Laboratory for Computational Sensing + Robotics

Johns Hopkins Medicine

I-STAR

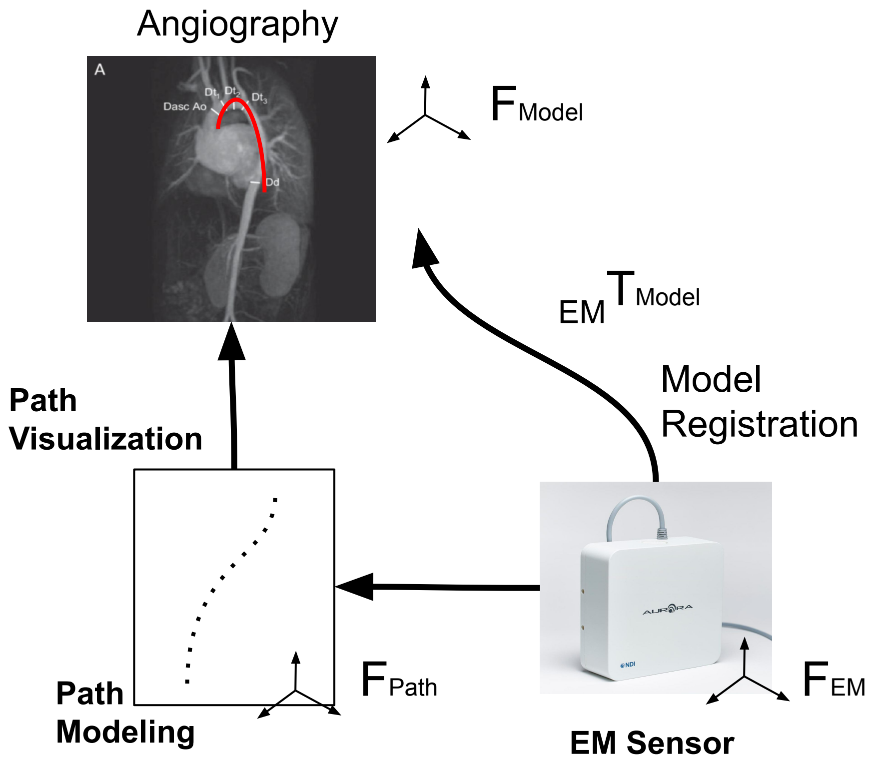
Background Reading Presentation

Electromagnetic Tracking of Endovascular Catheters

Department of Computer Science | Johns Hopkins University | Baltimore, MD

Project Diffuculties

1. Embedding of EM tracker in the catheter and/or guiding wire
2. Evaluation methods
3. Mapping from EM tracker frame to CT Angiography frame
    a. Rigid Transformation
    b. Non-rigid Transfomation



Paper 1: Prototype Design and Evaluation

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Simultaneous tracking of catheters and guidewires: comparison to standard fluoroscopic guidance for arterial cannulation

S Condino, E M Calabro, A Alberti, S Parrini, R Cioni, R N Berchiolli, M Gesi, V Ferrari, M Ferrari

Abstract:

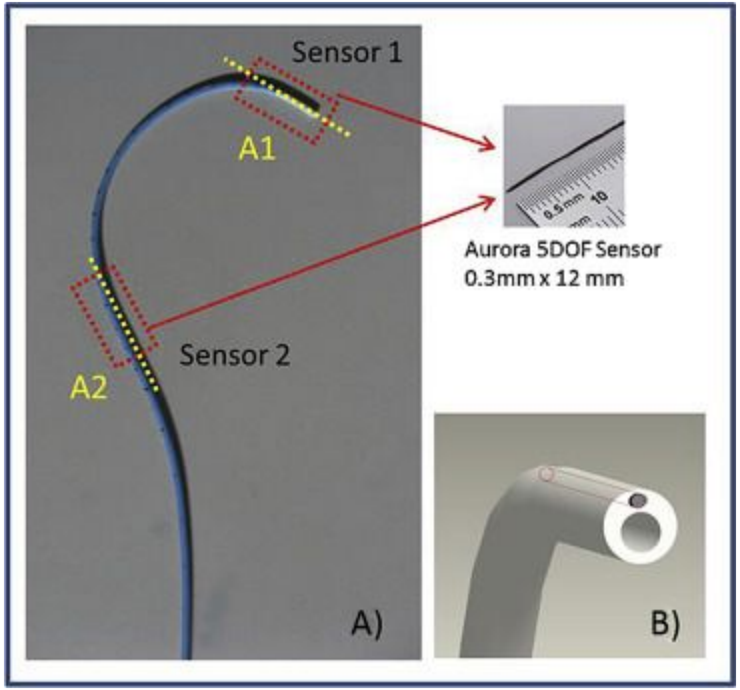
- Objective: To clinically assess the feasibility of EM sensorized catheter, to determine the reduction in radiation dose and contrast medium injection.

- Relevance to our project:
  - Outlines EM tracker embedding procedures for the catheter and guidewires.
  - Evaluation criteria and methods for the EM guided system.

