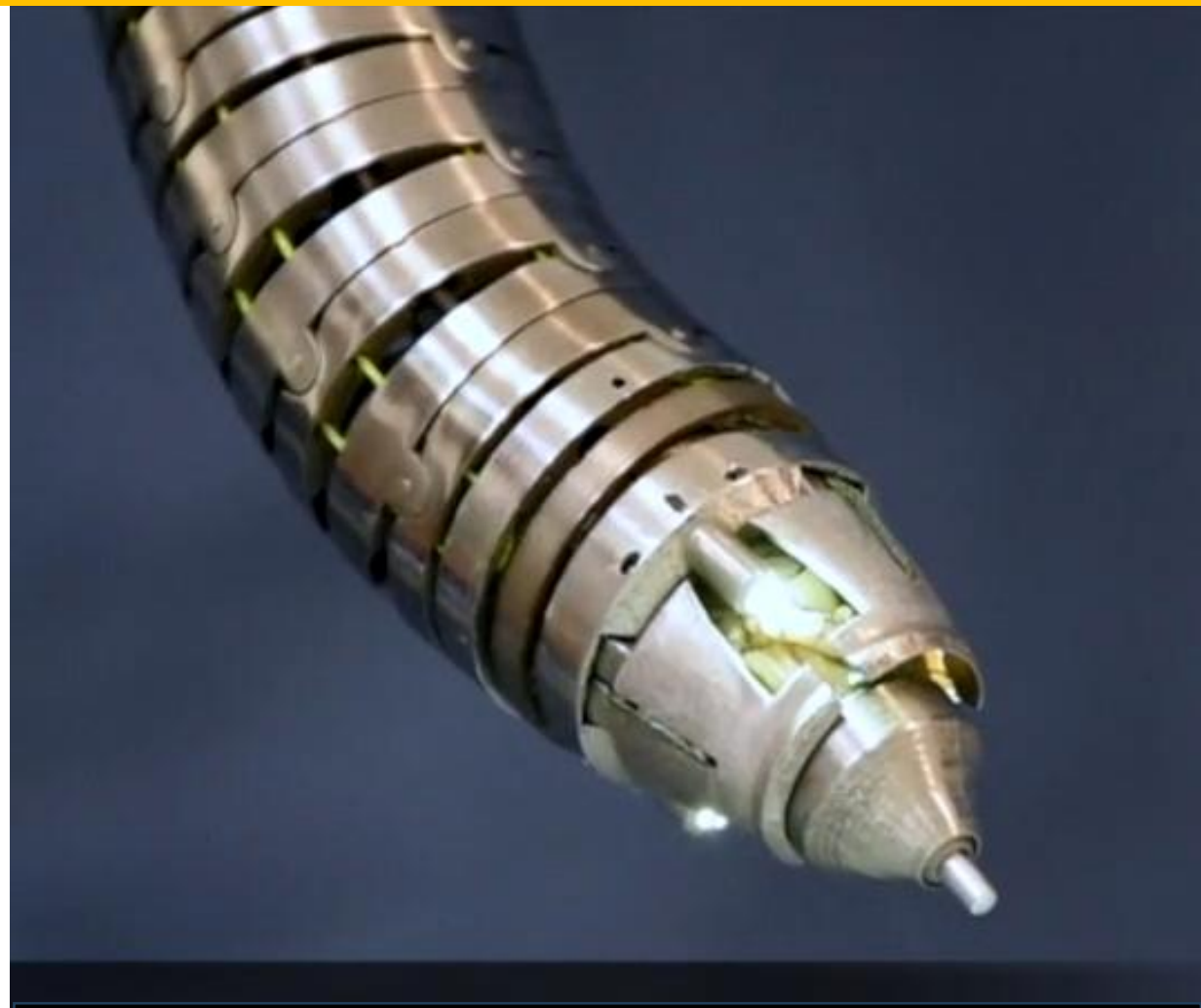


**EI Autonomy-** Invasive Ductal Carcinoma



# **Analytical Autonomy** - Surgical Aortic Valve Replacement (SAVR)

## Semiautonomous Robotic Manipulator for Minimally Invasive Aortic Valve Replacement



Izadyar Tamadon, S.M.Hadi Sadati, Virginia Mamone, Vincenzo Ferrari, Christos Bergeles, Arianna Menciassi

IEEE T-RO 2023

THIS WORK IS PARTIALLY SUPPORTED BY ARTERY. PROJECT NO 101017140

ARTERY AUTONOMOUS ROBOTICS

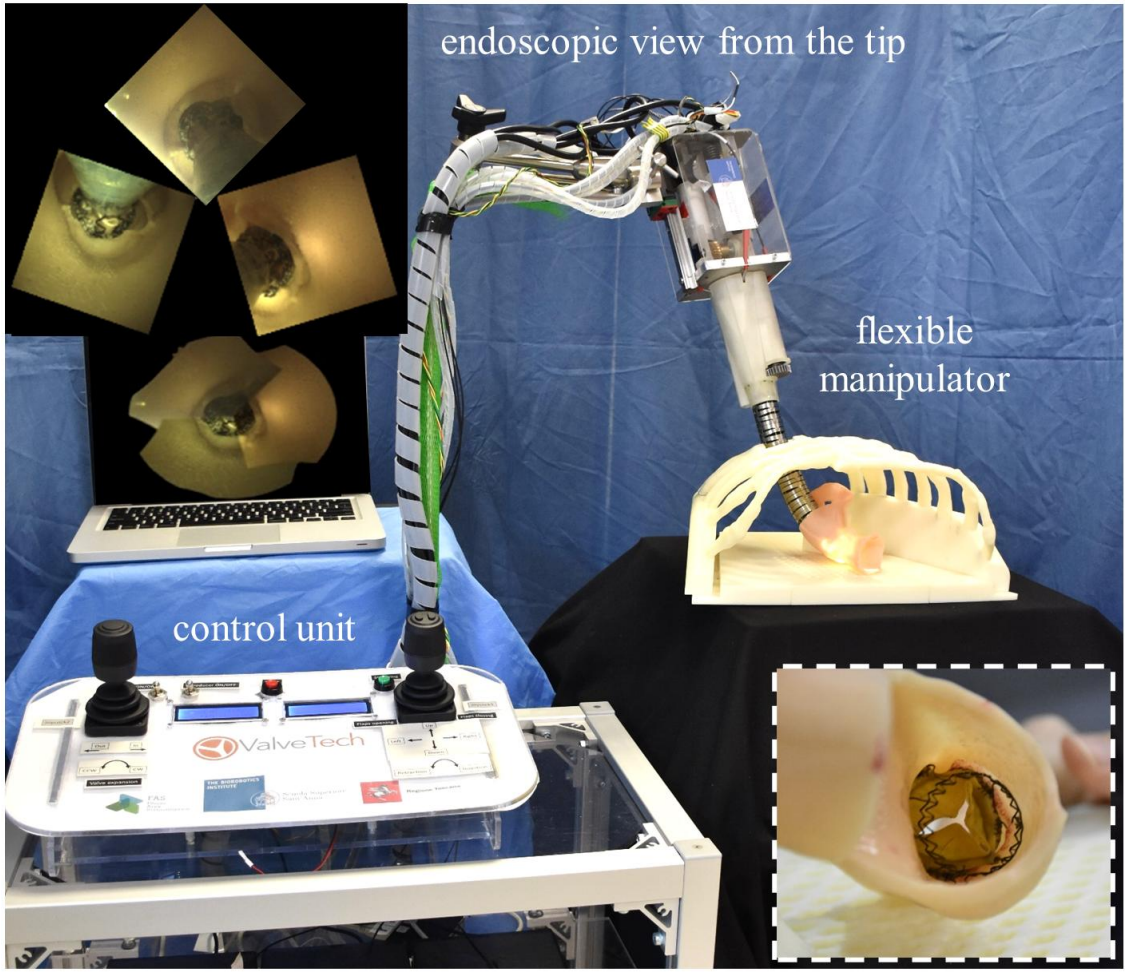
KING'S College LONDON

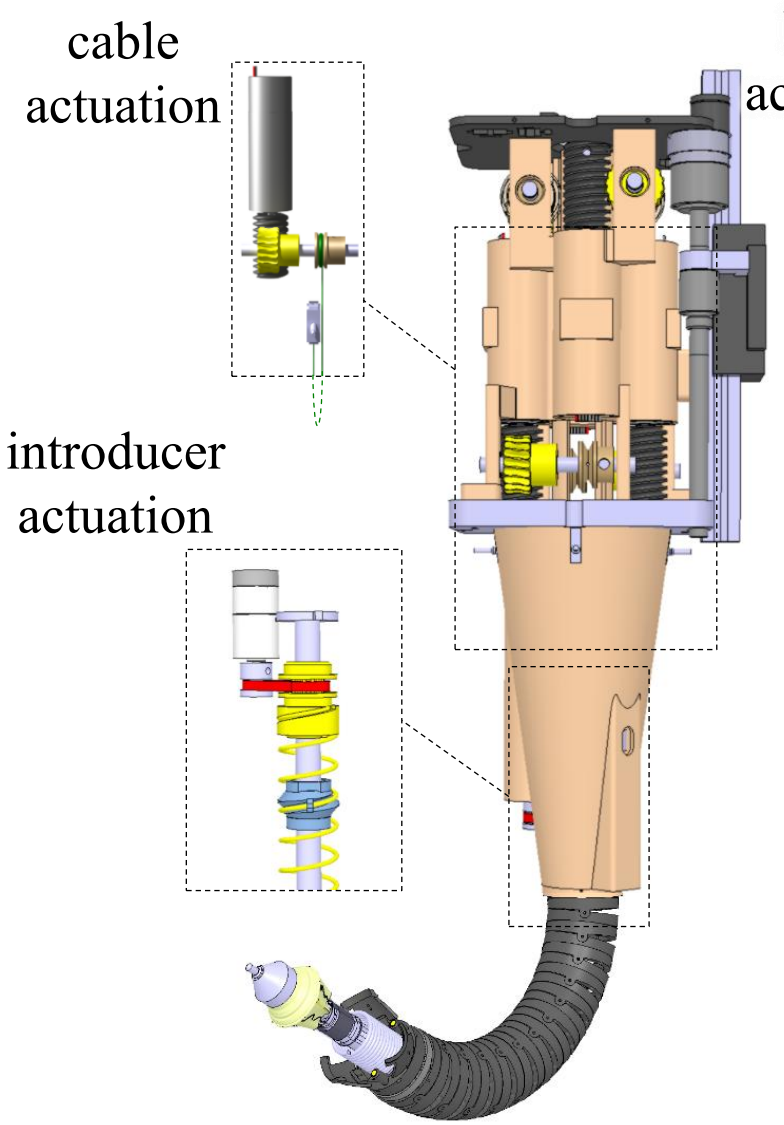
UNIVERSITY OF TWENTE.

THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

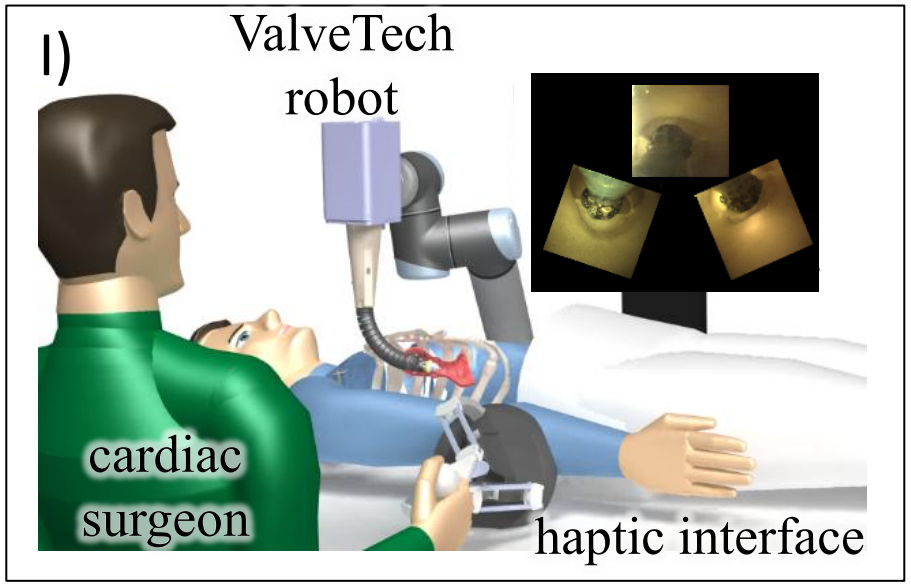
# ValveTech Design

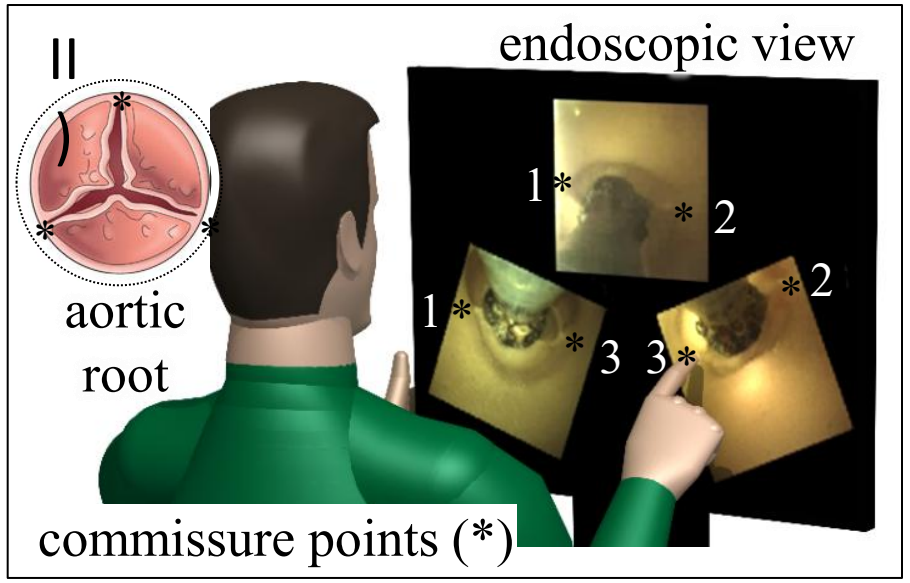


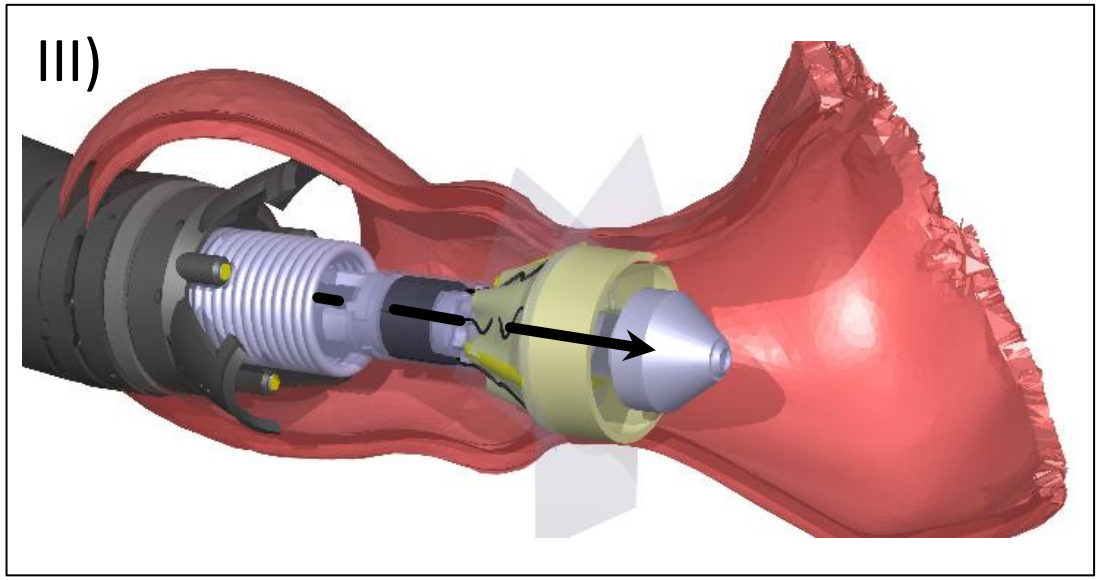




Dr. Izadyar Tamadon

# Semiautonomous Procedure




Dr. Izadyar Tamadon

# Mechanics

### Constant Curvature Kinematics

$$\left(\frac{\pi}{2} - \theta_{\mathrm{CC}}\right) - \tan^{-1}\left(\frac{\rho_{T_y} - \frac{l_M \sin(\theta_{\mathrm{CC}})}{\theta_{CC}}}{\rho_{T_x} - \frac{l_M(1-\cos(\theta_{\mathrm{CC}}))}{\theta_{\mathrm{CC}}}}\right) = 0.$$

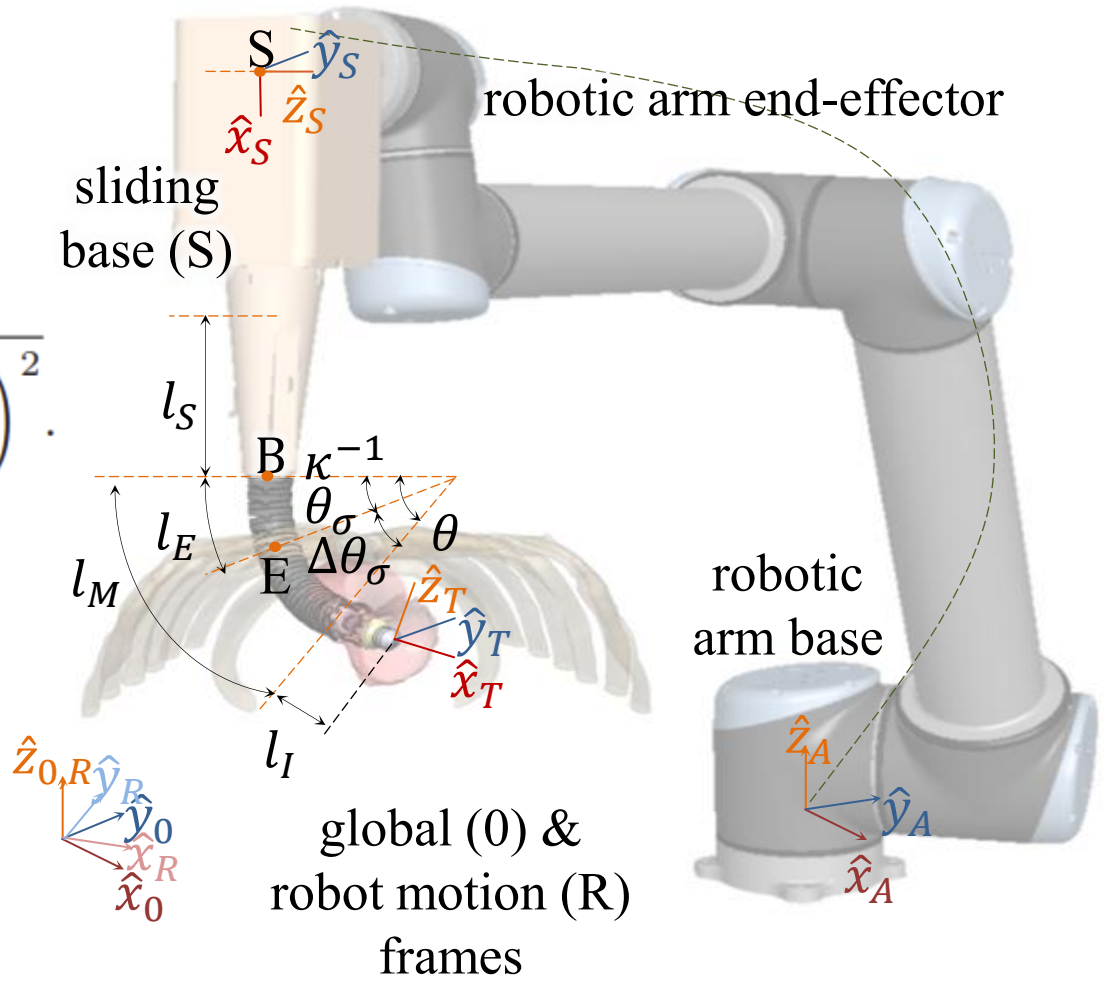
$$l_{ICC} = \sqrt{\left(\rho_{T_y} - \frac{\sin(\theta_{\mathrm{CC}})}{\kappa_{\mathrm{CC}}}\right)^2 + \left(\rho_{T_x} - \frac{1-\cos(\theta_{\mathrm{CC}})}{\kappa_{\mathrm{CC}}}\right)^2}.$$

### Quasi-static Mechanics

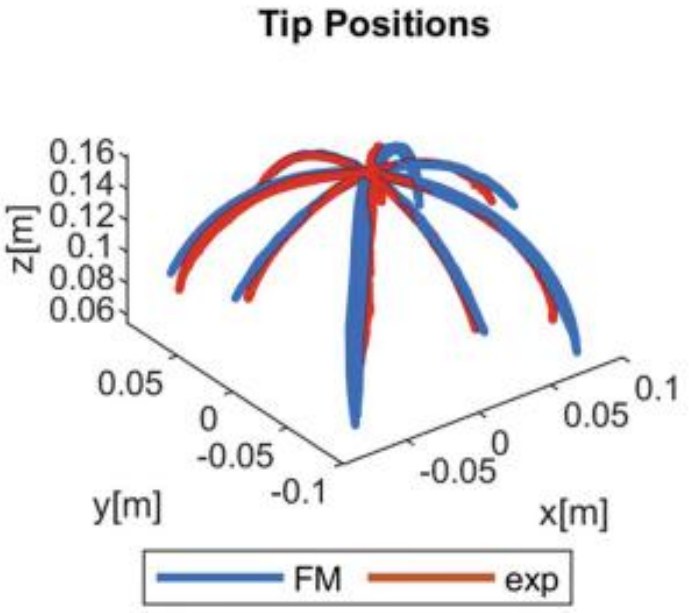
$$\bar{w}_{,q} = w_{C_{M,q}} + w_{C_{I,q}} + w_{F,q} + w_{\sigma,q} + w_{K,q}$$

