



JOHNS HOPKINS
UNIVERSITY

Design of a Robotic System for Ultrasound-Guided Central Line Placement

Students: Kesi Liang, Pranathi Golla, Xuanning Liu

Mentors: Dr. Axel Krieger, Lidia Al-Zogbi, Dr. Vinciya Pandian, Dr. Mathias Unberath, Wenhao Gu

Project Summary

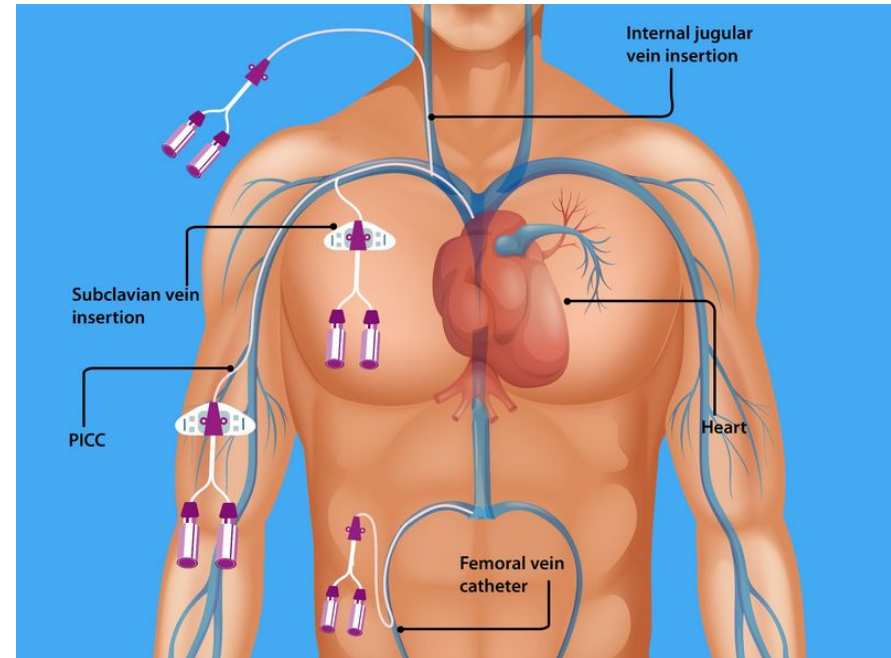
- **Problem:**

The complicated procedure of central line placement is physically and mentally demanding for clinicians:

- low accuracy
- low consistency
- low efficiency

High complexity leads to increased infection risk:

- Result in increased healthcare costs, and even death.



Project Summary

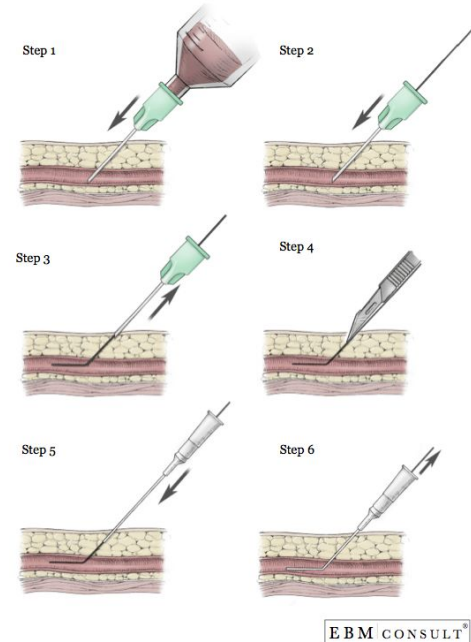
- **Project goal:**

A multi-object insertion system to simplify central line placement procedure to minimise the risk of infection