Method: EM Navigator Prototype

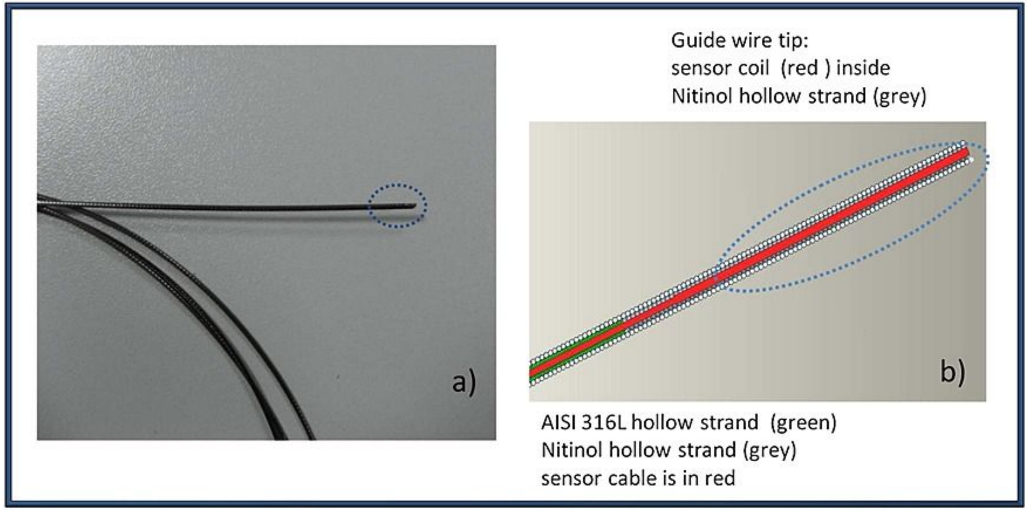
- Based on the Orienter from Angiologica, a steerable angiographic catheter.
- Removed the steering cable from its lumen.
- Inserted the Aurora sensors coils (5DOF, 0.5mm diameter x mm length) in the steering cable lumen, keeping the operative lumen free.
- Seeled with silicon glue.

- In our initial prototype, we may use the operative lumen, due to the lack of guiding wire lumen.



Method: EM Navigator Prototype

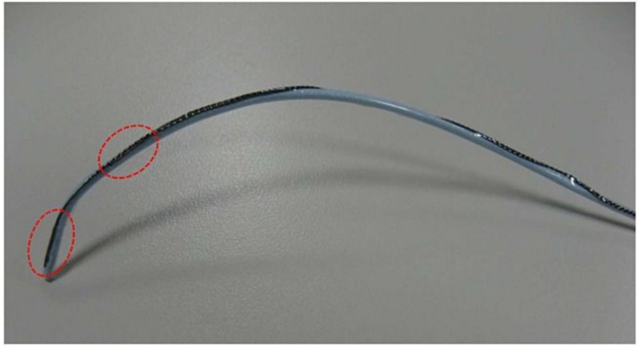
- Nitinol hollow wire used as a basis for guideware
- Inserted the Aurora sensors coils (5DOF, 0.3mm diameter x 12mm length) in the lumen.
- Strengthened with AISI 316L wire
- Coated with bio-compatible heat shrink tube (0.0001-0.004 inch diameter, Advanced Polymers, Inc.).

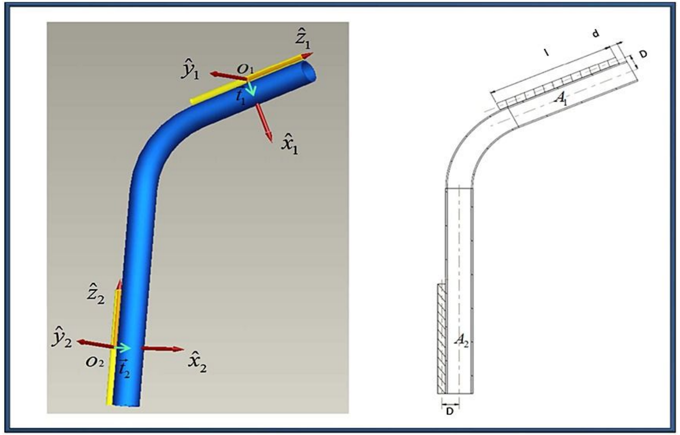


Method: EM Navigator Prototype (Extended)

- In an earlier study by the same authors, the EM sensors were attached onto the catheter via bio-compatible heat-shrink tubing (Advanced Polymers, Inc.)

- The operative lumen is also kept free.
- Suitable for future functional prototypes of our catheters.

