A Compact and Versatile Catheter Robot for Invasive Cardiac and Neurovascular Interventions

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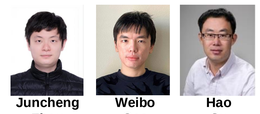
Website: http://haosu-robotics.github.io

Biomechatronics and Intelligent Robotics Lab



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Objectives and Challenges

- Endovascular interventions are complex procedures that pose significant clinical challenges to ensure high precision, efficiency, and safety in delicate vasculatures[1]
- Current penetration: less than 1% of endovascular surgeries are done robotically
- The current state-of-the-art robotic solutions have a large and cumbersome footprint necessitates dedicated room and staff.
- Extended set-up time and long learning curve
- Specifically, capital expense is a critical problem for hospitals
- We envision that the proposed novel portable and modular robot will bridge the gap and enhance clinical outcomes

State of the art Solutions for Endovascular Interventions

State of the art:

- Most for the robots have large footprint requires dedicated infrastructure
- Complex surgical workflow and limited with a specific set of endovascular instruments
- Requires specialized training and a long learning curve

Our solution:

- Portable architecture to enhance accessibility
- Modular design incorporated with direct drive motors to enable intuitiveness and simultaneous manipulation of instruments
- Task Autonomy to reduce the clinician's workload and enhance the procedural efficiency

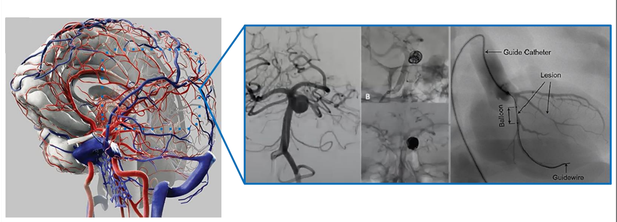
State-of-the-art Solutions

	Corindus CorPath GRX	Stereotaxis Genesis	MIT	Our Robot
Capital Equipment	Yes ✗	Yes ✗	Yes ✗	No ✓
Procedural Accuracy	High ✓	Medium ~	High ✓	High ✓
Portable Architecture	No ✗	No ✗	No ✗	Yes ✓
Open System (instrument lengths)	No ✗	No ✗	No ✗	Yes ✓
Facilitate different diameter instruments	No ✗	No ✗	No ✗	Yes ✓

Design Innovation: Portable and Modular Robot

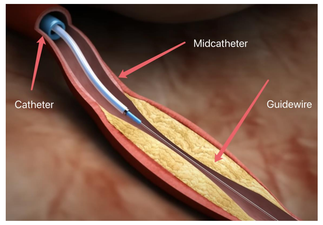
Portable Architecture

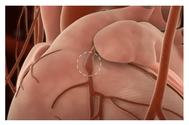
- Compact mechanisms with customized electronics have enabled to design of a portable platform to eliminate the accessibility barrier
- It facilitates lumen access through the femoral and radial entrees to perform various procedures (such as Neurovascular Embolization, Percutaneous Coronary Intervention [PCI])



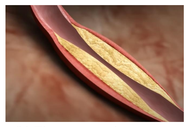
Percutaneous Coronary Intervention

- Percutaneous Coronary Intervention (PCI)
- A minimally invasive procedure used to open narrowed or blocked coronary arteries
- Restore blood flow to the heart muscle.

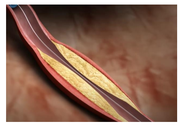




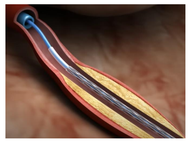
(a) X-ray imaging locates the narrowed artery



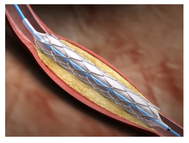
(b) The narrowed artery needs to be widened



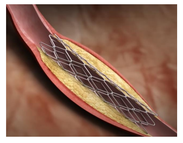
((c) Guidewire is first inserted through the lesion



(d) A midcatheter with balloon and stent is advanced over the guidewire



(e) The balloon inflates to expand the artery, The stent is expanded with the balloon

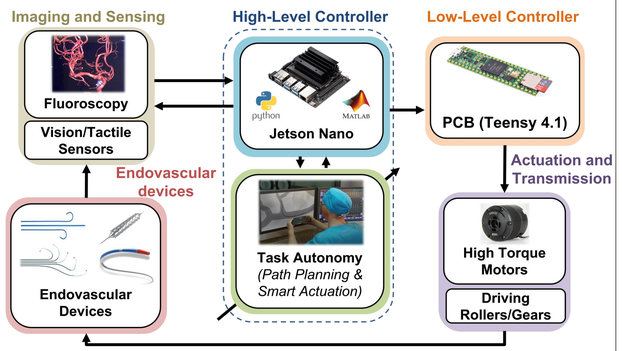


(g) The stent remains to support blood flow

Control Architecture of Endovascular Catheter Robot

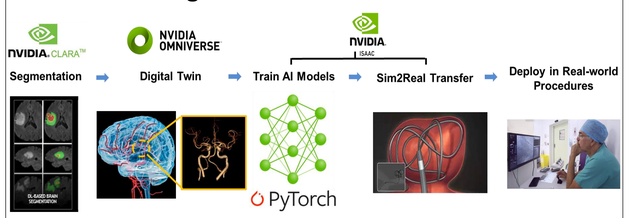
- Task autonomy reduces the clinician's workload and procedural efficiency (time and accuracy)