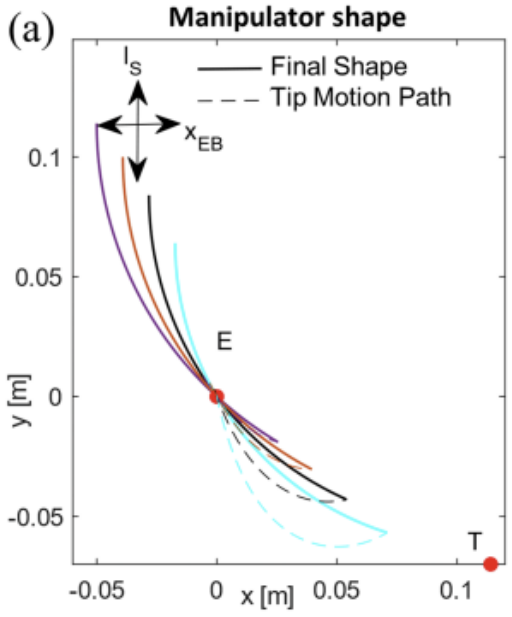
### Simultaneous IK & Load Estimation

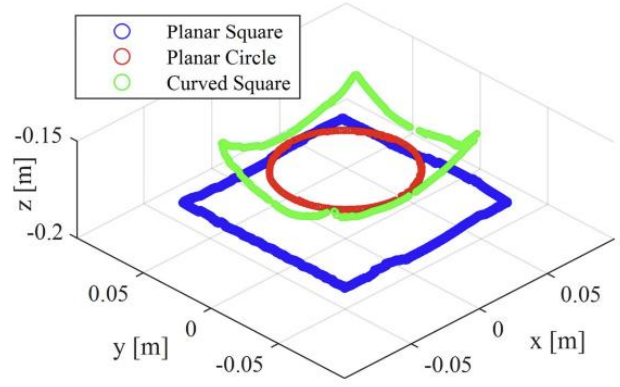
$$w_{K,q} = w_{P,q}$$

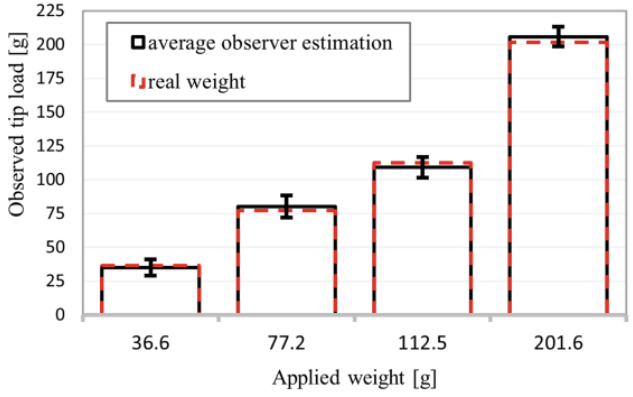


# Inverse Kinematics & Load Observation



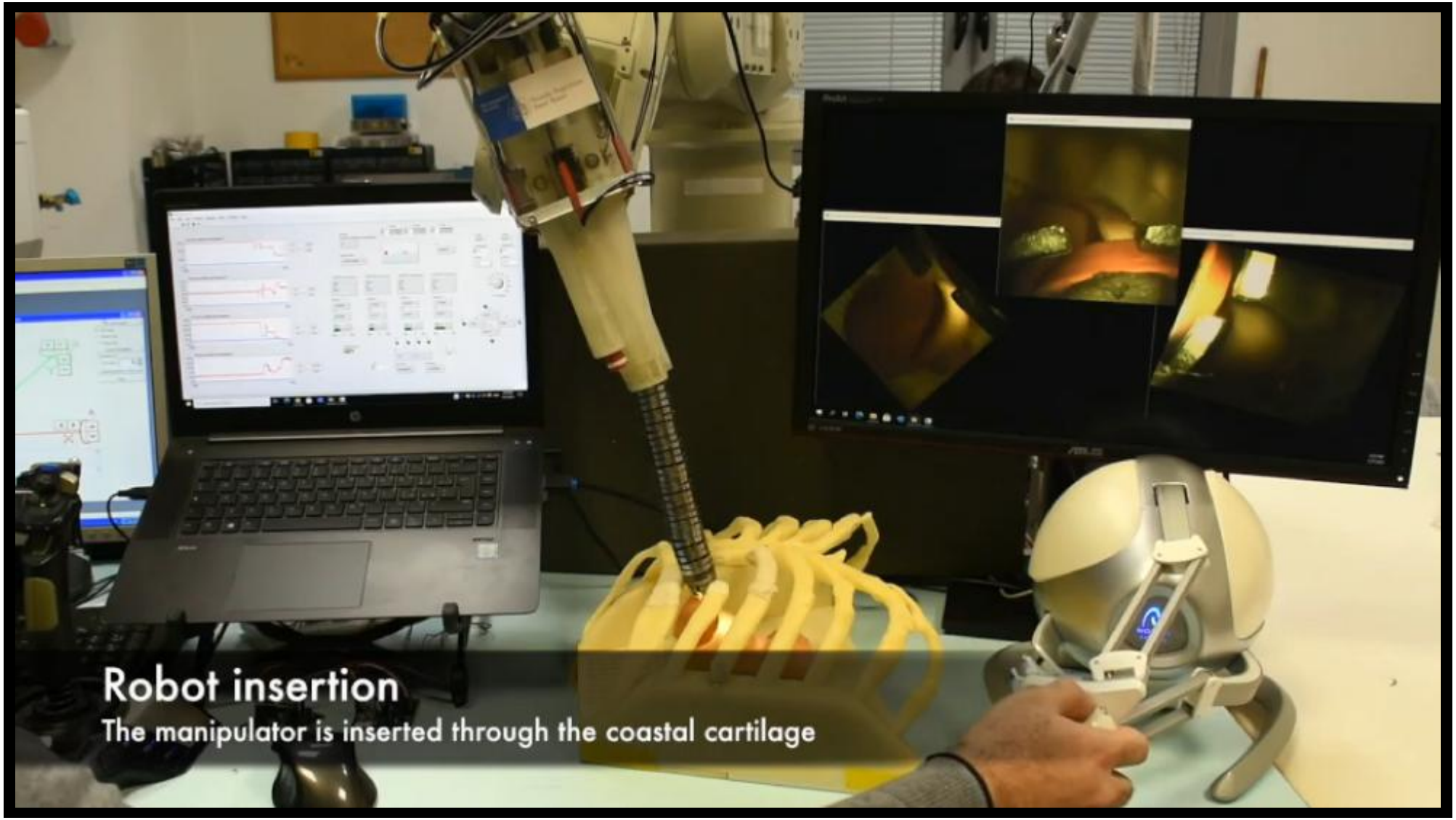



# Analytical Automation- System Performance

Dr. Izadyar Tamadon



# **Artificial Intelligence Autonomy-** Mechanical Thrombectomy

## Autonomous Endovascular Navigation for Acute Stroke

S.M.H. Sadati, L. Karstensen, N. Fischer, B. Jackson, H. Robertshaw, F. Mathis-Ullrich, A. Granados, C. Bergeles, T.C. Booth

HAMLYN Symposium 2025

NIHR | Cardiovascular MedTech Co-operative

wellcome EPSRC centre medical engineering

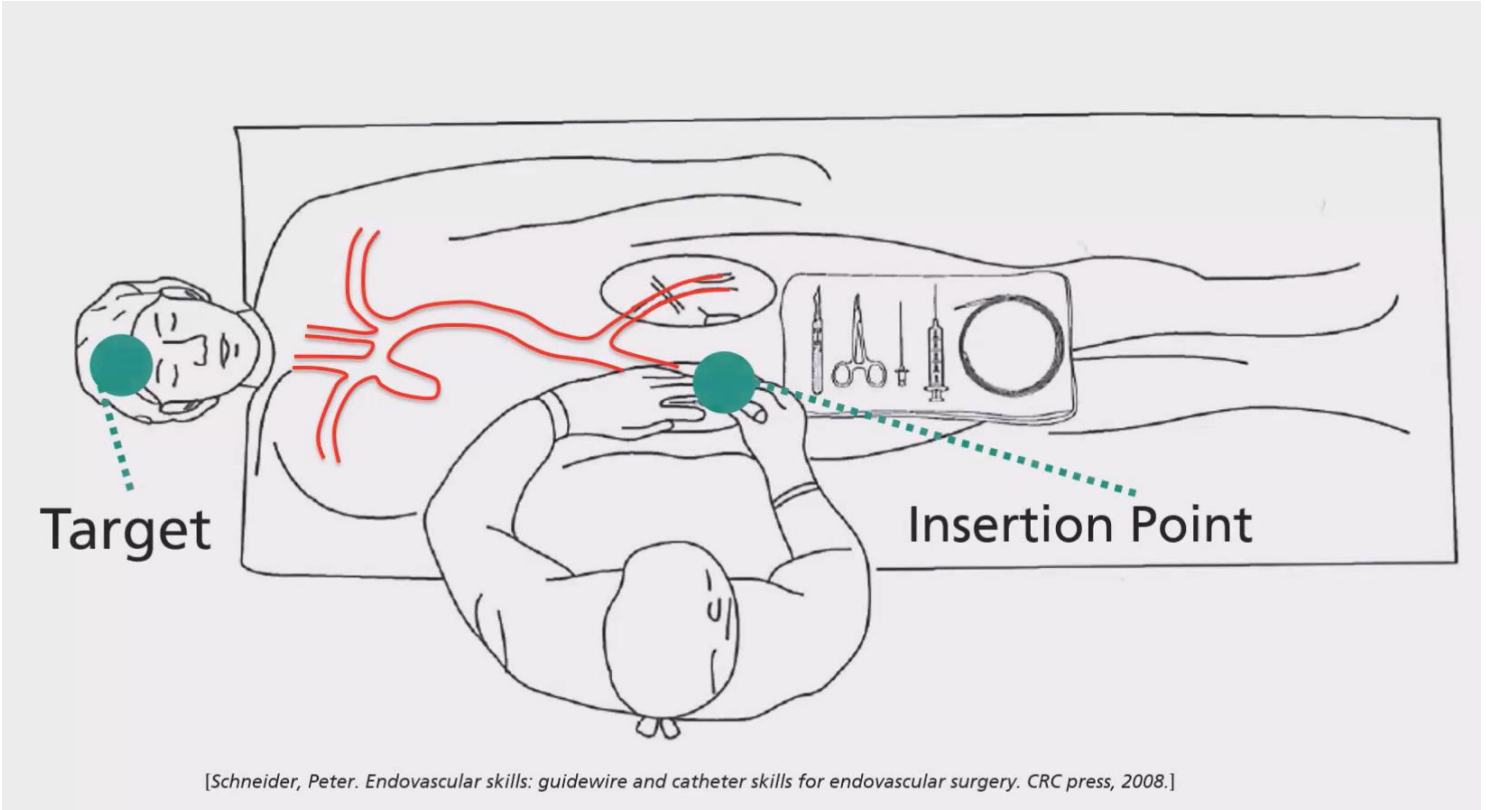
NHS Guy's and St Thomas' NHS Foundation Trust

NHS King's College Hospital NHS Foundation Trust

Queen Mary University of London

King's College London

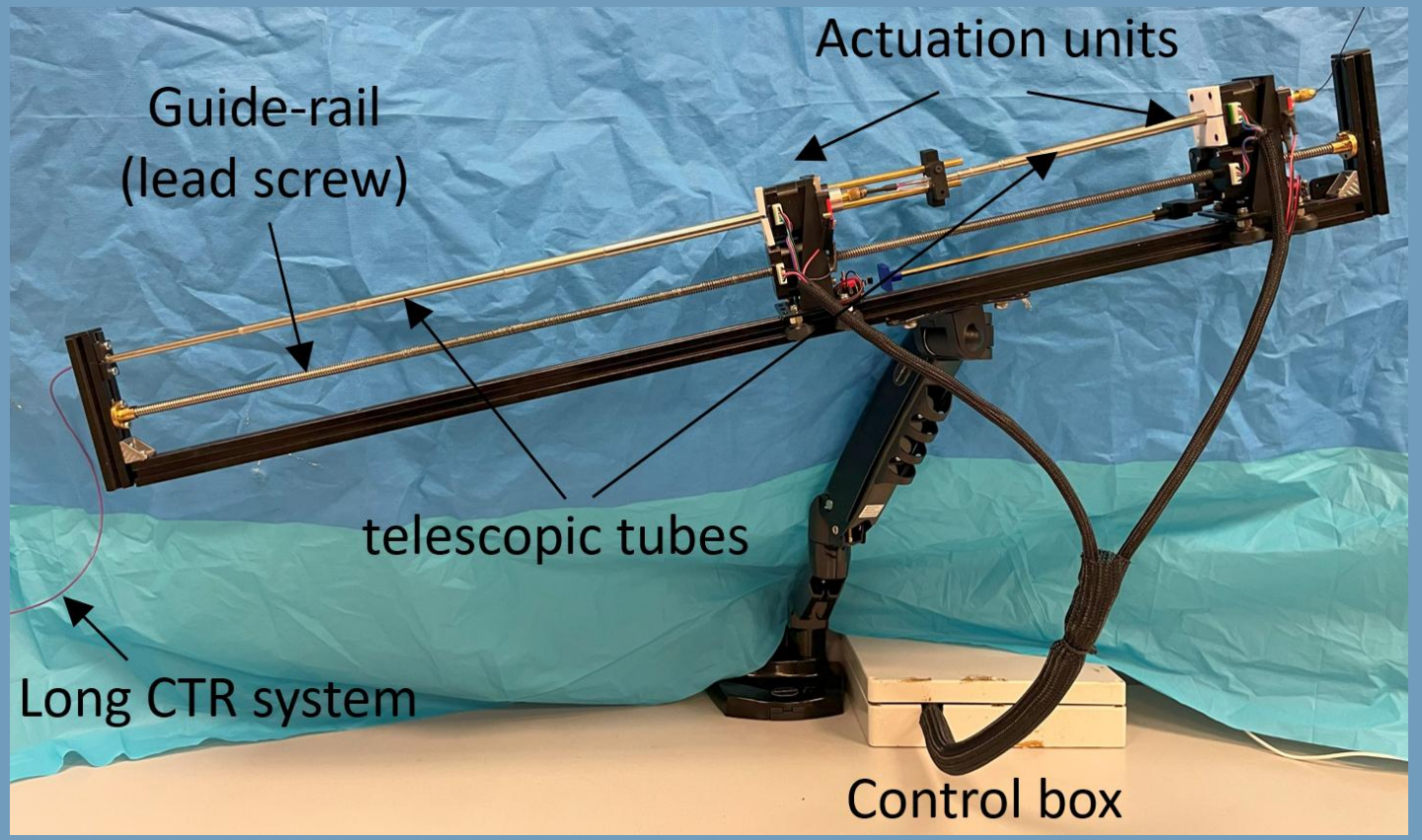
# Mechanical Thrombectomy in Acute Stroke – Standard Procedure




[Schneider, Peter. Endovascular skills: guidewire and catheter skills for endovascular surgery. CRC press, 2008.]