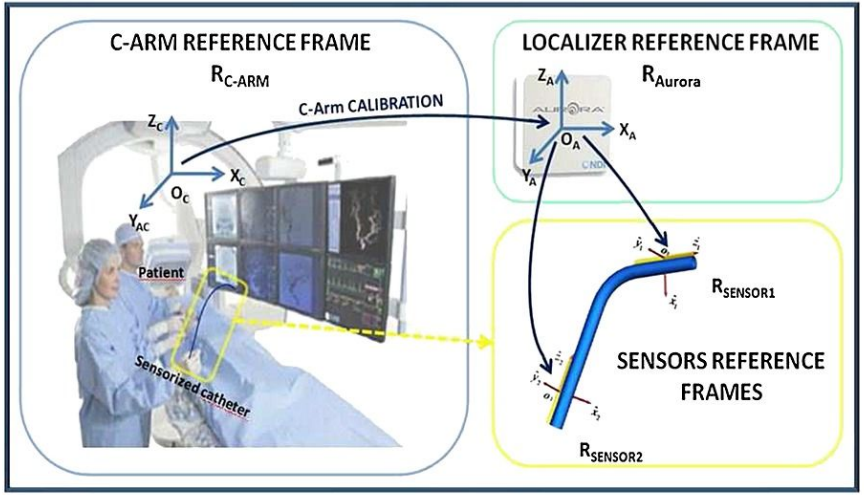


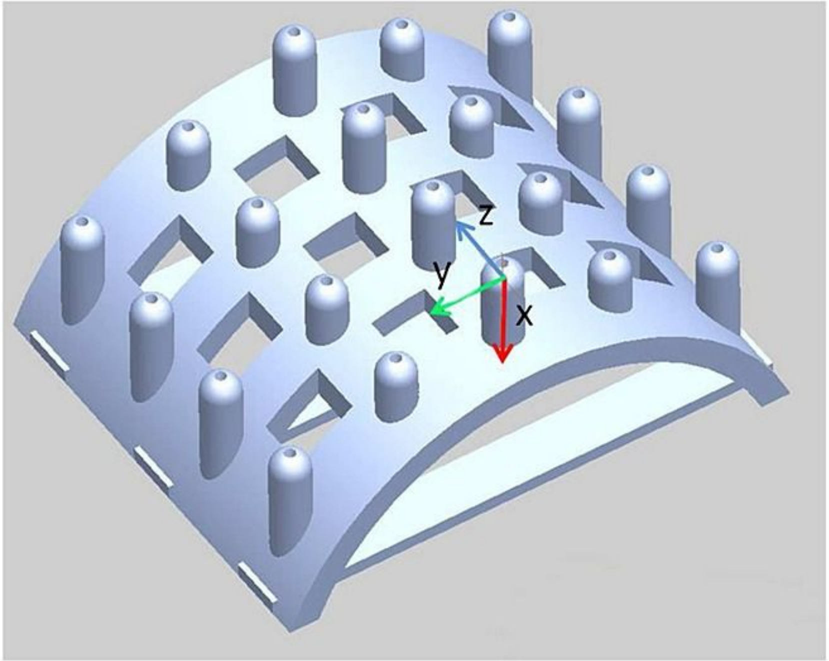


Condino, S., et al. "Electromagnetic navigation platform for endovascular surgery: how to develop sensorized catheters and guidewires." The International Journal of Medical Robotics and Computer Assisted Surgery 8.3 (2012): 300-310.

Method: EM-Imaging Registration

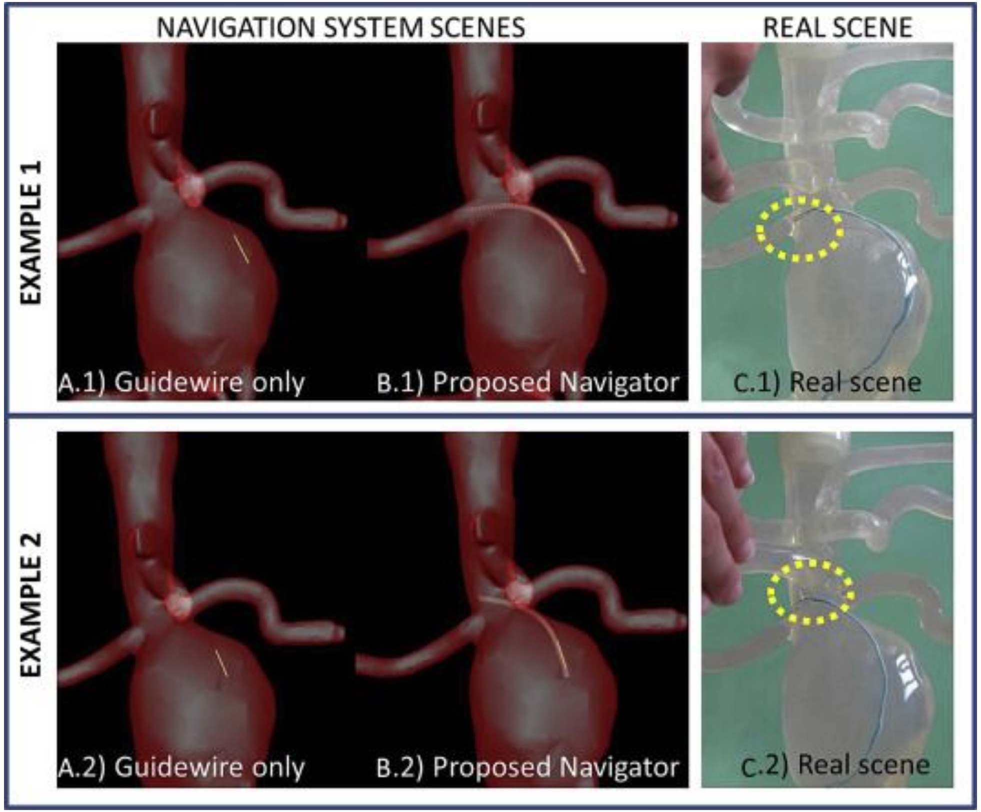
- The location and orientation of the catheter tip and guidewire is visualized through