- light-weight
- ultrasound-guided
- body-mountable

- **Deliverables:**

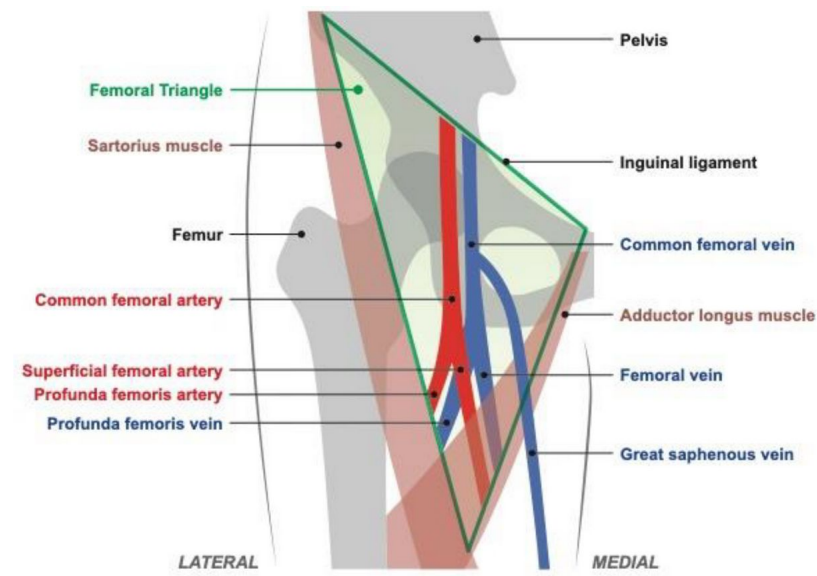
- High-level and low-level specifications
- CAD model
- Prototype
- Documentation
- Experimental evaluation



Paper #1 - AI-Enabled, Ultrasound-Guided HandHeld Robotic Device for Femoral Vascular Access

Introduction

- ▶ Femoral access is necessary for administering emergency drugs, emergency interventions etc.
- ▶ Ultrasound guided techniques have gain popularity lately for their accuracy and safety
- ▶ However, they demand skill and expertise
- ▶ In this paper, the authors developed a robotic device for femoral catheterisation



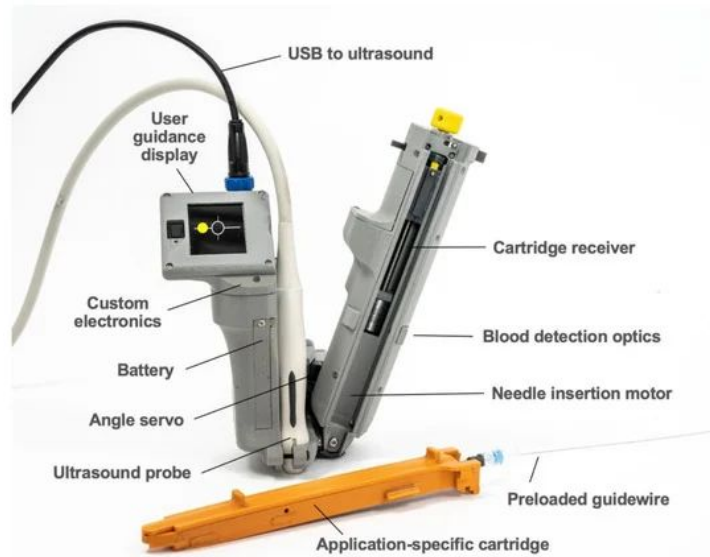
Paper #1 - AI-Enabled, Ultrasound-Guided HandHeld Robotic Device for Femoral Vascular Access

Design of the robotic system:

- ▶ Robotic arm to position the ultrasound probe
- ▶ Needle insertion mechanism
- ▶ Console with the AI algorithm that determines the insertion site

Validation of the robotic system:

- ▶ Phantom testing with 11 users
- ▶ Median time for needle injection decreased in three trials



Paper #1 - AI-Enabled, Ultrasound-Guided HandHeld Robotic Device for Femoral Vascular Access

Relevance to our project

- Blueprint for designing a robotic system for ultrasound guided central line placement
- Compact design for needle insertion

Limitations:

- ➔ Only for femoral access, not for jugular or subclavian access
- ➔ Only handheld; still taxing for the clinicians
- ➔ Only two degrees of freedom for needle insertion
- ➔ Only works for flat body parts, as in the case of femoral access

- ➔ Will cover subclavian access and make it translatable to jugular access
- ➔ Will design a patient-mountable robotic system
- ➔ Will add more degrees of freedom for both rotation and translation
- ➔ Will design for subclavian insertion in our project