# Open-source Precision Actuation, Tracking, & In-vitro Phantom

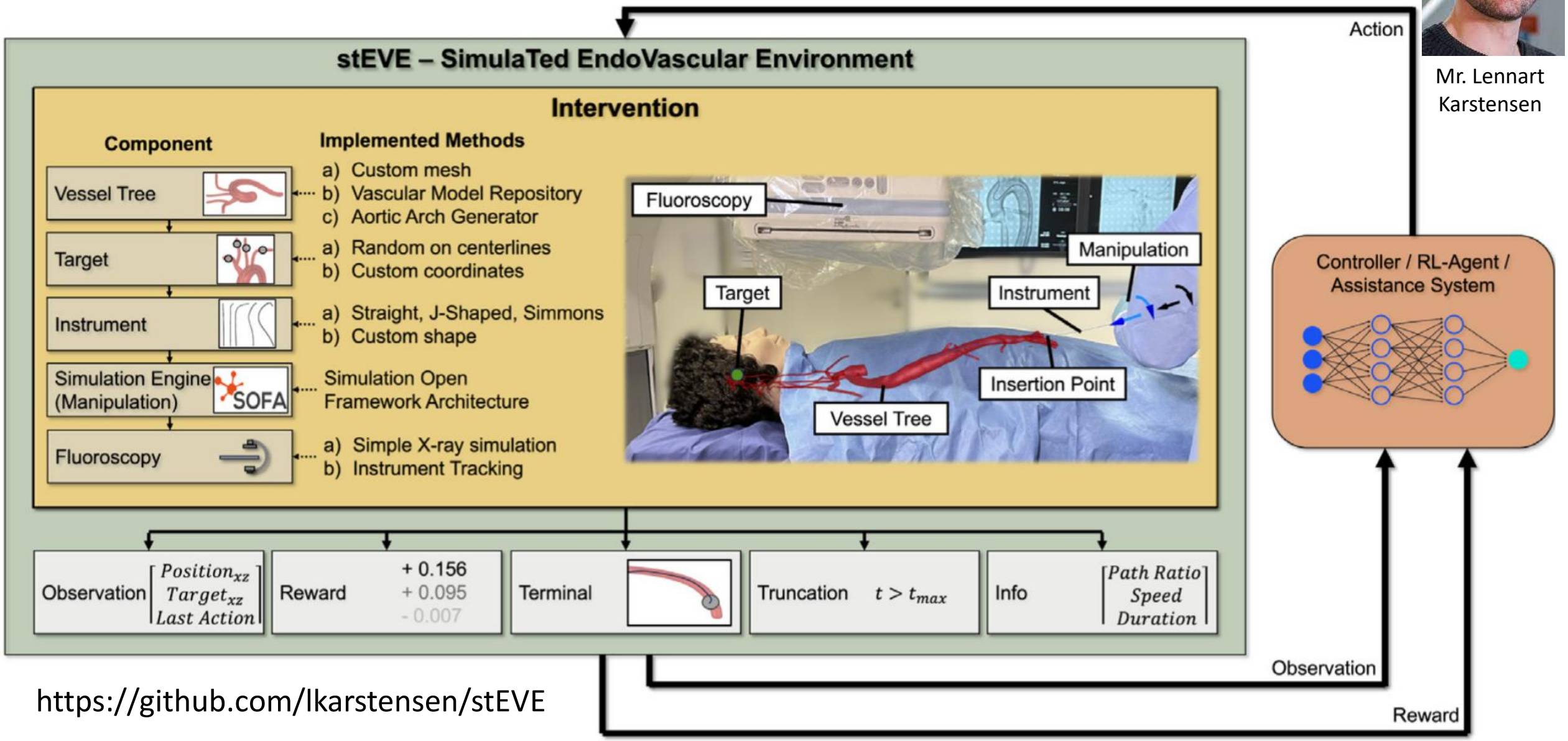
Dr. Nikola Fischer




https://github.com/KCL-BMEIS/robotic_endovascular_navigation_CTR

# simulated EndoVascular Environment (stEVE)

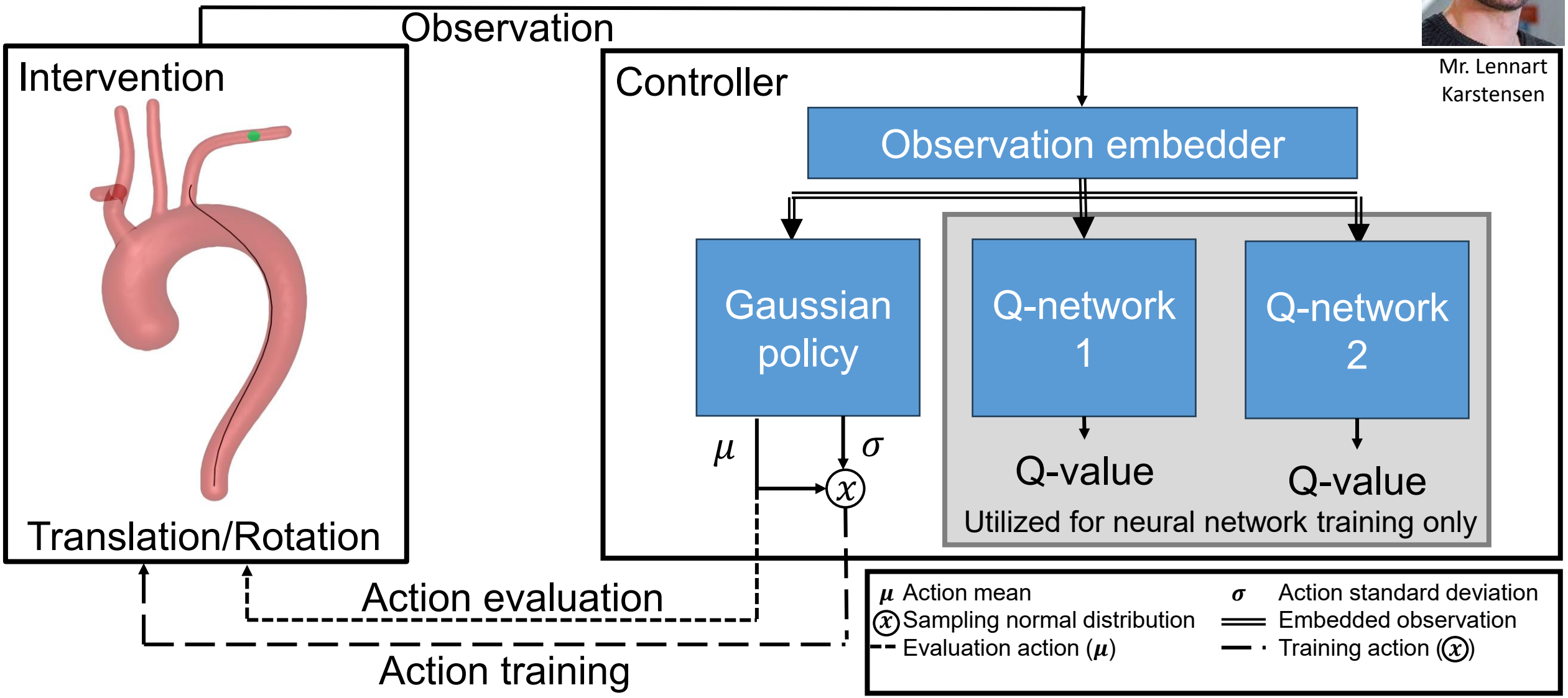
Mr. Lennart Karstensen



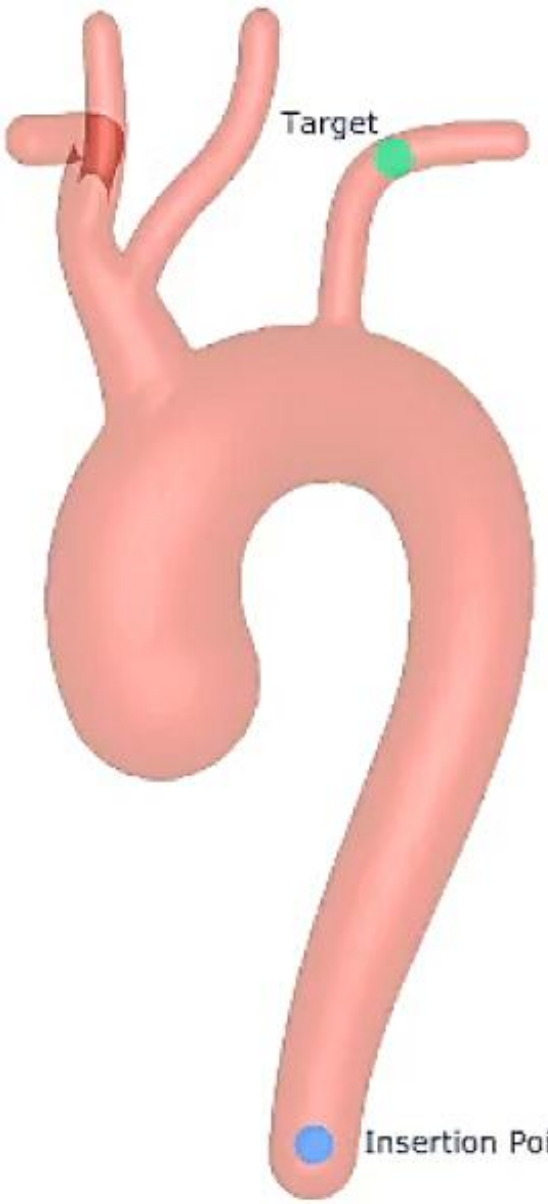

https://github.com/lkarstensen/stEVE

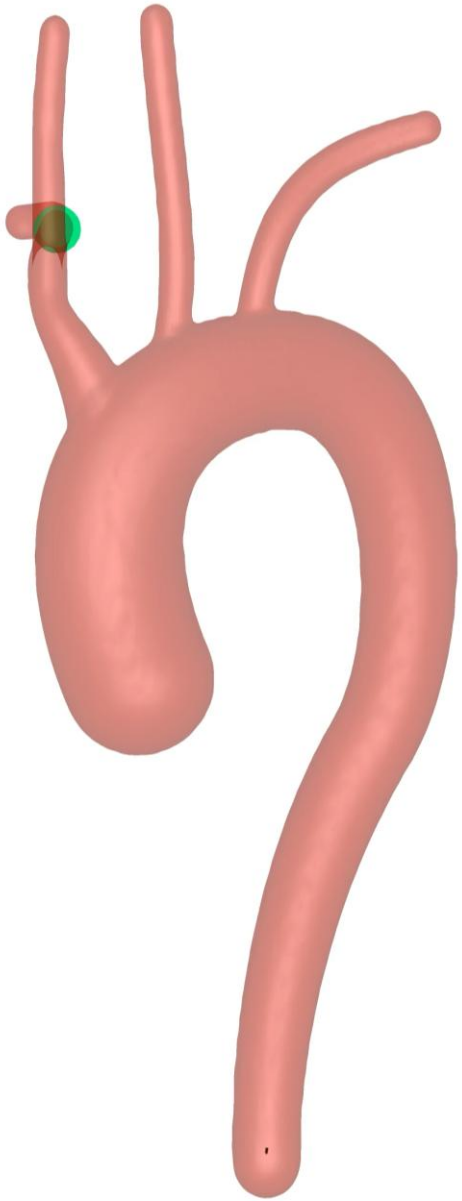
# Autonomous Navigation - Reinforcement Learning Setup

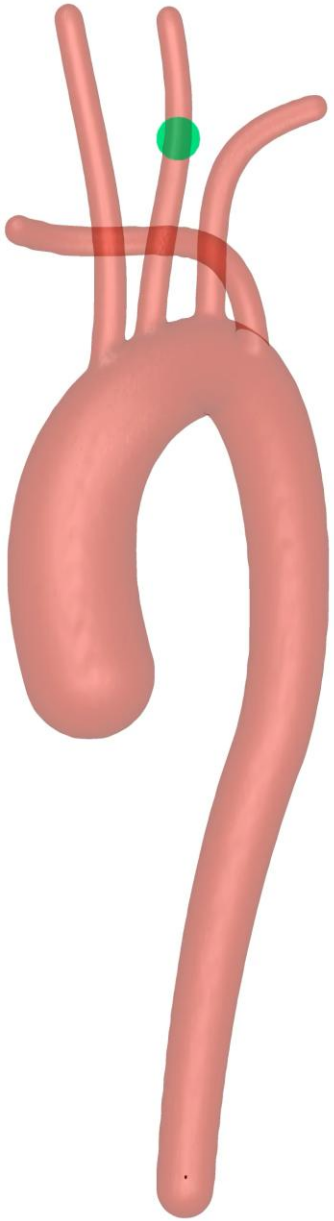
Mr. Lennart Karstensen



# Aortic Arch Experiments



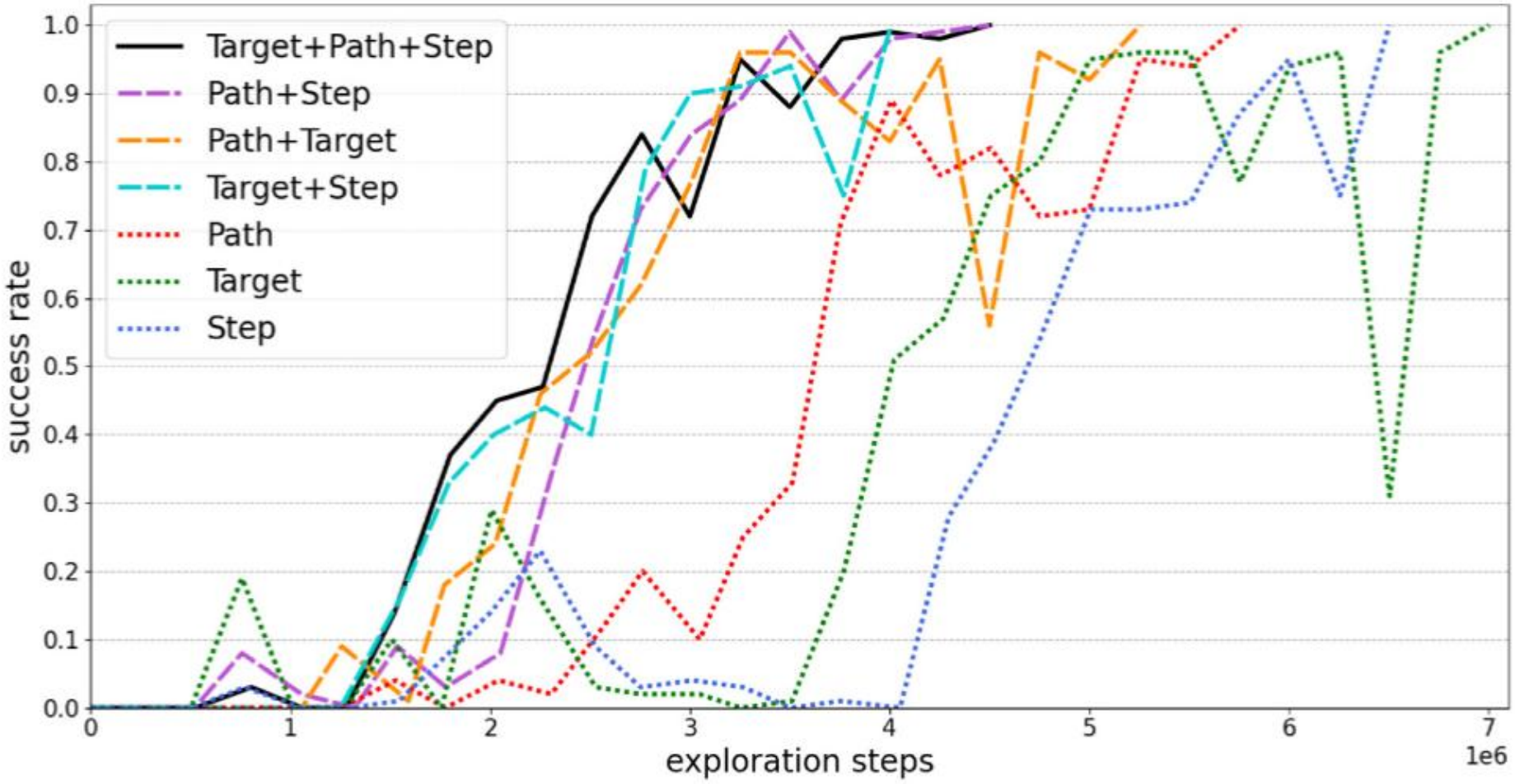





Mr. Lennart Karstensen

# Reward Function

Mr. Lennart Karstensen




$$R = R_{step} + R_{path} + R_{target}$$

with

$$R_{step} = -0.005$$

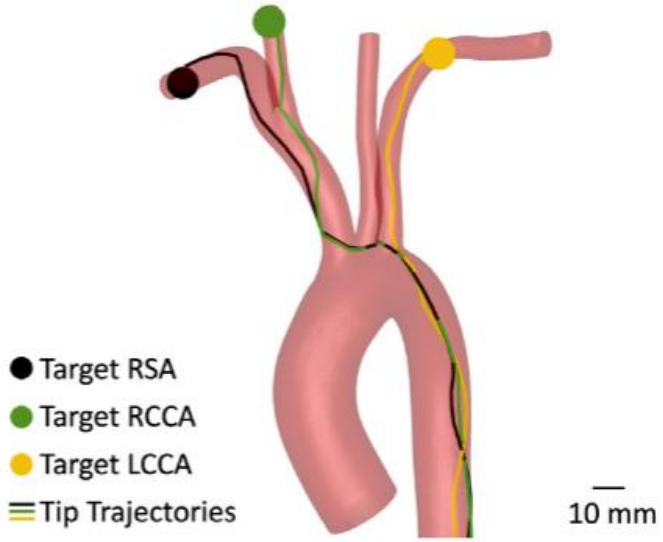
$$R_{path} = 0.001 \cdot \Delta pathlength$$

$$R_{target} = \begin{cases} 1.0 & \text{if target reached.} \\ 0 & \text{otherwise.} \end{cases}$$