Method: Path Visualization

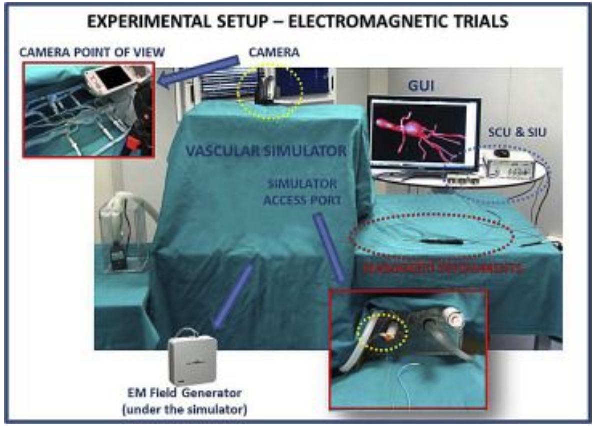
- Intraopterative CTA Superimposed with EM tracked Catheter Model.
- Multi-tracker allows for trajectory track, not just tip location track



Testing Setup

- Abdominal Aortic Aneurym Phantom, covered in surgical drape.
- GE Innova fluoroscopy unit

- 15 Participants
  - Experts (5): > 100 endovascular procedures.
  - Low experienced (10): < 20 procedures - per definition in previous studies.
- Randomized to fluoroscopic/EM-guided groups.
- Task: artery annulation.



Result: Similar Task Performance with EM vs Fluoroscopy Tracking

Quantitative:

- No statistical difference (McNemar's Test) between performance with the guidance modalities, regardless of experience level.

Qualitative:

- No statistical difference withIC3ST Scoring Questionnaire .

Review and Significance

- **Pros:**
  - Detailed sensorized catheter and guidewire construction methods.
  - Realistic Evaluation Setup - $\frac{3}{5}$ low experienced subjects failed.
- **Cons:**
  - Requires many (3) EM sensors to visualize catheter trajectory.
- **Takeaway:**
  - Use of bio-compatible heat-shrink tubing and silicon adhesive for sensor protection.
  - A blinded user-study setup for evaluation.

Paper 2: Rigid Transformation

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Electromagnetic Tracking of Registration and Navigation in Endovascular Anuerysm Repair: A Phantom Study

A. de Lambert, S. Esneault, A. Lucas, P. Haigron, Ph. Cinquin, J.-L. Magne

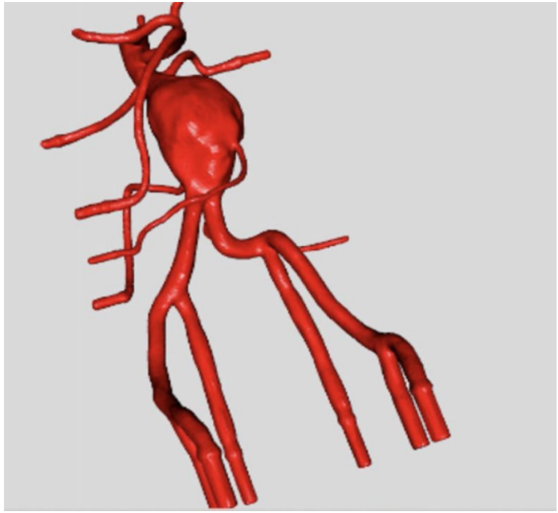
Abstract:

- Objective: To assess the feasibility of using an electromagnetic tracking for both registration and navigation in endovascular aneurysm repair.

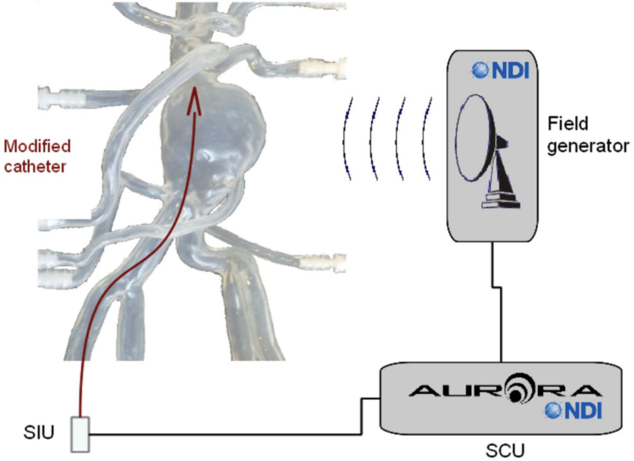
- Relevance to our project: The paper proposed a path based registration method to calculate the 3D **rigid-body** transformation between tracker frame and CT frame.