Overview of Control Architecture



- Under clinician supervision, a high-level controller deploys the autonomous path planning and smart actuation paradigms based on real-time device tracking
- Low-level controller facilitate precise joint-space control to perform simultaneous manipulation of endovascular devices

Sim2Real Digital Twin's Simulation Framework



Design, Simulation, and Human-Robot Interaction

Task 1: Neurovascular robot with haptic feedback
- Steerable guidewire
- Surgical instrument actuation
- Robot with haptic feedback

Task 2: Physics-informed digital twin's simulation framework
- Pre-operative simulation to train surgeons
- Intra-operative simulation for situational awareness modeling

Task 3: Investigate Human-Robot Interaction (HRI) for Surgical Skill Evaluation
- Surgical skill evaluation

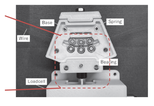
Mechatronics Design

Smart Actuation Paradigms

Either we chouse in vivo figures (Xray) or draw illustrations

Rotate and Retract | *Spin* | *Wiggle* | *Dotter*

Haptic feedback for situation awareness

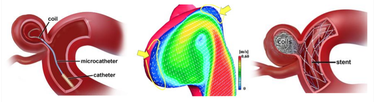


Create a CAD - Slave Haptic Module

Pre-operative simulation for surgeon training

Enables training in simulated environments

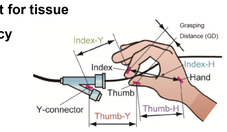
Intra-operative simulation for situation awareness



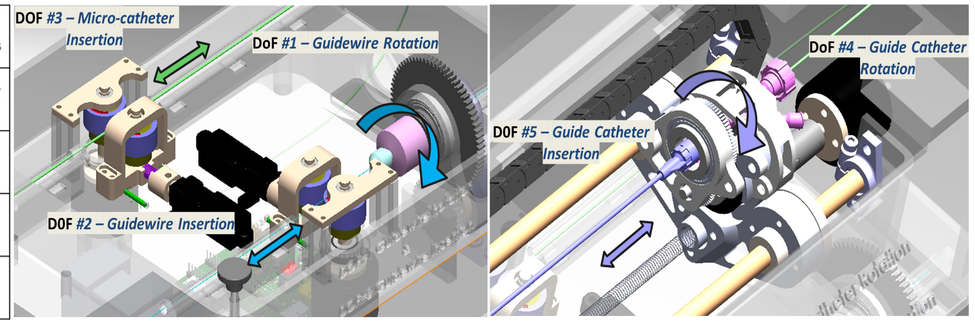
Improved catheter navigation | *Anticipate interaction with blood flow* | *Patient-specific simulation*

Scenarios
- Manual procedure: Surgeon
- Robot without haptics
- Robot with haptics
- Robot with simulation
- Robot with haptics and simulation

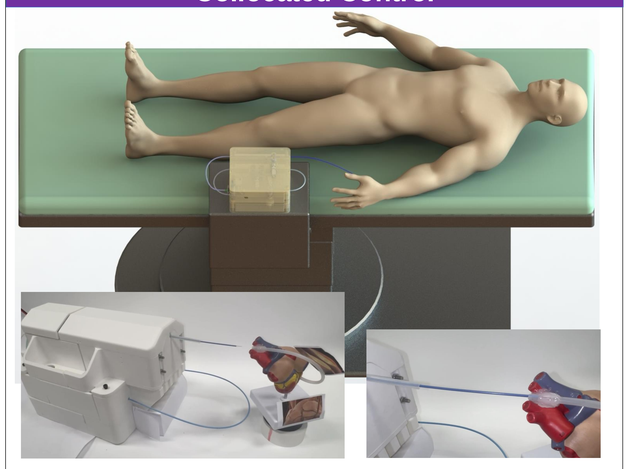
Metrics
- Average procedural duration and reaction time
- Respect for tissue
- Accuracy



Degrees of Freedom	Coordinate Control Features
2	*Rotate and Retract*
1	*Spin*
2	*Wiggle*
2	*Dotter*



Enabling Precise Force Intervention through Collocated Control



- Compact robotic actuation module
- Enables accurate insertion of the catheter to the target.

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