Paper Presentation

Development and Experimental Evaluation of Concurrent Control of a Robotic Arm and Continuum Manipulator for Osteolytic Lesion Treatment

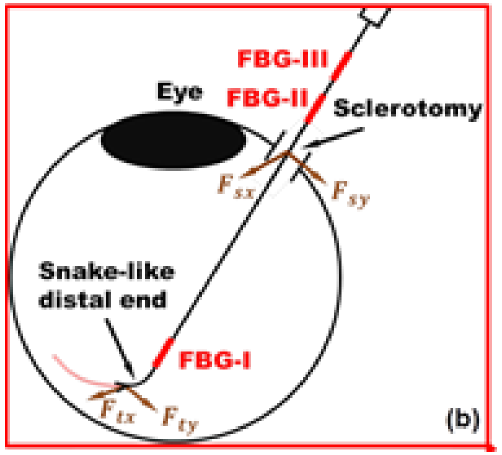
Presenter: Kaiyu Shi

Group 7 w/ Yishun Zhou

Mentors: Dr. Gang Li, Prof. Iordachita

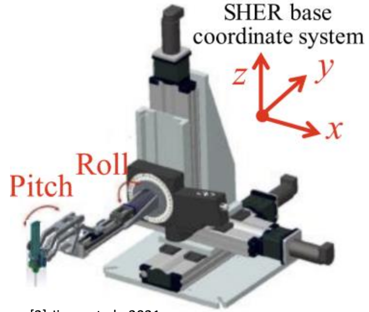
Project Recap

- Problem
  - Vitreoretinal surgery requires high dexterity and stability
  - Epiretinal membrane peeling: forces exceeding 7.5 mN can cause irreversible damage and loss of vision
- Overall Goal
  - Create a high dexterity manipulator (SHER + I^2RIS) with force feedback at the tip for robot assisted vitreoretinal surgery
- Project Goal
  - Simulate control of combined manipulator with force sensors, with input via a Phantom Omni device



From Dr. Iordachita


[3] *3D Systems*



[2] Jinno et al., 2021

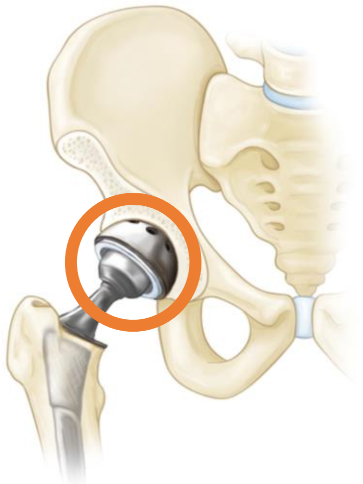
Paper Overview

P. Wilkening, F. Alambeigi, R. J. Murphy, R. H. Taylor and M. Armand, "**Development and Experimental Evaluation of Concurrent Control of a Robotic Arm and Continuum Manipulator for Osteolytic Lesion Treatment**," in IEEE Robotics and Automation Letters, vol. 2, no. 3, pp. 1625-1631, July 2017, doi: 10.1109/LRA.2017.2678543.

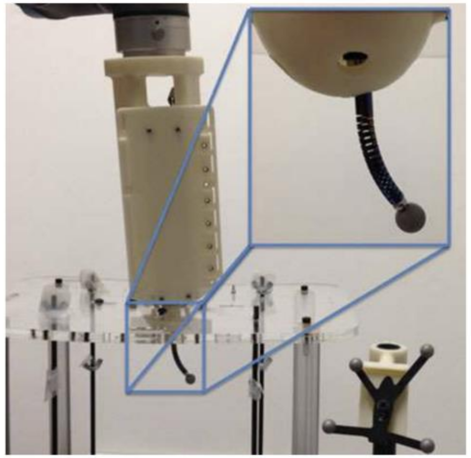
- Snake-like mechanism attached to UR5 positioning robot to perform treatment on osteolytic lesions
- Presents kinematics and method of calibration
- Uses constrained optimization to move the robot while respecting virtual fixtures and constraints
- Evaluated with pre-programmed paths