Methods: Setup

Preoperative Imaging:
CT volumes of phantoms



Electromagnetic Tacking System:
Aurora® Magnetic Tracking

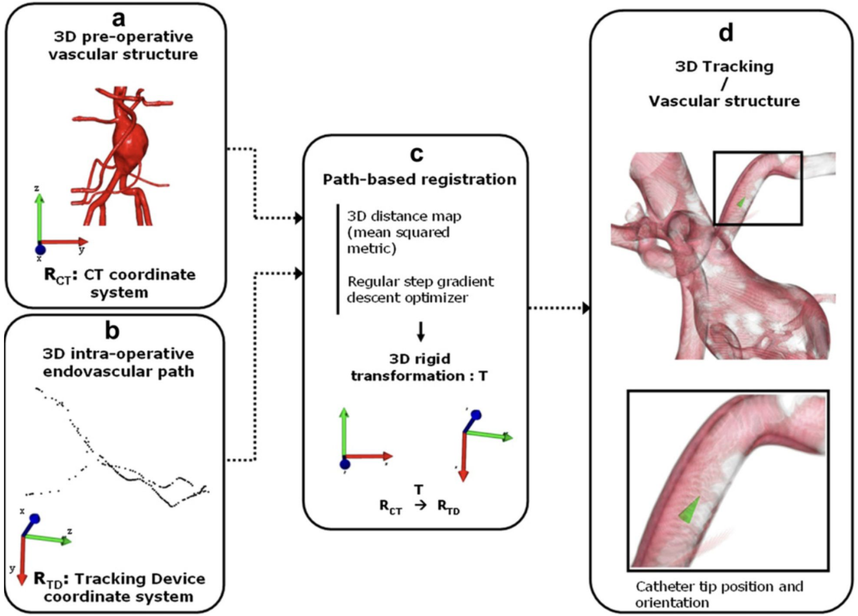


Methods: Registration

1. Initial Registration Parameters:
   determined based on pose of the magnetic source with respect to the phantom

2. Loss Function:
   sum of squared distances between each sensor point and the closest point on the vessel wall extracted from the CT scan

3. Optimization:
   regular step gradient descent optimizer



Result: Evaluation 1

Evaluation Method:

distance between the (1) reference points extracted from the CT volume expressed in sensor frame after registration and (2) the reference points directly measured in sensor frame by manually locating them with the Aurora® magnetic pointer

Table 1
Registration accuracy for phantom A (registration errors are expressed in mm).

	P1	P2	P3	P4	Mean registration error	Mean registration error: z component
Test 1	1.32	1.15	0.88	0.96	1.08	0.4
Test 2	1.67	1.48	1.38	1.05	1.4	0.29
Test 3	1.56	1.38	1.17	0.89	1.25	0.32
Test 4	1.84	1.78	1.89	1.08	1.65	0.37
Test 5	1.01	1.29	1.32	1.33	1.24	0.72
Test 6	1.31	1.21	1.29	1.21	1.25	0.96
Test 7	1.1	1.21	1.29	1.21	1.2	0.68
					1.3	0.53

Registration Successful Rate: 100%

Duration of Registration:
5-10 s on an Intel i7 870, 6 G0 RAM PC

Results: Evaluation 2

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Evaluation Method:

the ability for three surgeons to catheterise a renal artery using only the 3D navigation software, without direct vision or fluoroscopy/angiography. Due to limited number of samples, a non-parametric Kruskal and Wallis test was used to evaluate the agreement between the three surgeons.

Table 2
Time for left renal artery catheterization for each surgeon (Times are expressed in seconds).

	Test1	Test 2	Test 3	Test 4	Test 5	Mean time	Median time
Operator 1	59	21	18	15	49	32	21
Operator 2	40	32	17	22	17	26	22
Operator 3	37	33	24	19	20	27	24

Review and Significance

- **Pros:**
  - Proposed a method to perform the registration between EM tracker frame and CT frame
  - Included a user study regrading the usability of catheterising with 3D navigation software only
  -
- **Cons:**
  - The number of reference points and users are limited

- **Takeaway:**
  - The registration method for sensor frame and CT frame
  - The method to evaluation the accuracy of the registration
  - User study may be needed

Paper 3: Non-Rigid Registration

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Int J Comput Assist Radiol Surg. 2018; 13(6): 855–864.
Published online 2018 Apr 12. doi: 10.1007/s11548-018-1743-5
PMCID: PMC5973972
PMID: 29651714

Learning-based endovascular navigation through the use of non-rigid registration for collaborative robotic catheterization

Wenqiang Chi,[1] Jindong Liu,[1] Hedyeh Rafii-Tari,[1] Celia Riga,[2] Colin Bicknell,[2] and Guang-Zhong Yang[1]

Abstract:

- Objective: To address the problem of anatomical variability among aortic arches for a semiautonomous catheter platform.

- Relevance to our project: Proposes a method of adapting to potential different patient anatomies using non rigid registration.