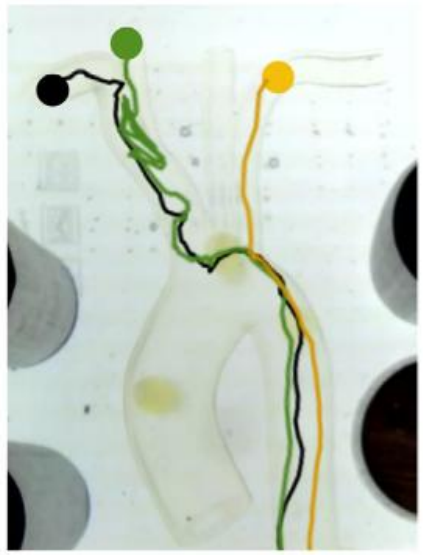
# In-vitro Benchmark


Results of the Benchmark experiments for 100 trials in simulation. *BasicWireNav* additionally evaluated for 10 trials on the camera (TC) and fluoroscopic (TF) test benches.

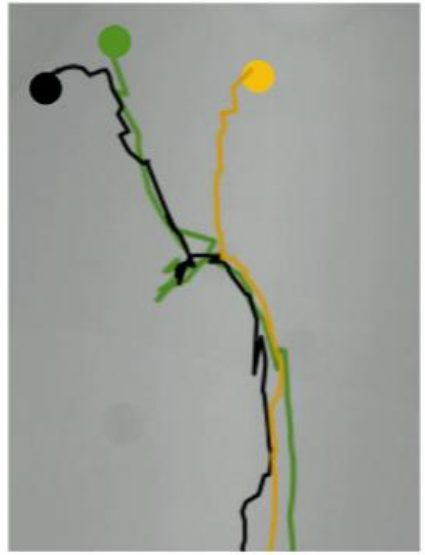
| Benchmark | Evaluation | Success rate | | Path Ratio [%] *failed* | | Duration [s] *successful* | |
|---|---|---|---|---|---|---|---|
| BasicWireNav | Simulation | 98/100 | 10/10 | 94.3 | – | 9.6 | 9.8 |
| | TC | 97/100 | 9/10 | 81.6 | 87.4 | 13.6 | 18.1 |
| *100 trials* *10 trials* | TF | – | 10/10 | – | – | – | 19.1 |
| ArchVariety | Simulation | 90/100 | | 73.5 | | 19.3 | |
| | TC | 84/100 | | 75.9 | | 22.0 | |
| DualDeviceNav | Simulation | 40/100 | | 67.8 | | 45.8 | |




(a)

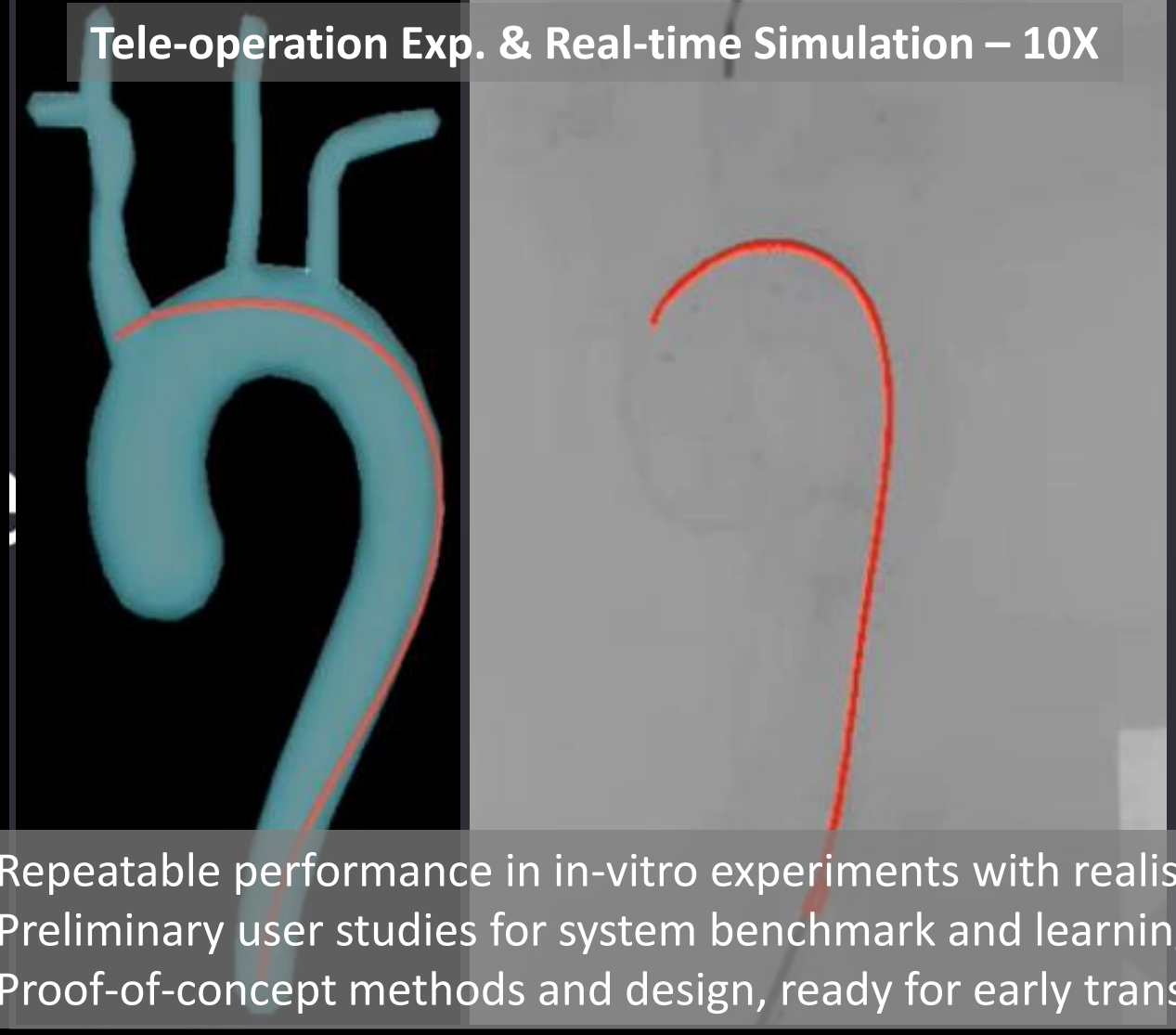


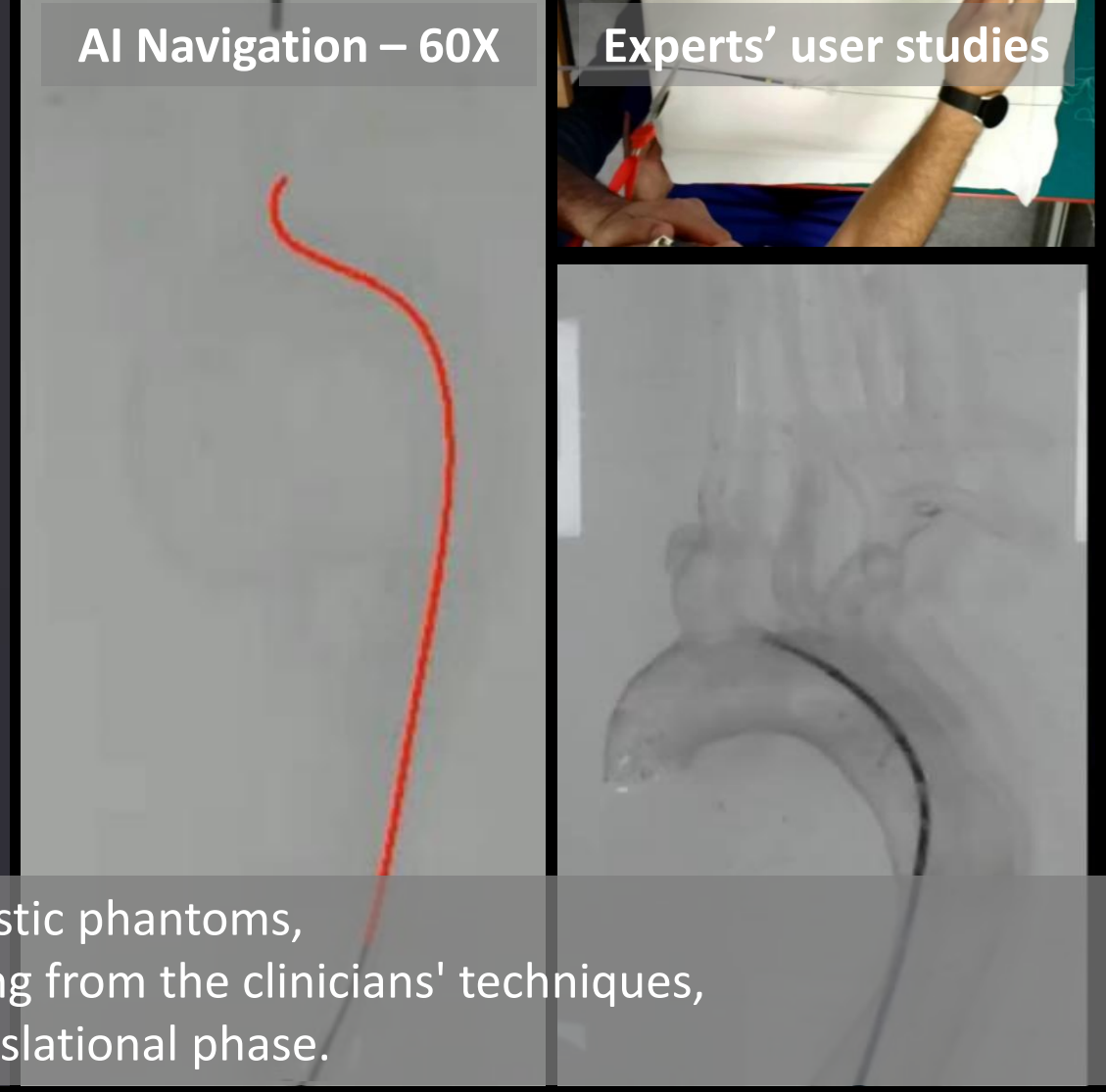
(b)



(c)

Mr. Lennart Karstensen









- Repeatable performance in in-vitro experiments with realistic phantoms,
- Preliminary user studies for system benchmark and learning from the clinicians' techniques,
- Proof-of-concept methods and design, ready for early translational phase.