Motivation

- Osteolysis due to polyethylene liner wear
- Acetabular cup obstructs open access
- Less invasive surgery by drilling through screw holes of acetabular cup
- Scrape remaining lesion using dexterous manipulator



https://aorecon.aofoundation.org/education/surgical-insights/160.html



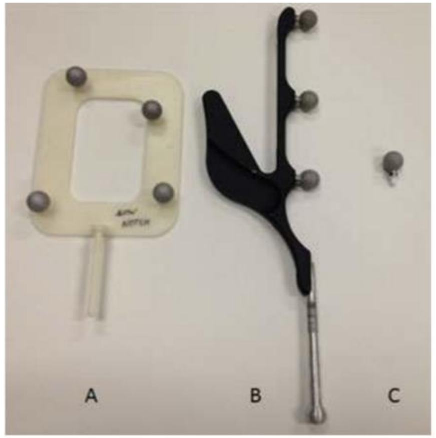
[1] Wilkening et al., 2017

Takeaways

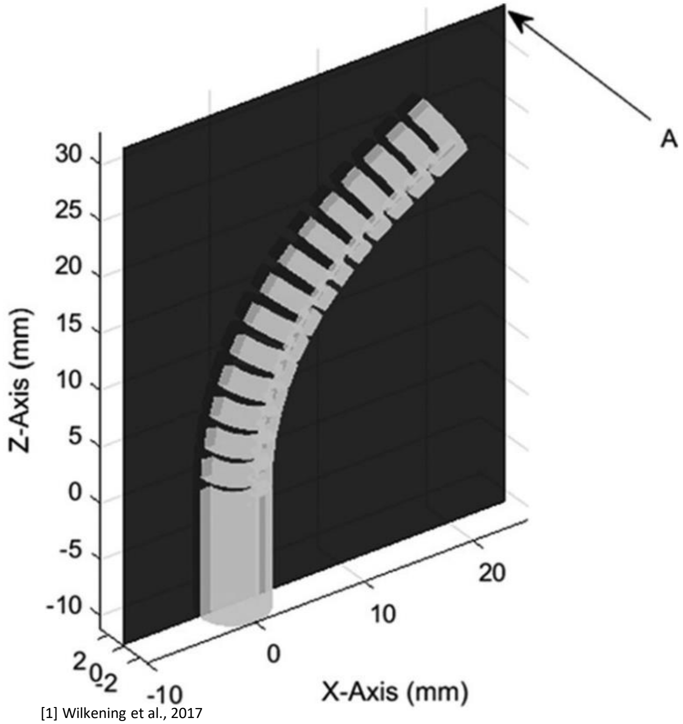
- Concurrently controlled systems enable manipulation in constrained environments
- Snake-like manipulators actuated with wire can introduce error into kinematic systems due to uncertainty and collisions with surfaces

Robot: CDM

- Continuum Dexterous Manipulator (CDM)
  - 1 DoF
  - Calibrated with Polaris NDI system & jig