Methods: Setup

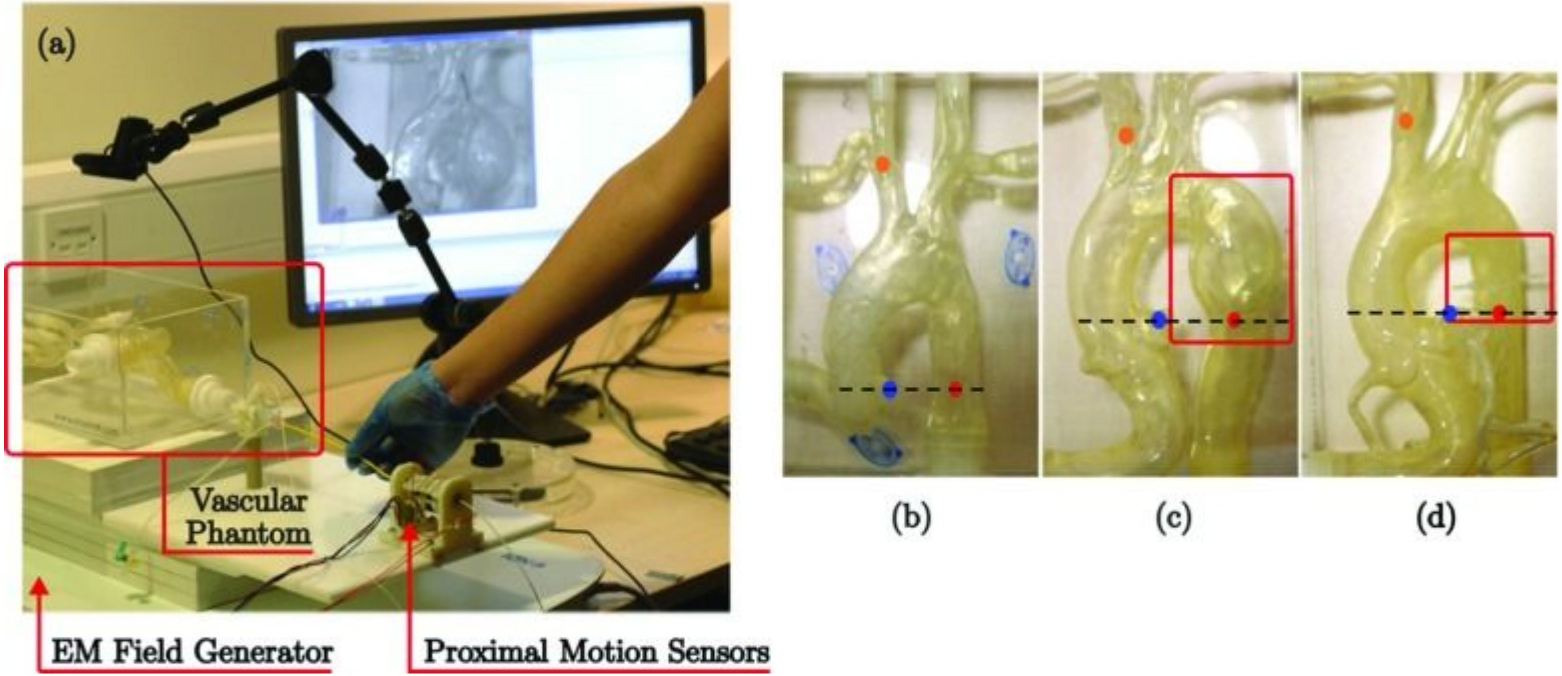

Figure 3. of paper

Methods: LfD Framework

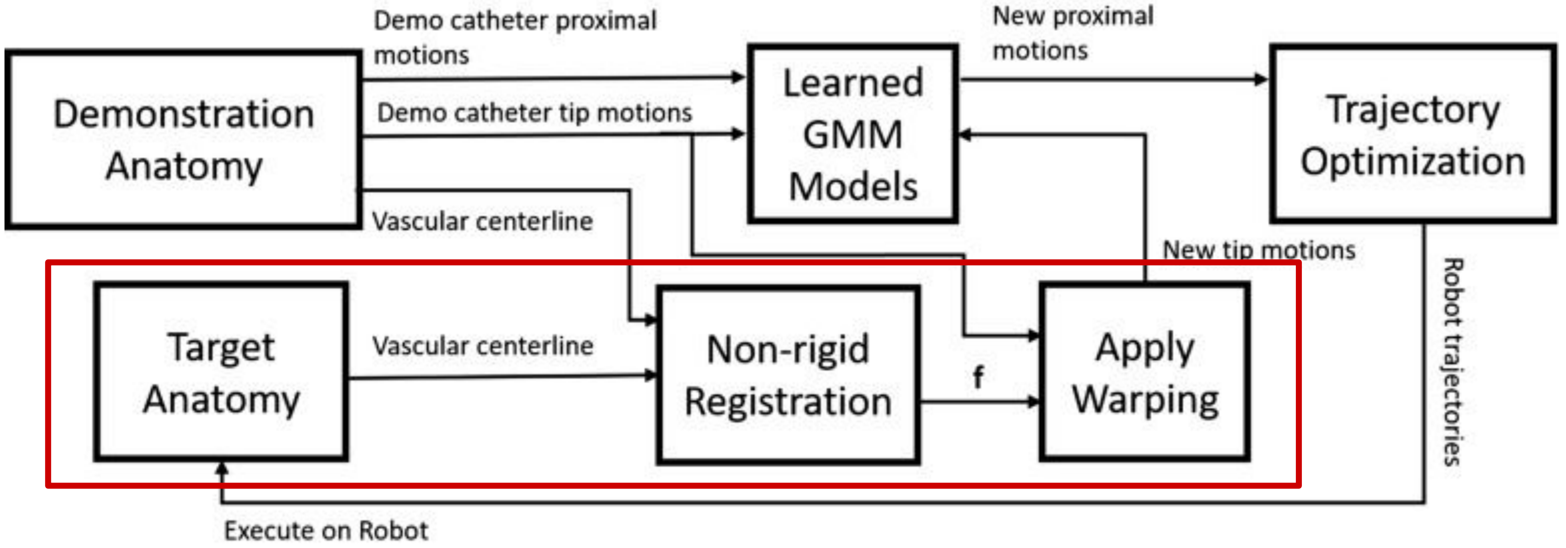

Figure 2. of paper

Methods: Non-rigid Registration

1. Extract the vessel center line of the three phantoms from their CT scans using 3DSlicer
2. Coherent Point Drift (CPD) used to perform non-rigid transformation between the center lines of demo and target anatomies.
3. Apply transformation function to warp demo trajectory to target trajectory.