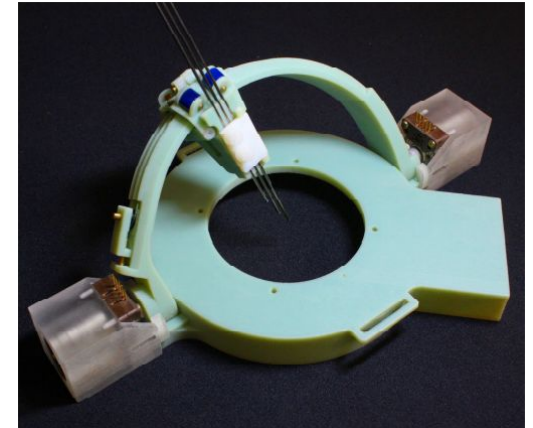
Paper #2 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Introduction:

- Main goal: Design of a MRI compatible robotic system to perform multiple probes insertion
- Cryoablation: freeze and destroy abnormal tissue by using a cryoprobe
- MRI is used to visualize the probes and the formation of the ice ball
- Tradition procedure is inefficient and depends on expertise

Specifications:

- Diameter of base: 11 cm
- Remote center of motion: 15 mm above skin
- Maximum force: 2.71 N
- Workspace: average depth of 125 mm and maximum tilt of $\pm 45^\circ$



F. Y. Wu, M. Torabi, A. Yamada, A. Golden, G. S. Fischer, K. Tuncali, D. Frey, and C. Walsh, "An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation," Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE 2013, 08 2013.

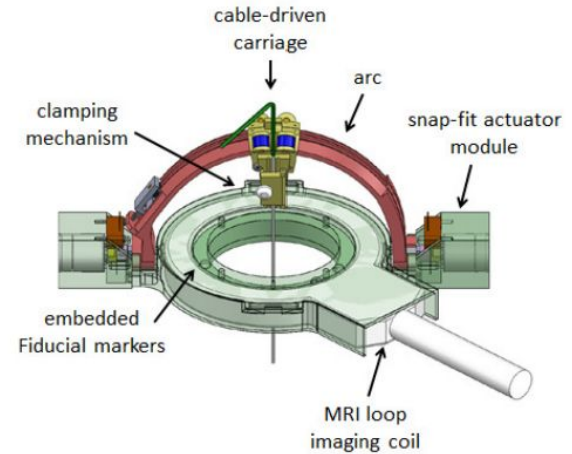
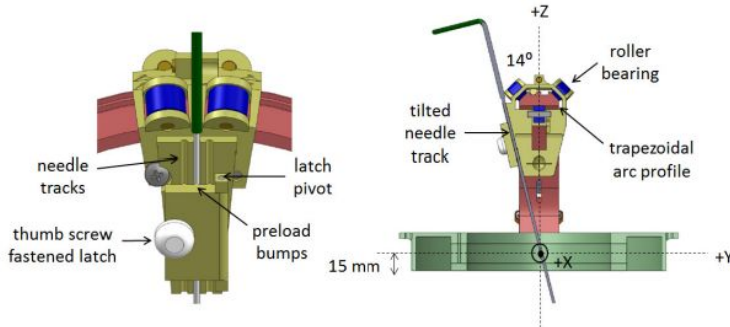
Paper #2 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Base:

- Mounted to patient by adhesive pads
- Motors on both sides, driving arc and carriage

Sliding:

- Cable driven: driving pulley -> carriage -> tensioning pulley
- Tensioning mechanism to fine tune the pulley and eliminate backlash



Arc and carriage:

- Add two degree of freedom for rotation
- Use wide roller bearings to decrease friction and stress
- Small actuator modules containing piezoelectric encoder-based motors

F. Y. Wu, M. Torabi, A. Yamada, A. Golden, G. S. Fischer, K. Tuncali, D. Frey, and C. Walsh, "An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation," Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE 2013, 08 2013.

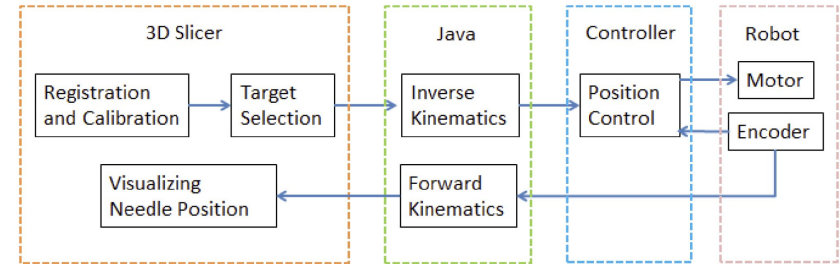
Paper #2 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Software: A 3D Slicer Image-Guided-Therapy (IGT) module