[1] Wilkening et al., 2017



[1] Wilkening et al., 2017

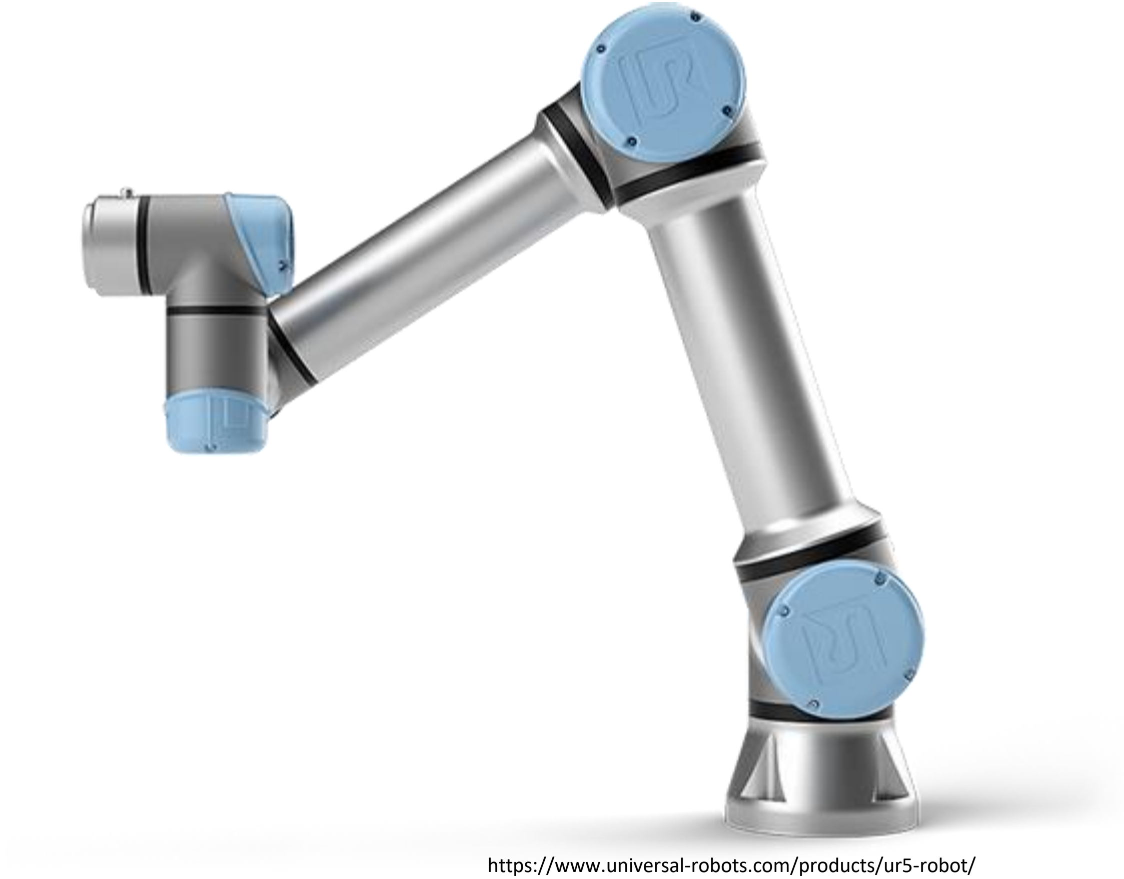
$$p_{\mathrm{CDM},x} = B_n(l)$$

$$p_{\mathrm{CDM},z} = \sum_{i=1}^{3} a_i \sin\left(b_i p_{\mathrm{CDM},x} + c_i\right).$$

Robot: UR5

- Commercial robot from Universal Robotics
  - 6 DoF
  - Used to position and rotate CDM through the screw hole

$$F_{\mathrm{UR5}}\left(q_{\mathrm{UR5}}\right)$$



https://www.universal-robots.com/products/ur5-robot/

Kinematics

$$F_{\text{Combined}}(q) = F_{\text{UR5}}(q_{\text{UR5}}) * F_{\text{Base}} * p_{\text{CDM}}$$

↑

Technically: $p_{Combined}(q)$

$$q = [q_1 \dots q_7]$$

Jacobians

$$Jacobian = \frac{\delta F(q)}{\delta q} = \begin{bmatrix} \frac{\delta x}{\delta q_1} & \cdots & \frac{\delta x}{\delta q_n} \\ \vdots & \ddots & \vdots \\ \frac{\delta z}{\delta q_1} & \cdots & \frac{\delta z}{\delta q_n} \end{bmatrix}$$

$$J_{\text{Combined}}(q) = [\, J_{\text{UR5}}(q)\, J_{\text{CDM}}(q) \,];\ J_{\text{Combined}}(q) \in \mathbb{R}^{6\times 7}$$