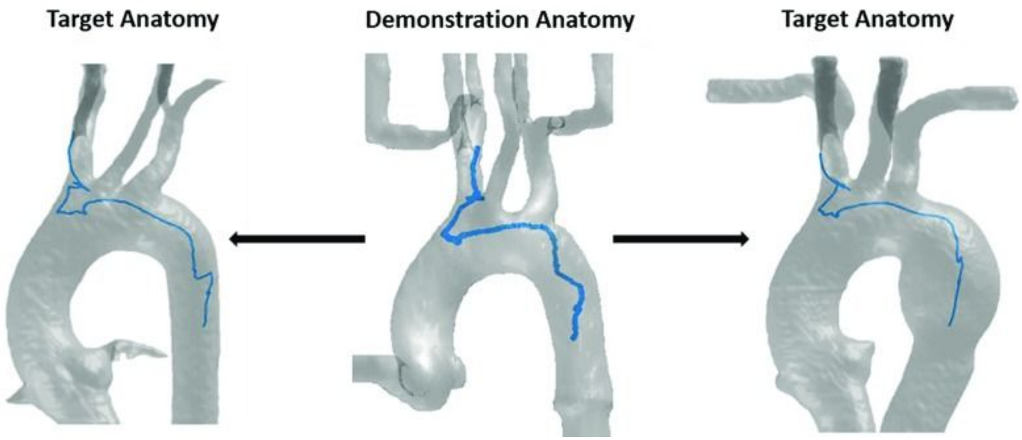

Figure 1. of paper

Methods: Robot Execution

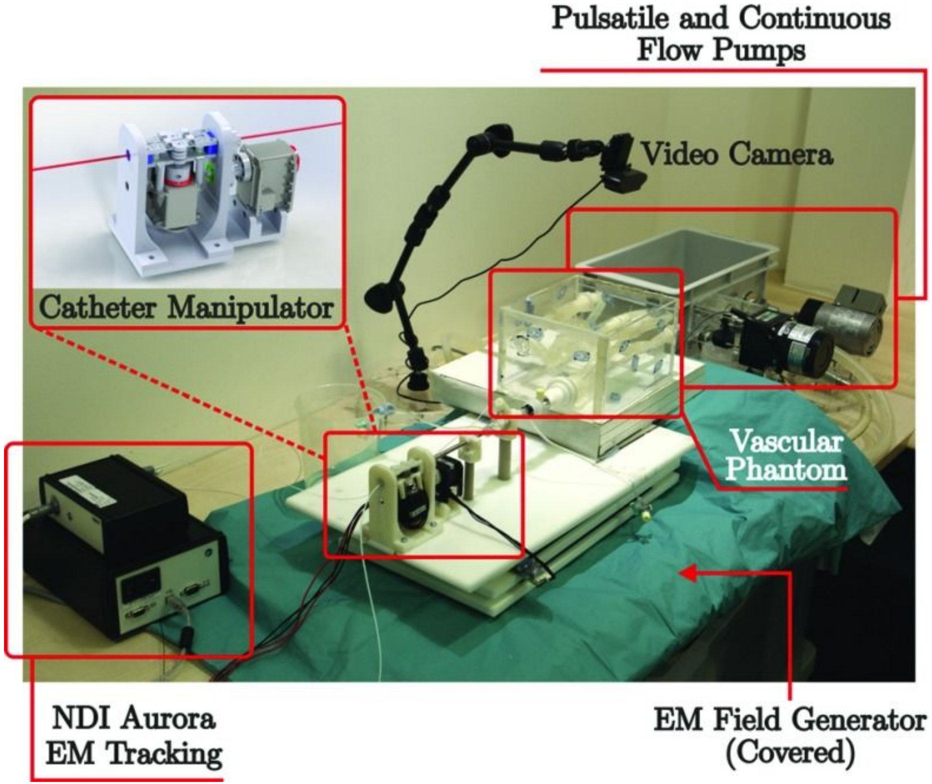

Figure 4. of paper

Results

- Success rate of cannulation:
  - 98.1% for dry simulation
  - 94.4% for continuous flow simulation
- Low for pulsatile flow due to changing phantom shape