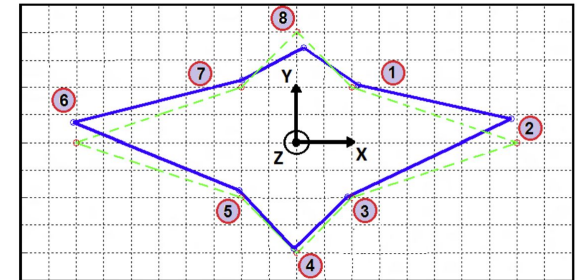
- ❖ Perform device registration and calibration
- ❖ Plan probe trajectory
- ❖ Visualize robot movement

Validation:

- ❖ FEA and MATLAB validation before prototyping
- ❖ Bench level test evaluate the angular accuracy and repeatability
- ❖ Check accuracy of moving to target location



	Forward	Backward
Arc (q_1)	$-0.02^\circ \pm 0.17^\circ$	$-0.02^\circ \pm 0.25^\circ$
Carriage (q_2)	$0.43^\circ \pm 0.18^\circ$	$-0.41^\circ \pm 0.17^\circ$



Paper #2 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

Relevance to our project:

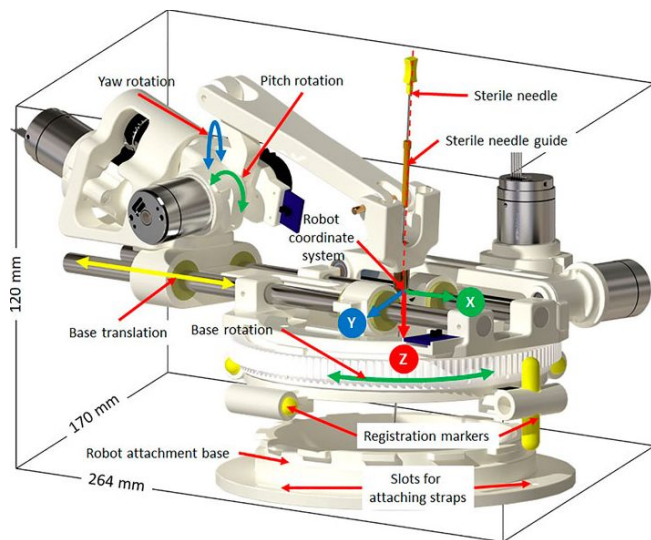
- ❖ Compact patient-mountable device for insertion task
- ❖ Design architecture helps divide problem into subtasks
- ❖ Inspires mechanism design for multiple objects insertion and actuation

Limitations:

- Only adjusts probe orientation, not insertion
- Only two degree of freedom for angle adjustments
- Only works for flat body parts

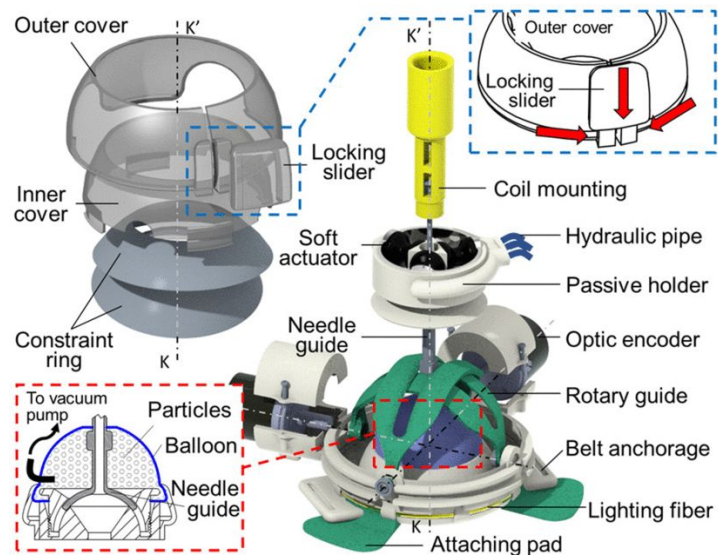
- We will cover both angle adjustments and insertions
- Add more degrees of freedom for both rotation and translation
- A design for subclavian insertion in our project

