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

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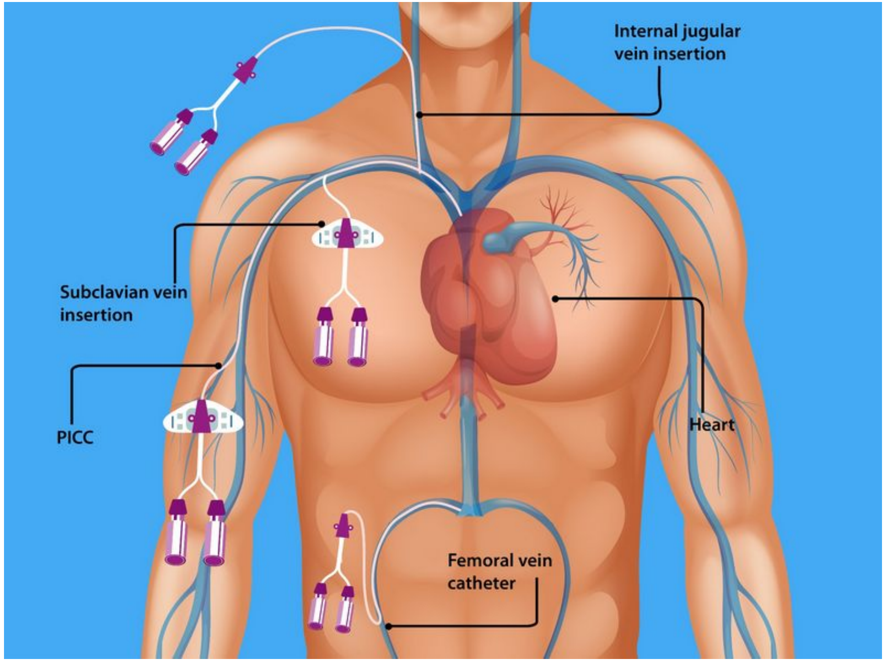
Project Summary

- **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.



Y. Haddadin, P. Annamaraju, and H. Regunath, "Central line associated blood stream infections," in StatPearls, StatPearls Publishing, 2017.