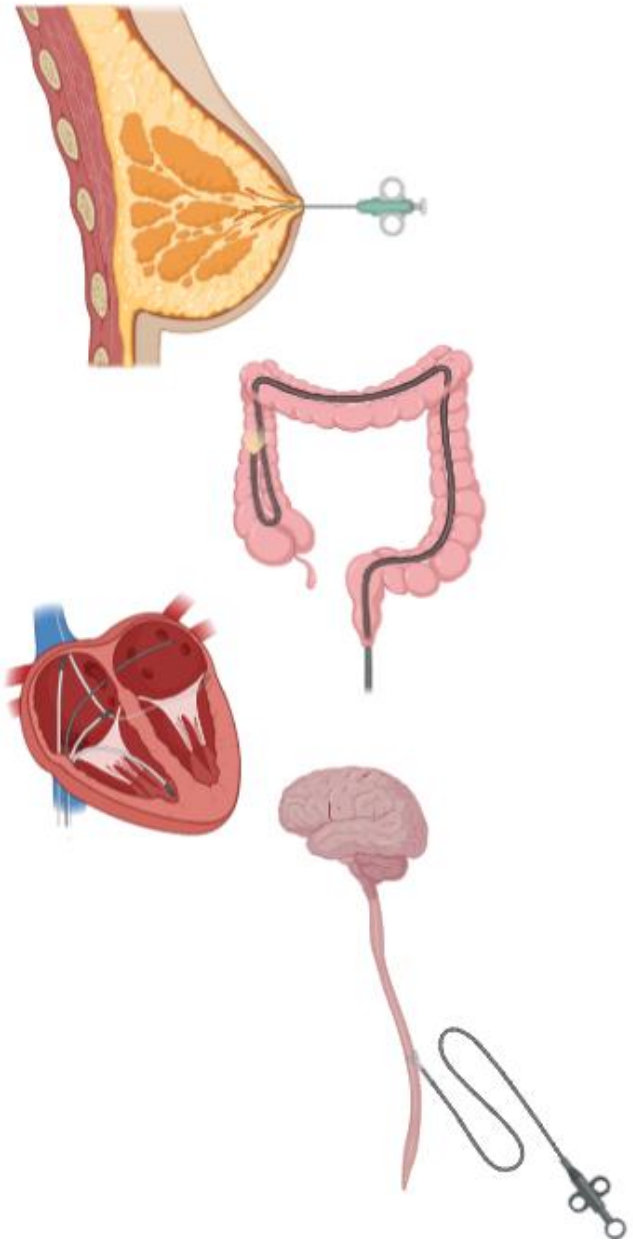
| 2021- Seed funding | 2023- 1st major funding (under review) | 2026- 2nd major funding | 2028- VC fund raising |
|---|---|---|---|
| **Proof-of-concept** | **Early Translational Phase** | **Mid Translational Phase** | **Pre-clinical Studies** |
| - Proof-of-concept design<br>- Preliminary phantom & user studies | - Improved Design based on medical requirements<br>- Thorough phantom, ex-vivo, cadaver, & user studies<br>- QMS, health economics, & entrepreneurship training | - Spinout & Design under QMS<br>- Market analysis<br>- Animal study | - Venture Capital fund raising<br>- Pre-clinical animal studies<br>- First in-human study |

# Variable Stiffness Soft Eversion Growing Robot via Temperature Control of Low-Melting Point Alloy Pressurised Medium

Shamsa Al Harthy, S.M.Hadi Sadati, Zicong Wu,
Carlo A. Seneci, and Christos Bergeles
IEEE ISMR 2024

KING'S College LONDON

# Challenges Within Endoluminal Surgical Context



**Compliance:**

Limited force exertion

Buckling

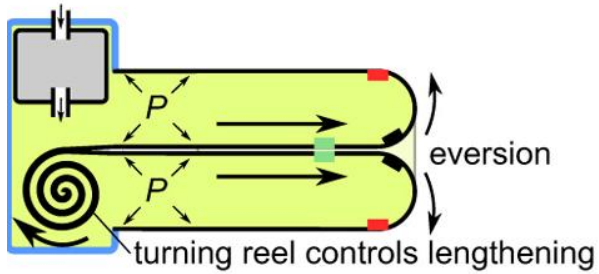
Challenging to deliver payloads

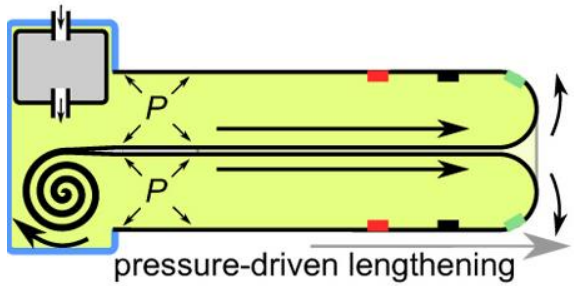
**Rigidity:**

Limited reach & flexibility

Tissue damage

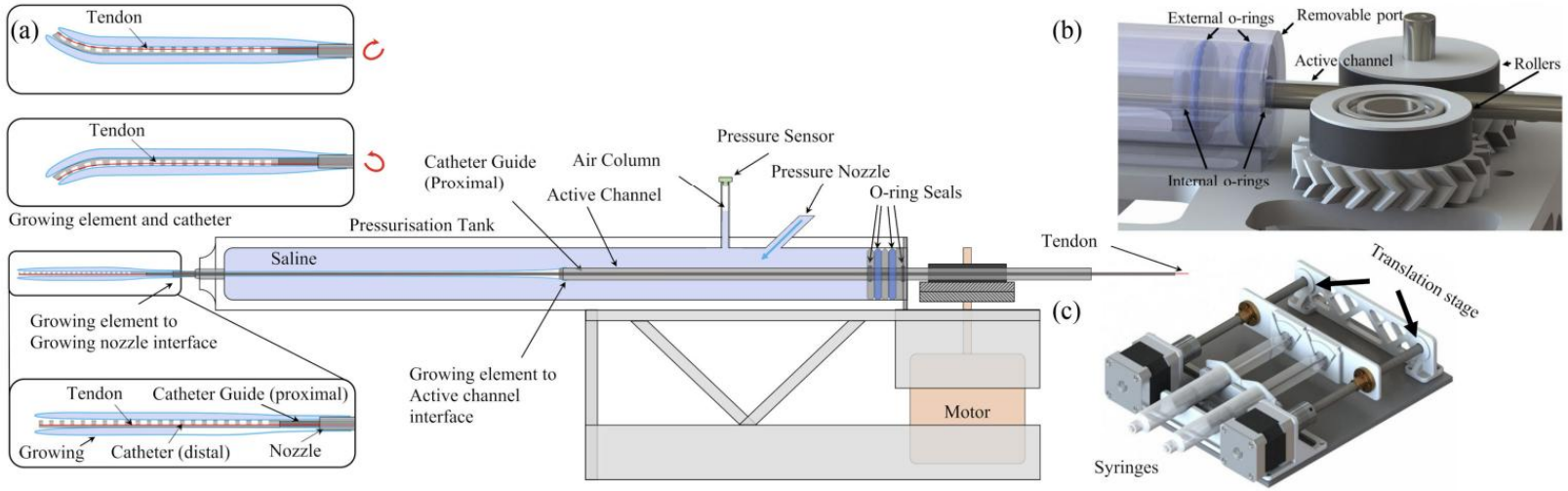
Tool damage & limited durability

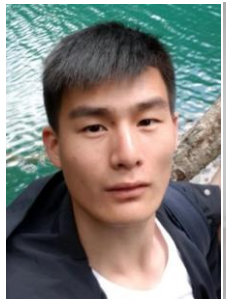



Hawkes *et al*. (2017)

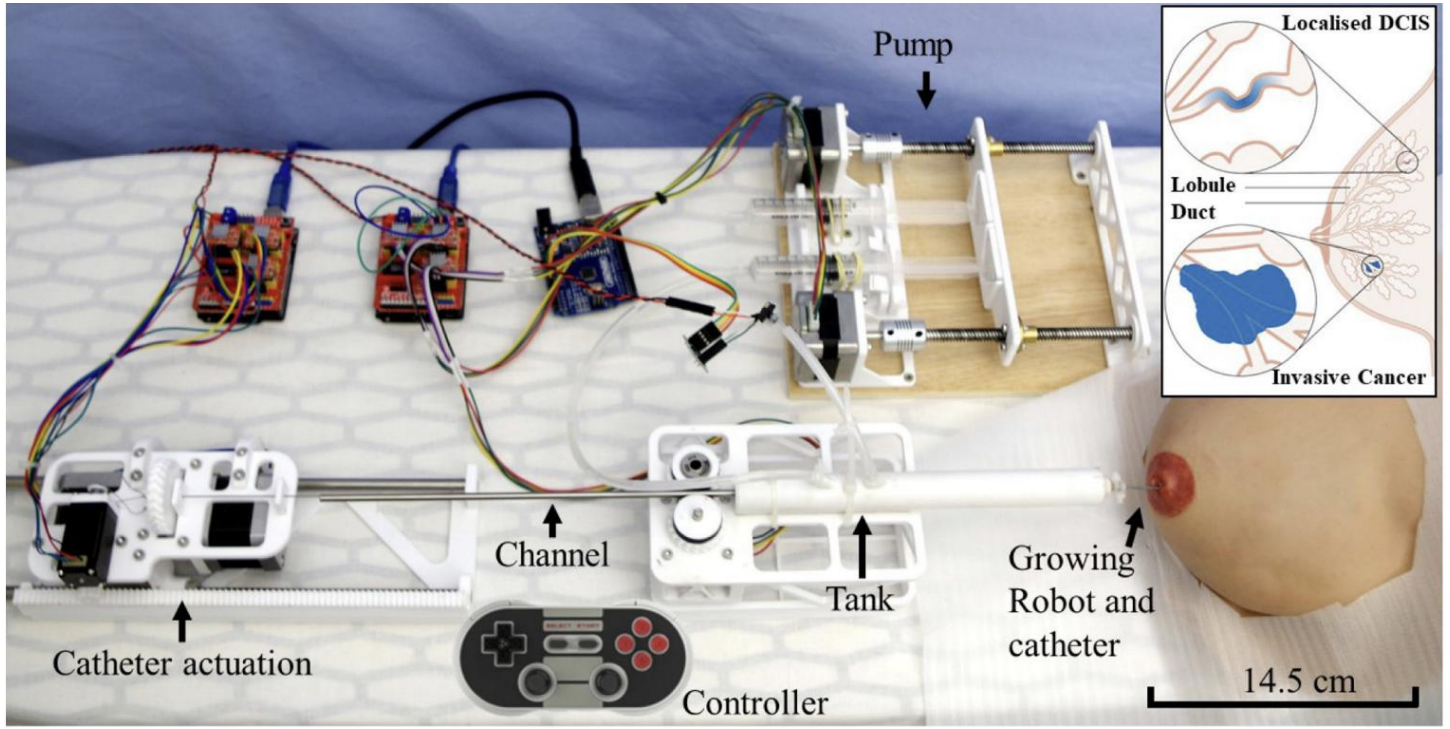
# Design Principle – Hydraulic Actuation