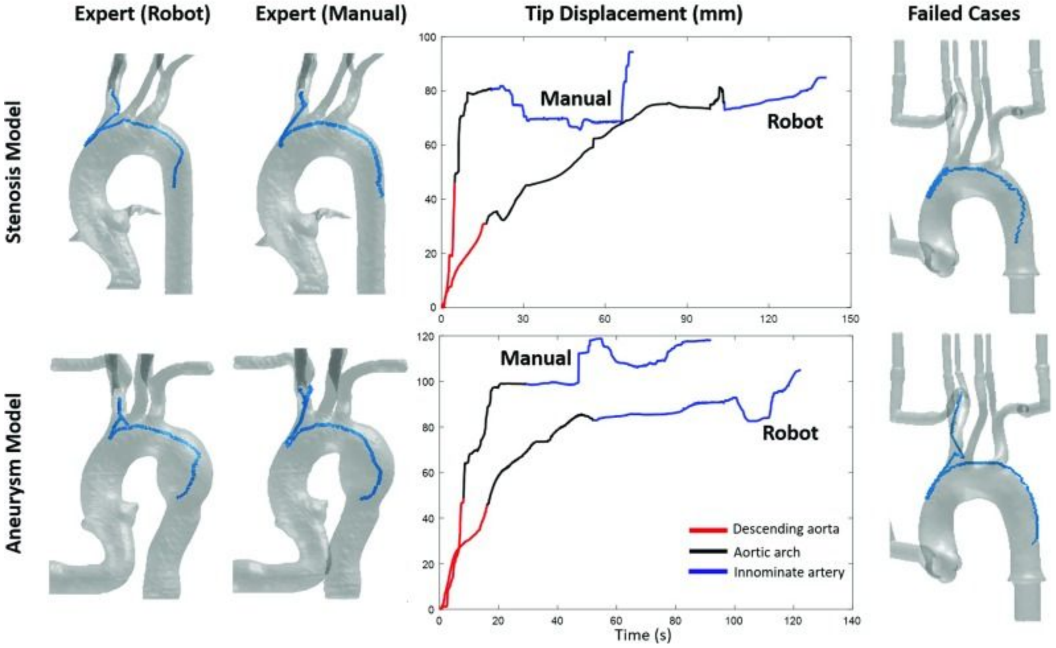

Figure 6. of paper

Results

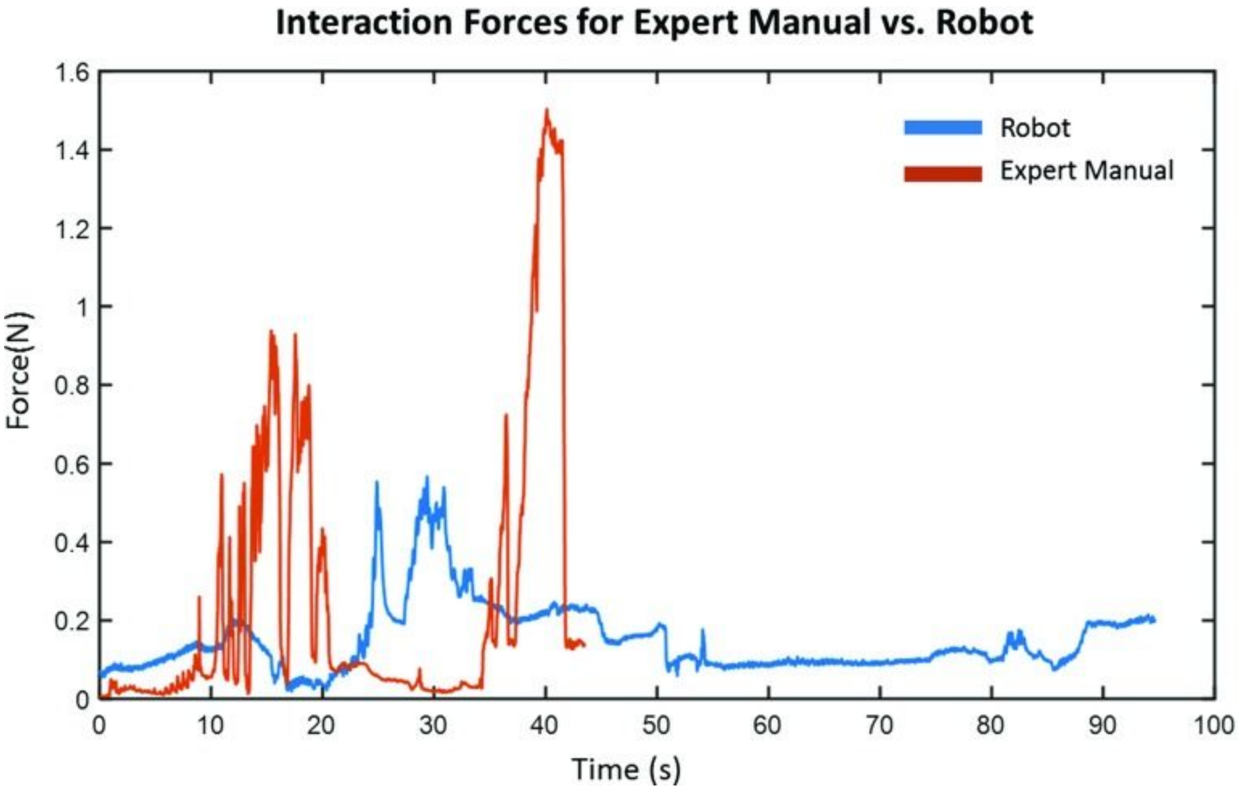

Figure 7. of paper

Review and Significance

- **Pros:**
  - Adapted to different patient anatomies
  - Good proof of concept
- **Cons:**
  - Low performance in pulsatile flow
- **Takeaway:**
  - Using CPD to help us perform registration from tracker frame to CT frame
    - Directly use tracked path as vessel center line