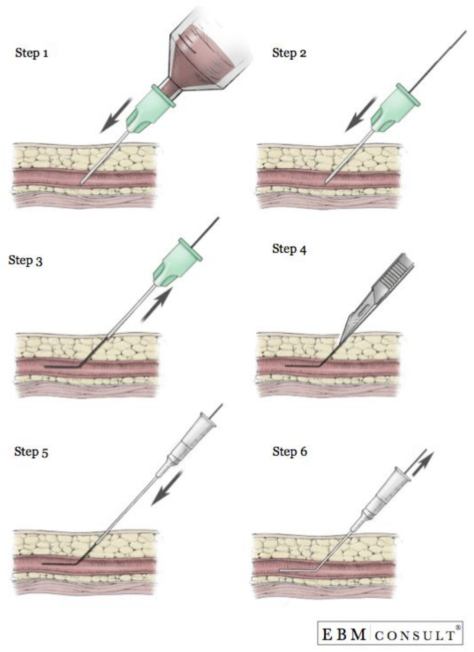
Project Summary

- **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

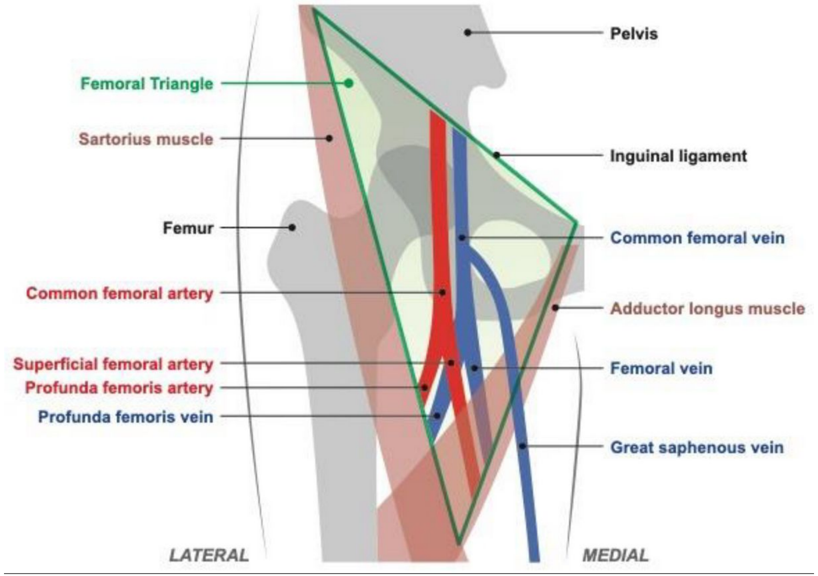


J. R. Roberts and J. R. Hedges, Roberts and Hedges’ clinical procedures in emergency medicine E-book. Elsevier Health Sciences, 2013.
Seldinger Technique for Central Intravenous (IV) Line Placement (ebmconsult.com)

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

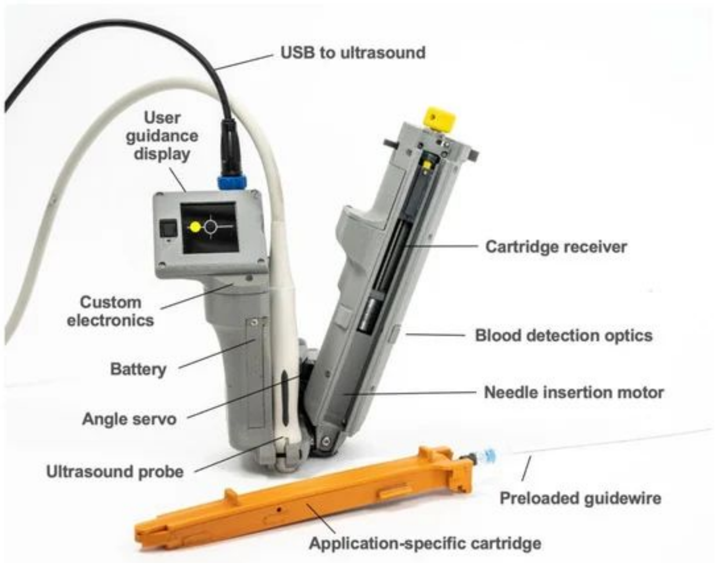


Brattain, Laura J., Theodore T. Pierce, Lars A. Gjesteby, Matthew R. Johnson, Nancy D. DeLosa, Joshua S. Werblin, Jay F. Gupta et al. "AI-enabled, ultrasound-guided handheld robotic device for femoral vascular access." *Biosensors* 11, no. 12 (2021): 522.

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 and needle insertion mechanism
- ► Robot weighs 0.64 kg, is battery operated
- ► Needle is 23 cm long
- ► 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

Brattain, Laura J., Theodore T. Pierce, Lars A. Gjesteby, Matthew R. Johnson, Nancy D. DeLosa, Joshua S. Werblin, Jay F. Gupta et al. "AI-enabled, ultrasound-guided handheld robotic device for femoral vascular access." *Biosensors* 11, no. 12 (2021): 522.

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 handheld; still taxing for the clinicians
- → Only two degrees of freedom for needle insertion

- → Will design a patient-mountable robotic system
- → Will add more degrees of freedom for both rotation and translation

Brattain, Laura J., Theodore T. Pierce, Lars A. Gjesteby, Matthew R. Johnson, Nancy D. DeLosa, Joshua S. Werblin, Jay F. Gupta et al. "AI-enabled, ultrasound-guided handheld robotic device for femoral vascular access." *Biosensors* 11, no. 12 (2021): 522.

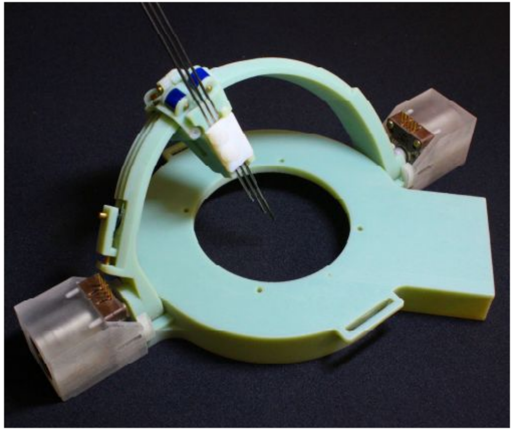
Paper #2 - An MRI Coil-Mounted Multi-Probe Robotic Positioner for Cryoablation