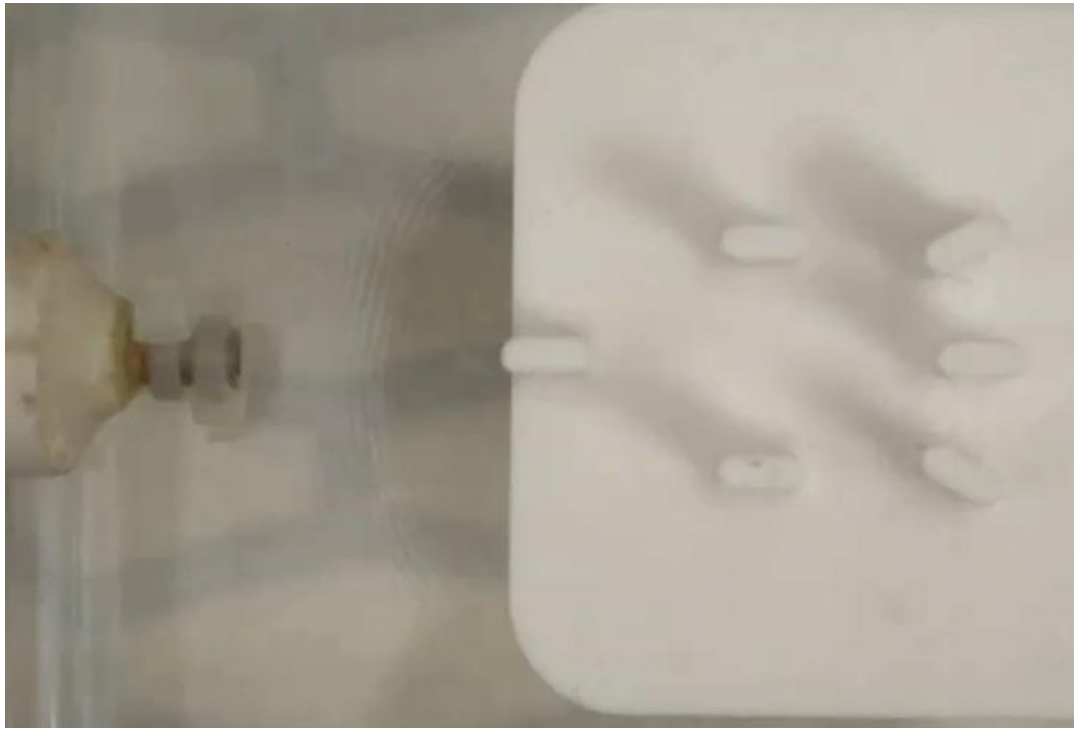


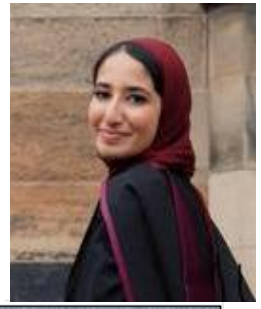
Dr. Zicong Wu

Dr. Pierre Berthet-Rayne

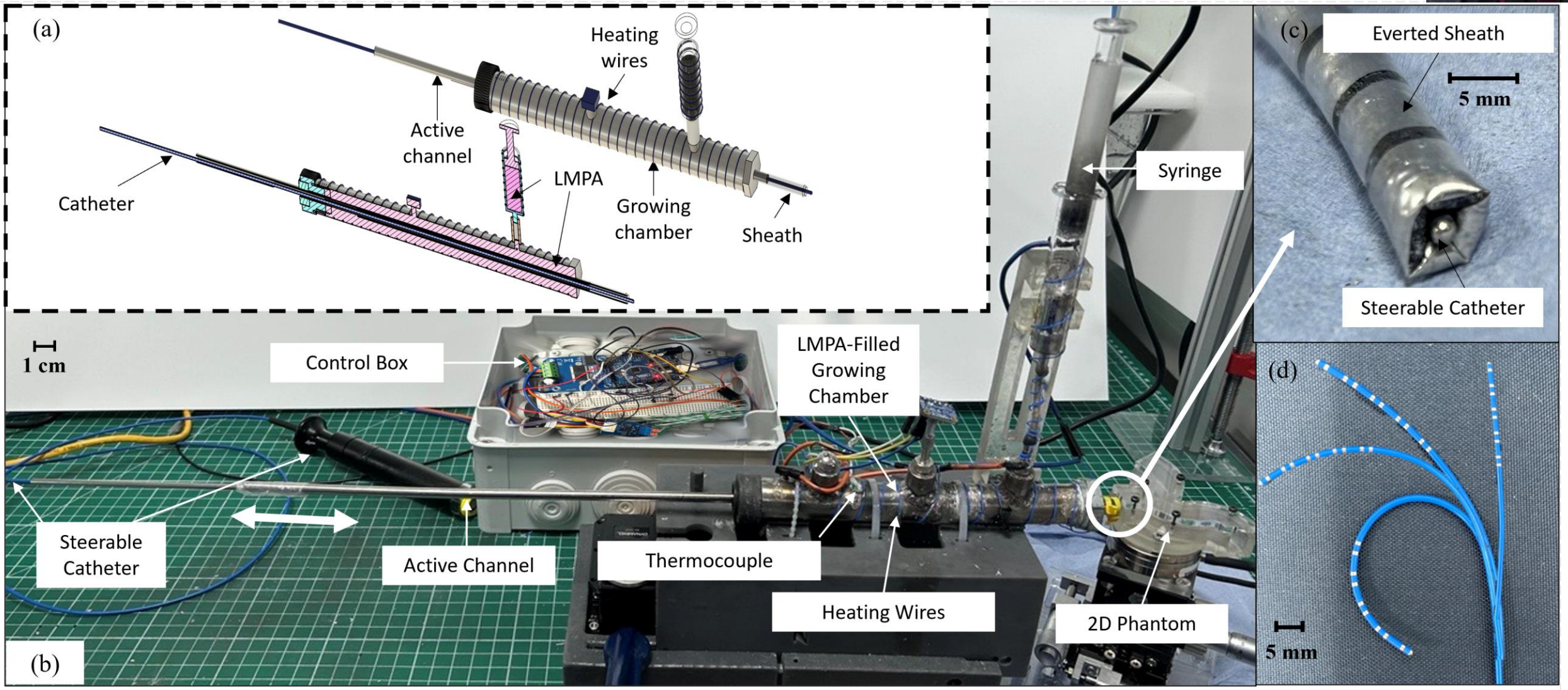


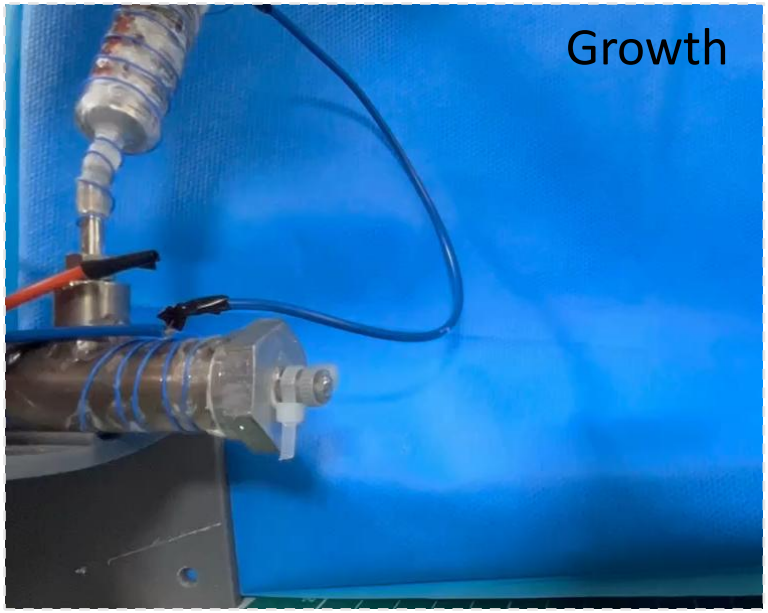
# Design Principle – LMPA Actuation

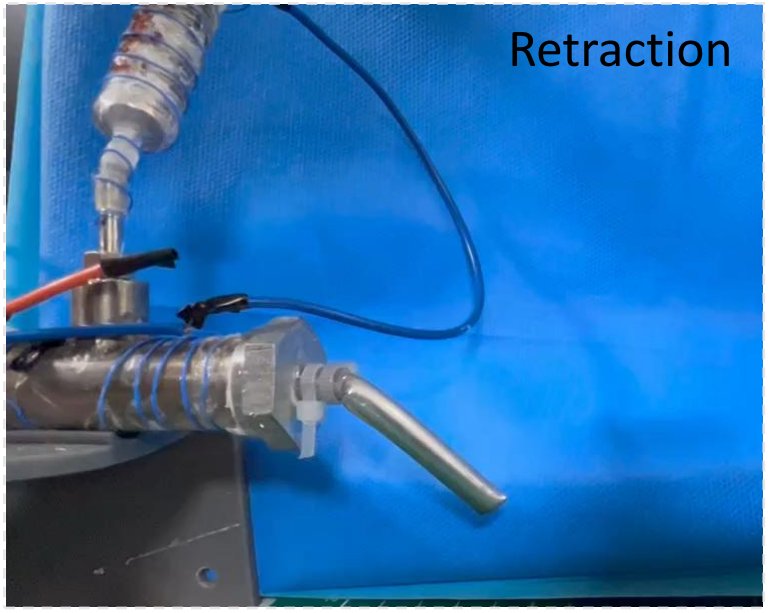


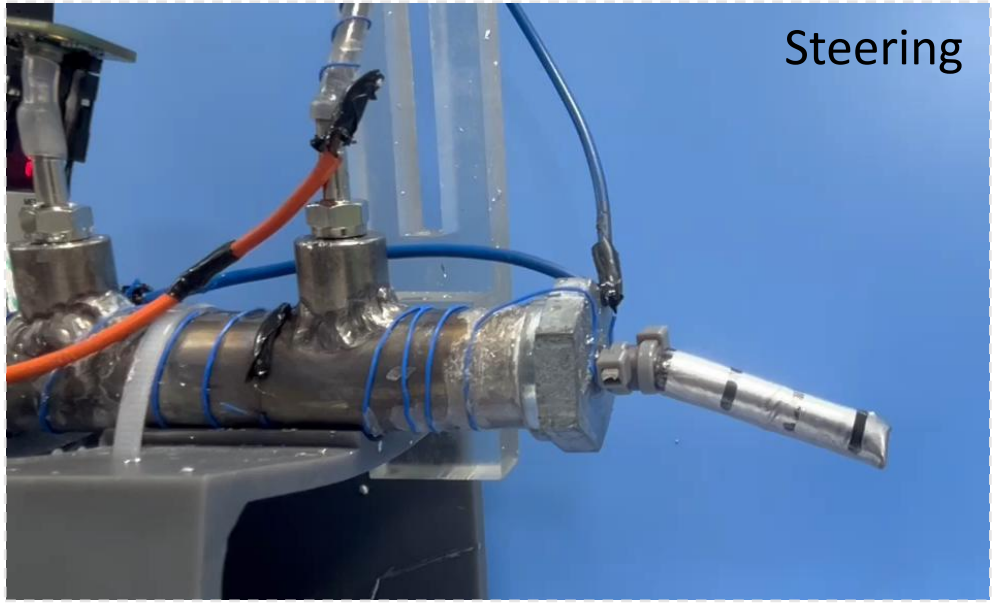
Ms. Shamsa Al-Harthy

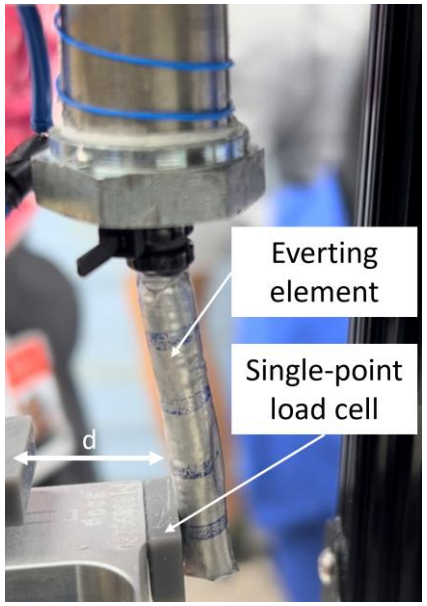


# Working Principle

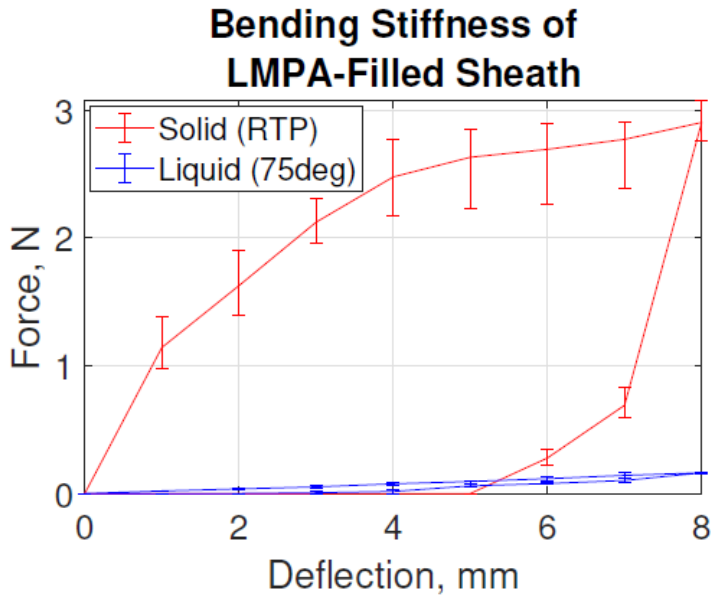


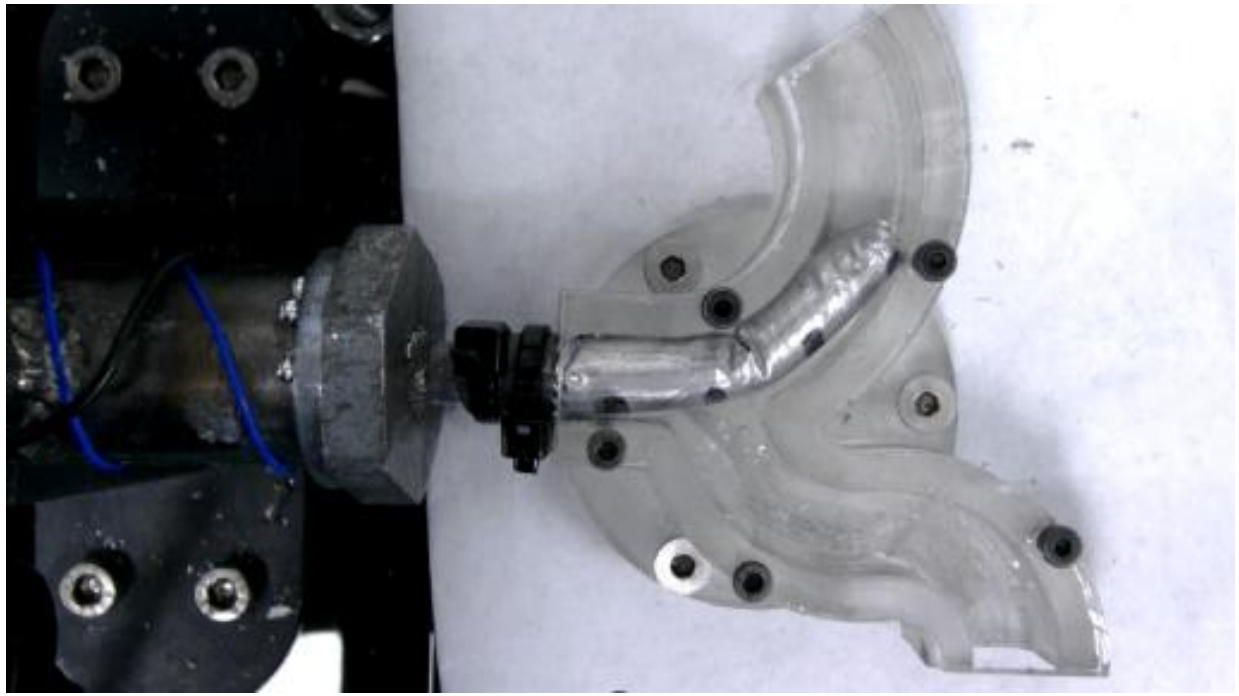



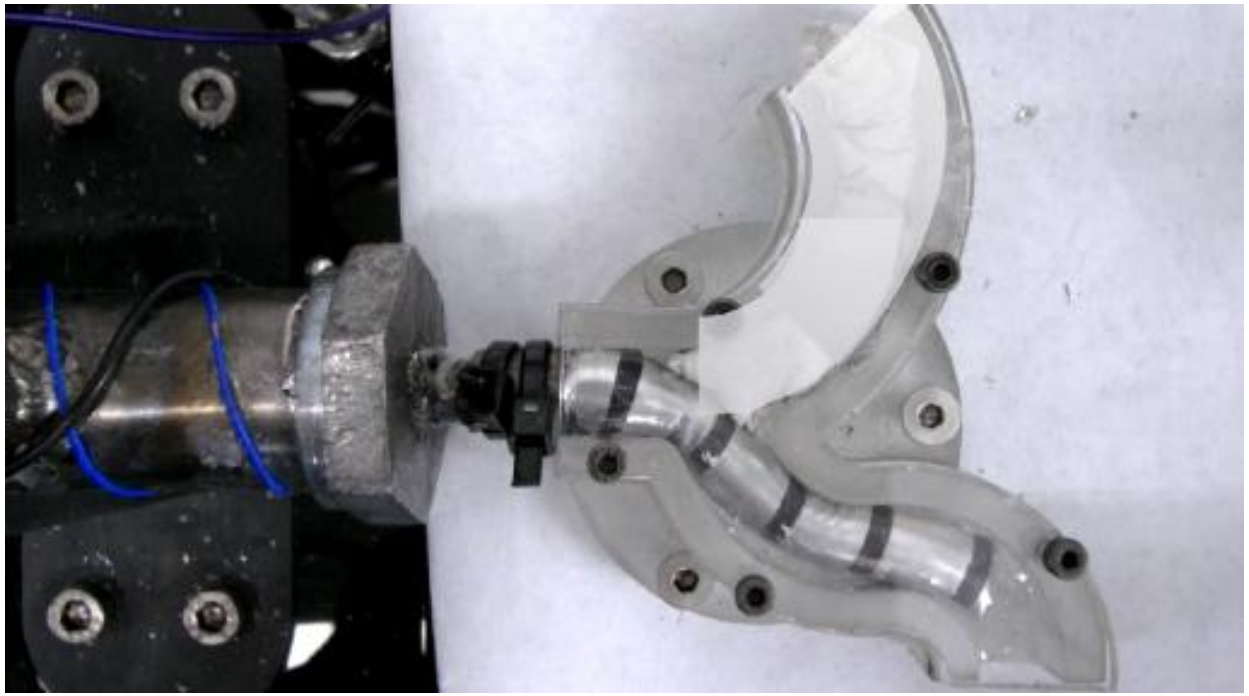

Ms. Shamsa Al-Harthy



# Embodied Intelligence- System Performance

Ms. Shamsa Al-Harthy





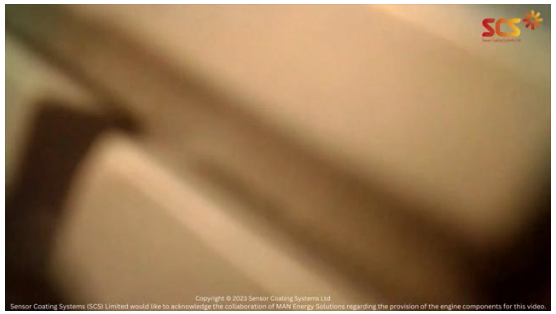
# *TMT* Modelling Toolbox for Structural & EI Optimization

*Sadati et al. IJRR 22*

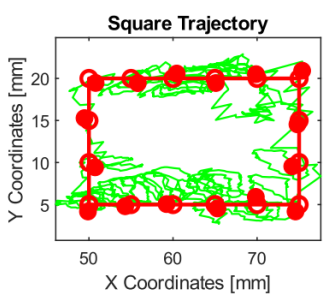

***TMTDyn-*** a Matlab Package for ***Reduced-Order*** Modelling and Control of ***Intelligent*** Soft Manipulators

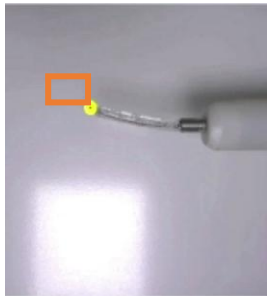
# *TMTDyn* for Planning & Control

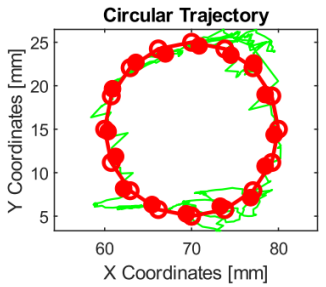


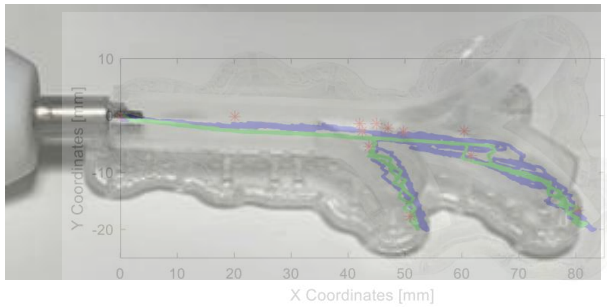



***ASME GT 25 (u prep)***

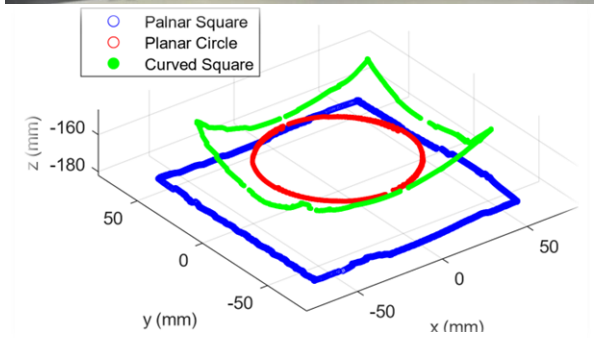


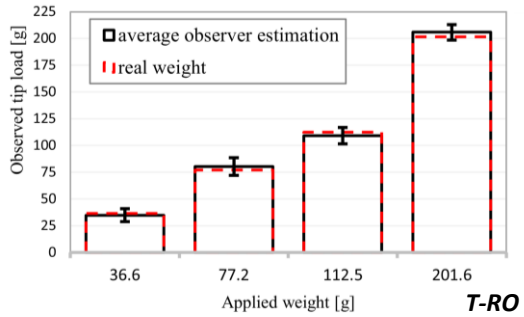