- **Body-Mounted Robotic System for MRI-Guided Shoulder Arthrography: Cadaver and Clinical Workflow Studies**



- MRI-guided
- Shoulder arthrography
- Needle insertion only
- **Body-mounted**
- **4 DoF**

- Design of a Percutaneous MRI-Guided Needle Robot With Soft Fluid-Driven Actuator



- MRI-guided
- Ablation
- Needle insertion only
- 2 DoF
- **Body-mounted**

Z. He, Z. Dong, G. Fang, J. D.-L. Ho, C.-L. Cheung, H.-C. Chang, C. C.-N. Chong, J. Y.-K. Chan, D. T. M. Chan, and K.-W. Kwok, "Design of a Percutaneous MRI-Guided Needle Robot With Soft Fluid-Driven Actuator," IEEE Robotics and Automation Letters, vol. 5, no. 2, pp. 2100–2107, 2020.

Conclusion

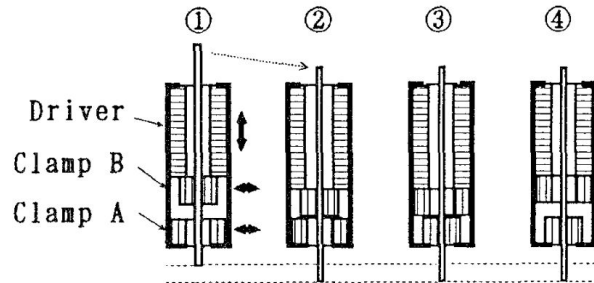
Paper 1	Paper 2	Paper 3	Paper 4	Our design
<ul style="list-style-type: none">• Ultrasound-guided• Hand-held• Femoral access• Needle insertion only• 2 DoF	<ul style="list-style-type: none">• MRI-guided• Body-mounted• Cryoablation• Multiple objects insertion• 2 DoF	<ul style="list-style-type: none">• MRI-guided• Body-mounted• Shoulder arthrography• Needle insertion only• 4 DoF	<ul style="list-style-type: none">• MRI-guided• Body-mounted• Ablation• Needle insertion only• 2 DoF	<ul style="list-style-type: none">• Ultrasound-guided• Body-mounted• Subclavian access• Multiple objects insertion• 4 DoF

References

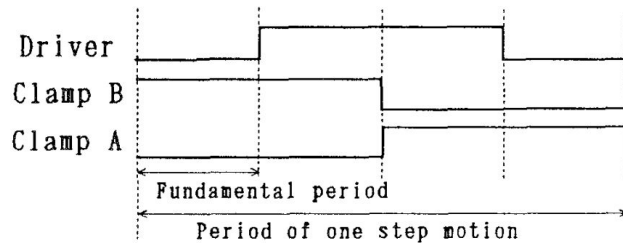
- L. J. Brattain, T. T. Pierce, L. A. Gjestebly, M. R. Johnson, N. D. DeLosa, J. S. Werblin, J. F. Gupta, A. Ozturk, X. Wang, Q. Li, et al., “AI-enabled, ultrasound-guided handheld robotic device for femoral vascular access,” *Biosensors*, vol. 11, no. 12, p. 522, 2021.
- N. Patel, J. Yan, G. Li, R. Monfaredi, L. Priba, H. Donald-Simpson, J. Joy, A. Dennison, A. Melzer, K. Sharma, et al., “Body-mounted robotic system for MRI-guided shoulder arthrography: Cadaver and clinical workflow studies,” *Frontiers in Robotics and AI*, p. 125, 2021.
- F. Y. Wu, M. Torabi, A. Yamada, A. Golden, G. S. Fischer, K. Tuncali, D. Frey, and C. Walsh, “An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation,” *Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE 2013*, 08 2013.
- Z. He, Z. Dong, G. Fang, J. D.-L. Ho, C.-L. Cheung, H.-C. Chang, C. C.-N. Chong, J. Y.-K. Chan, D. T. M. Chan, and K.-W. Kwok, “Design of a Percutaneous MRI-Guided Needle Robot With Soft Fluid-Driven Actuator,” *IEEE Robotics and Automation Letters*, vol. 5, no. 2, pp. 2100–2107, 2020.

Supporting material

Piezo driver explanation



(a) Sequence of electrode feeding



(b) Timing chart