Constrained Optimization & Constraints

For each time step: $q_{i+1} = q_i + \Delta q$

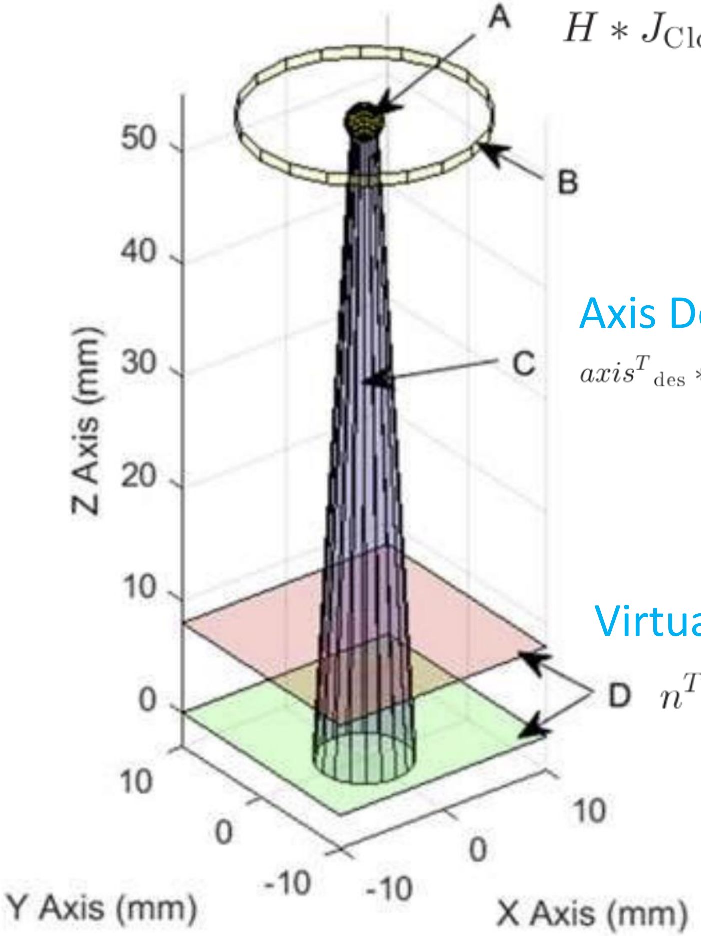
$$\text{argmin}_{dq} \underbrace{||J_{\text{Combined}} * dq - dx_{obj}||^2}_{\text{Objective}}.$$

Max joint velocities:

$$dq \geq dq_{\text{Lower}}; -dq \geq -dq_{\text{Upper}}$$

Rotational Center of Motion (RCM)

$$H * J_{\text{Closest}} * dq_{\text{UR5}} \geq h$$



Axis Deviation

$$axis^T{}_{\text{des}} * J_{\text{Base}} * dq \geq \cos(\theta_{\text{tol}}) - axis_{\text{des}} * axis_{\text{cur}}$$

Virtual Wall

$$n^T * J_{\text{Base}} * dq \geq e - n^T * p_{\text{Base}}$$

[1] Wilkening et al., 2017

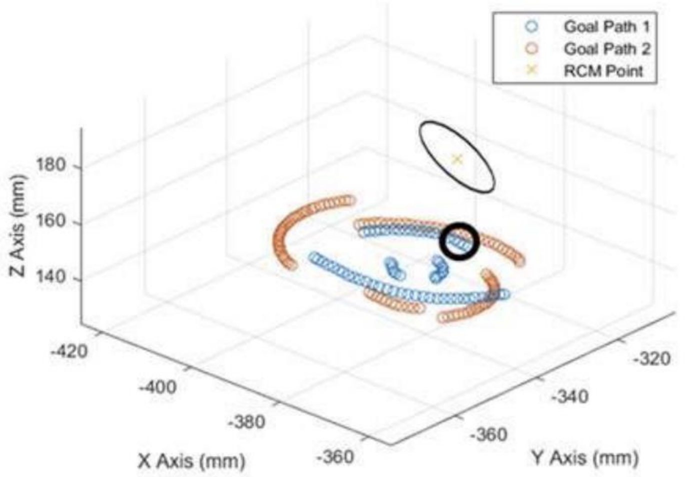
Evaluation

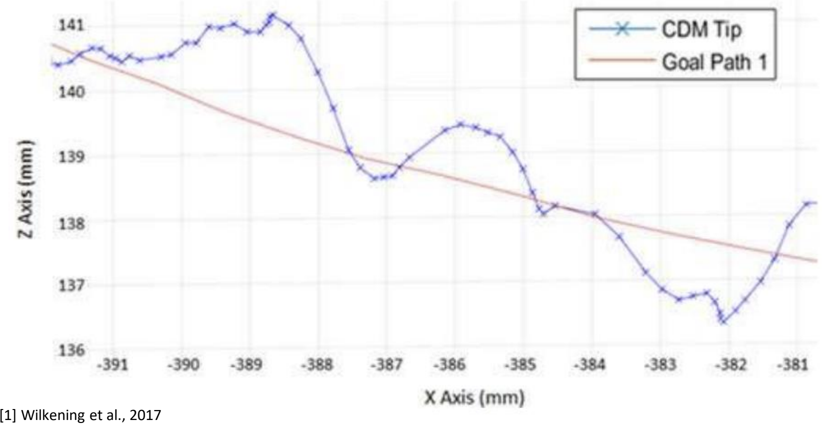
- Compared optically tracked position to sequences of goal paths