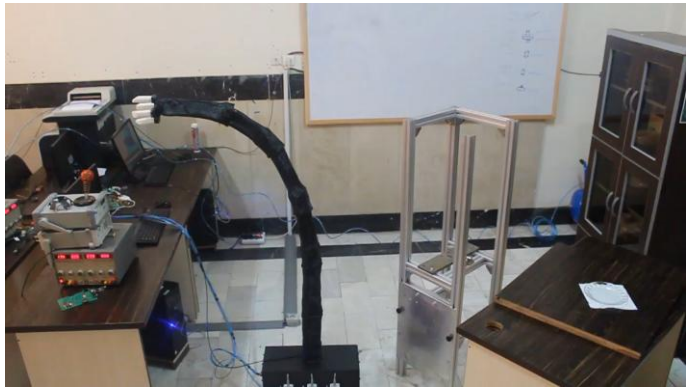



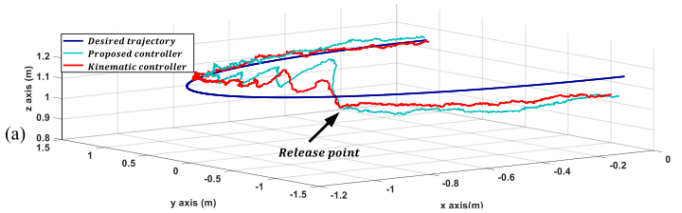

***RA-L 23***

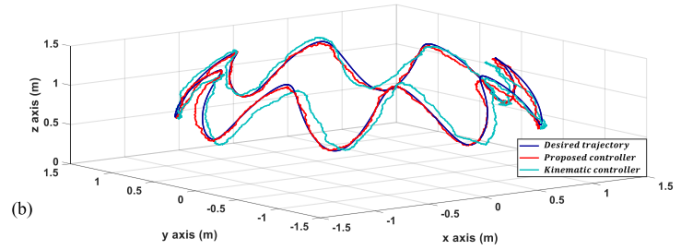




***T-RO 23***



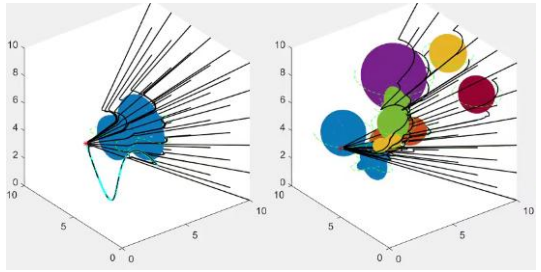



***CEP 23***

# Vision: ARThA- Autonomous Robotic Thrombectomy in Acute Stroke

AI- & field-based automation



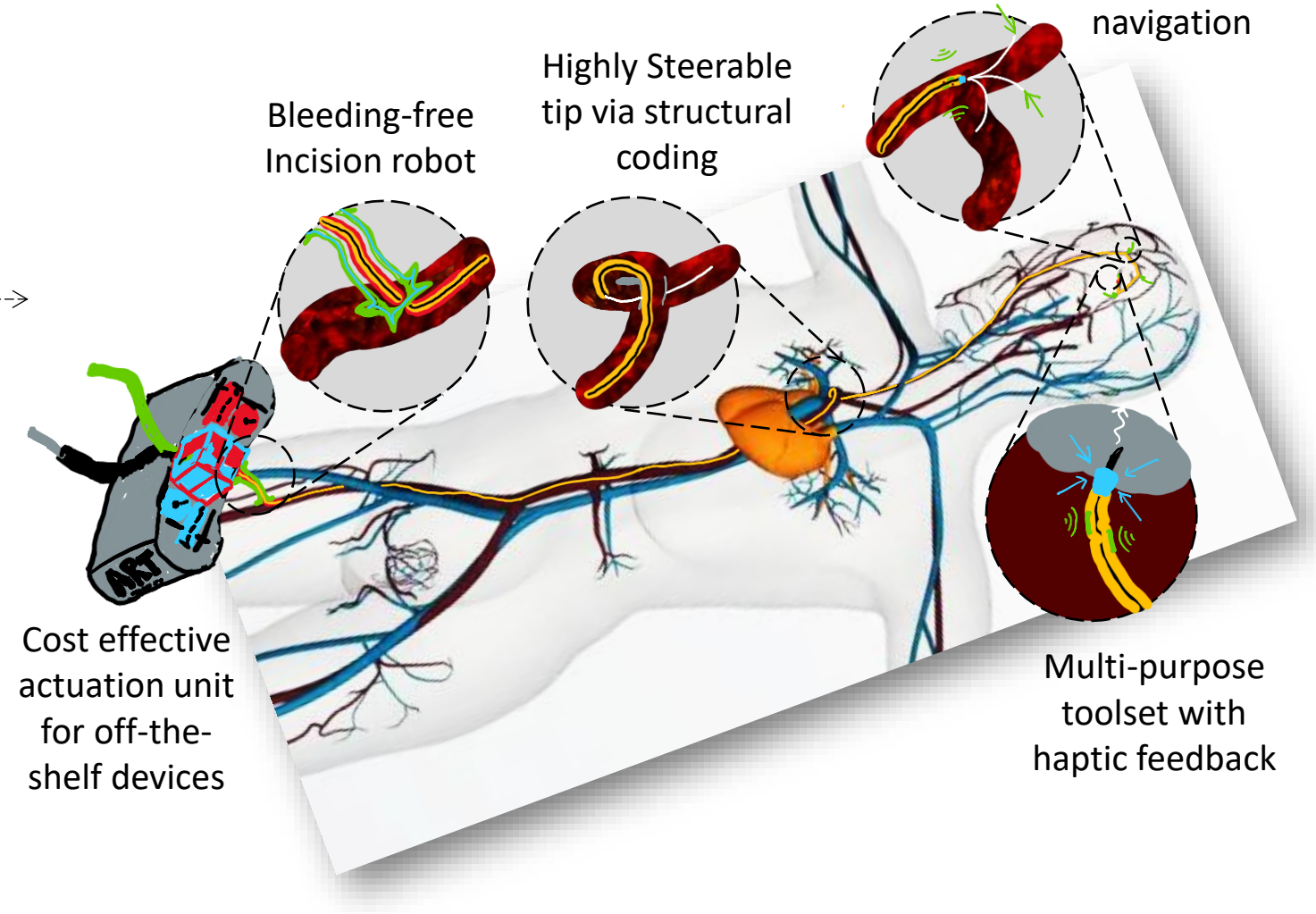
Haptic Tele-manipulation, system verification, & user-study


Fluoroscopic image-based mapping, real-time simulation, and force observation

Model-informed AI-based Autonomous navigation

Highly Steerable tip via structural coding

Bleeding-free Incision robot



Cost effective actuation unit for off-the-shelf devices

Multi-purpose toolset with haptic feedback

# Thank you!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NIHR | Cardiovascular MedTech Co-operative

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ARTERY AUTONOMOUS ROBOTICS

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wellcome EPSRC centre medical engineering

NHS Guy's and St Thomas' NHS Foundation Trust

NHS King's College Hospital NHS Foundation Trust

Queen Mary University of London

KING'S College LONDON