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

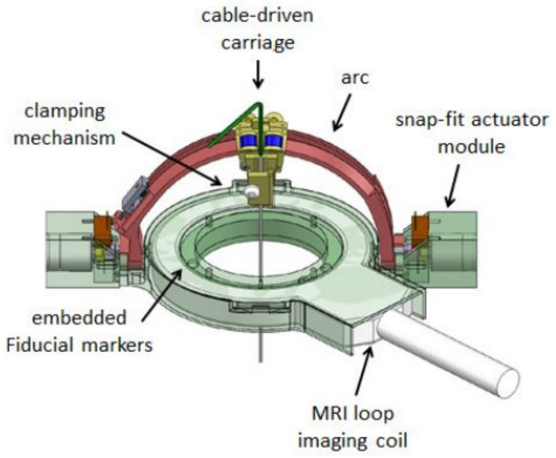
Specifications:

- 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 ±45°



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

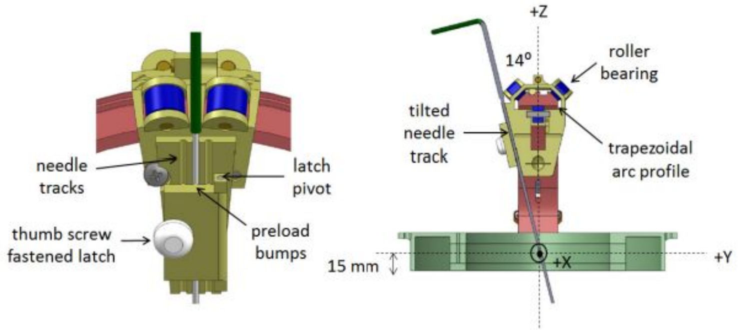


Base:

- 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:

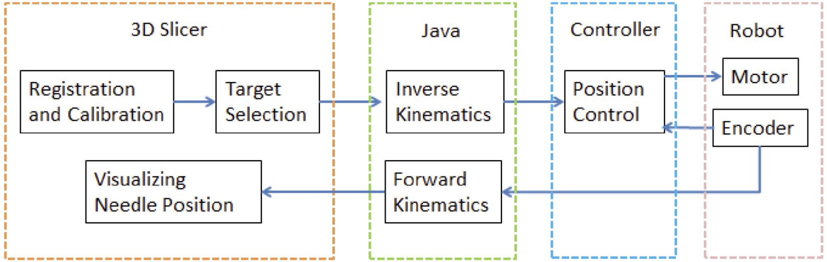
- Add two degree of freedom for rotation
- Use wide roller bearings to decrease friction and stress
- Small actuator modules containing piezoelectric encoder-based motors

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

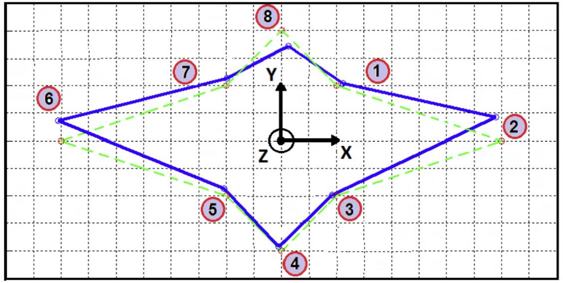
- ❖ Perform device registration and calibration
- ❖ Plan probe trajectory
- ❖ Visualize robot movement



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°±0.17°	-0.02°±0.25°
Carriage (q_2)	0.43°±0.18°	-0.41°±0.17°



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

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:

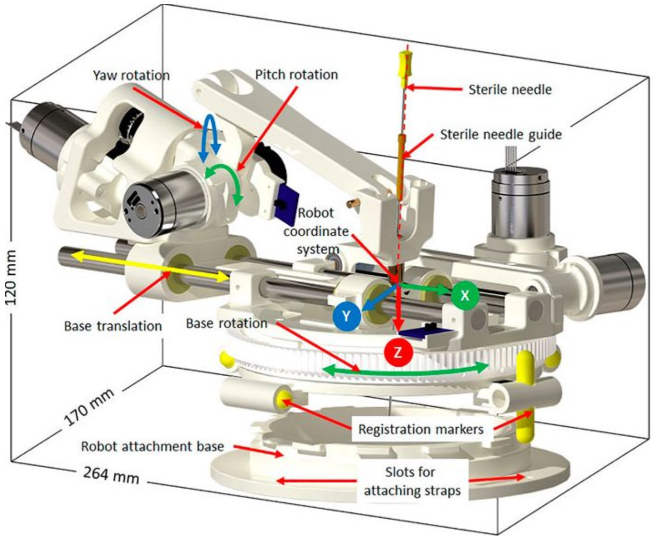
- Only adjusts probe orientation, not insertion
- Only two degree of freedom for angle adjustments
- Only works for flat body parts