TABLE I
SUMMARY OF CDM TIP ERRORS FROM FOLLOWING TWO PATHS FOR MULTIPLE TRIALS

	Path 1		
	Trial 1	Trial 2	Trial 3
Mean Error (mm)	0.46	0.43	0.51
Maximum Error (mm)	1.0	1.0	1.0
Stdev of Error (mm)	0.31	0.28	0.3
	Path 2		
	Trial 1	Trial 2	
Mean Error (mm)	0.34	0.35	
Maximum Error (mm)	1.0	1.0	
Stdev of Error (mm)	0.3	0.29	

[1] Wilkening et al., 2017





[1] Wilkening et al., 2017

Results and Conclusion

- Able to calculate new joint values ~20ms (50 Hz)
- Mean error of 0.42 mm (RMS)
  - Max error of 1.0 mm
- System able to reach areas behind acetabular cup
- Major source of error is uncertainty of CDM shape due to:
  - Friction between wire and CDM
  - Uncertainty of plastic deformation
  - Used different CDM for calibration vs experiment

Future Work

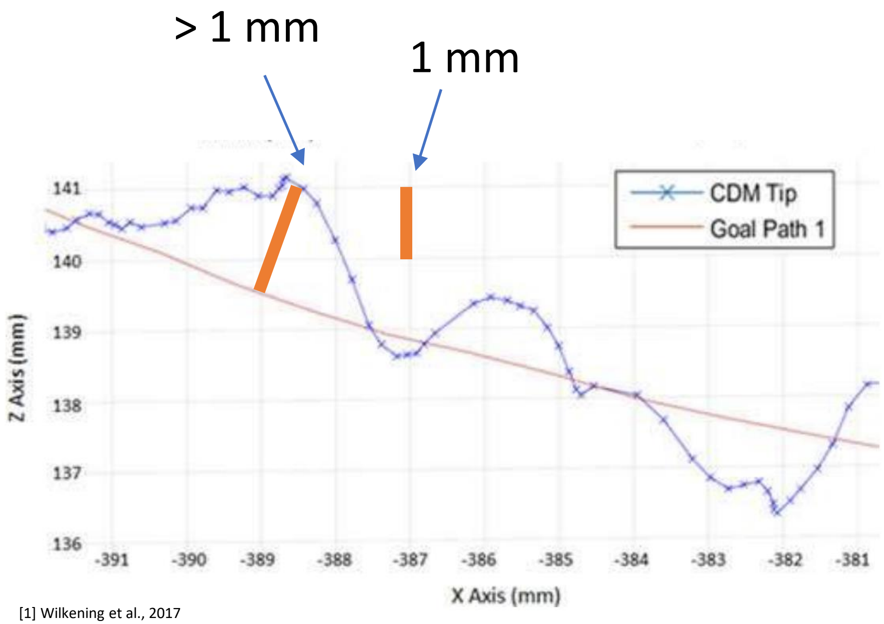
- Use Polaris tracker on tip to approximate CDM shape and dynamically generate more accurate Jacobian
  - Lower error
  - Faster convergence than open loop Jacobian
  - Compensate for plastic deformation

Pros

- Clear math
- Visualization and explanation of constraints
- Discussion of error

Cons

- 1 mm max error?



[1] Wilkening et al., 2017

- Could have better presentation of experiments
- More clarity needed on how optical calibration will be used for feedback in a surgical setting

Relevance

- Similar system to our project:
  - Positioning robot + ‘Snake’ manipulator
  - Concurrent control

- Approach to constraints and evaluation informs our approach

- CDM error something to consider

References

[1] P. Wilkening, F. Alambeigi, R. J. Murphy, R. H. Taylor and M. Armand, "Development and Experimental Evaluation of Concurrent Control of a Robotic Arm and Continuum Manipulator for Osteolytic Lesion Treatment," in IEEE Robotics and Automation Letters, vol. 2, no. 3, pp. 1625-1631, July 2017, doi: 10.1109/LRA.2017.2678543.

[2] Makoto Jinno, Gang Li, Niravkumar Patel, Iulian Iordachita, “An Integrated High -dexterity Cooperative Robotic Assistant for Intraocular Micromanipulation”, 2021., Kokushikan University

[3] 3D Systems. “Touch.” *3D Systems*, 4 June 2020, www.3dsystems.com/haptics-devices/touch.

Questions?