- 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

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 #3

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

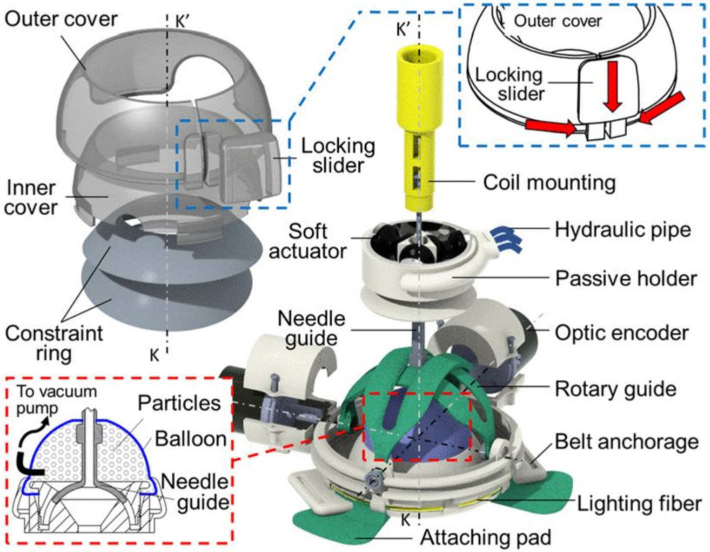


- MRI-guided
- Shoulder arthrography
- Needle insertion only
- **Body-mounted**
- **4 DoF**

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.

Paper #4

- **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
• Ultrasound-guided • Hand-held • Femoral access • Needle insertion only • 2 DoF	• MRI-guided • Body-mounted • Cryoablation • Multiple objects insertion • 2 DoF	• MRI-guided • Body-mounted • Shoulder arthrography • Needle insertion only • 4 DoF	• MRI-guided • Body-mounted • Ablation • Needle insertion only • 2 DoF	• Ultrasound-guided • Body-mounted • Subclavian access • Multiple objects insertion • 4 DoF

References

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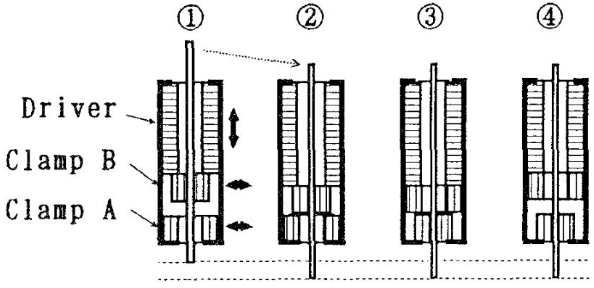
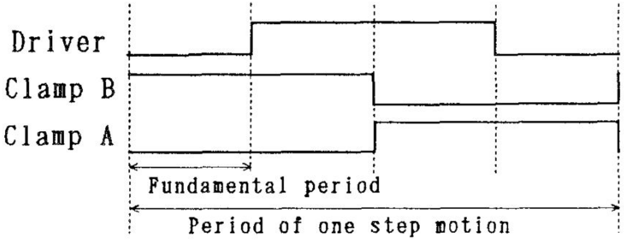
- N. Patel, J. Yan, G. Li, R. Monfaredi, L. Priba, H. Donald-Simpson, J. Joy, A. Dennison, A. Melzer, K. Sharma, et al., “Body-mounted robotic system for MRI-guided shoulder arthrography: Cadaver and clinical workflow studies,” Frontiers in Robotics and AI, p. 125, 2021.
- F. Y. Wu, M. Torabi, A. Yamada, 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

H. Morita, K. Furutani and N. Mohri, "Electrical discharge device with direct drive method for thin wire electrode," *Proceedings of 1995 IEEE International Conference on Robotics and Automation*, Nagoya, Japan, 1995, pp. 73-78 vol.1, doi: 10.1109/ROBOT.1995.525266.