Cooperative Control of Dual-Arm Concentric Tube Continuum Robots

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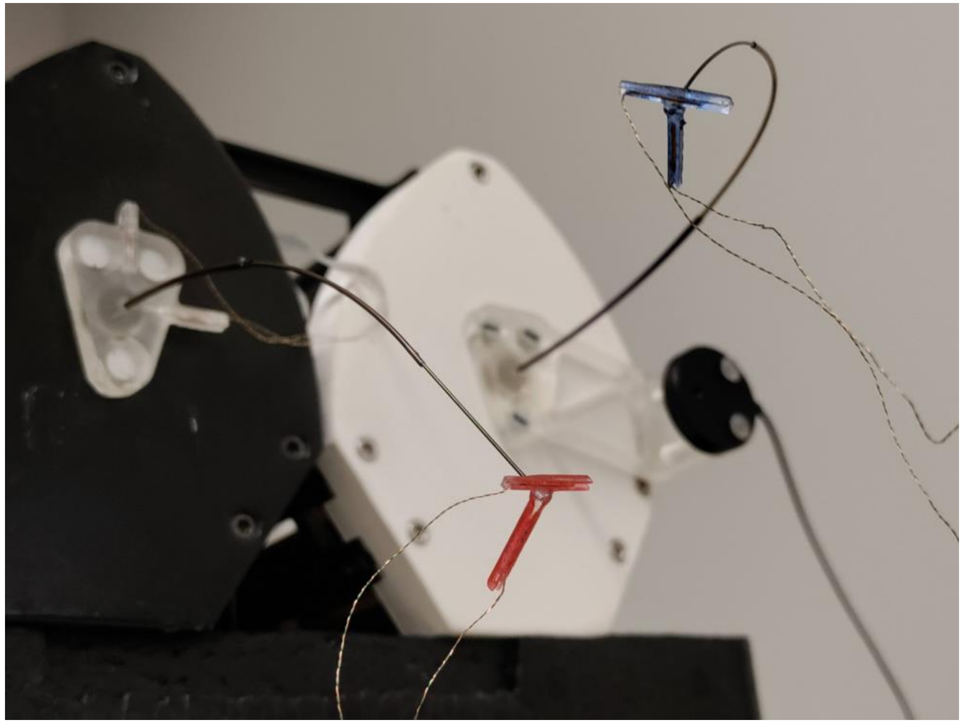
Background & Motivation

Concentric Tube Continuum Robots (CTCRs)

Dual-Arm Concentric Tube Continuum Robots (DA-CTCRs)

Overview

Cooperative control of Dual-Arm Concentric Tube Continuum Robots (DA-CTCRs)



Goal: Provide ***automatic assistance*** in control of DA-CTCRs.

Contribution: a modular hierarchy-based control framework, with tasks that can be executed based on priority using ***redundancy resolution***.

Results: Functionality of ***semi-autonomous control*** demonstrated in a variety of meaningful scenarios on simulated and real robot models.

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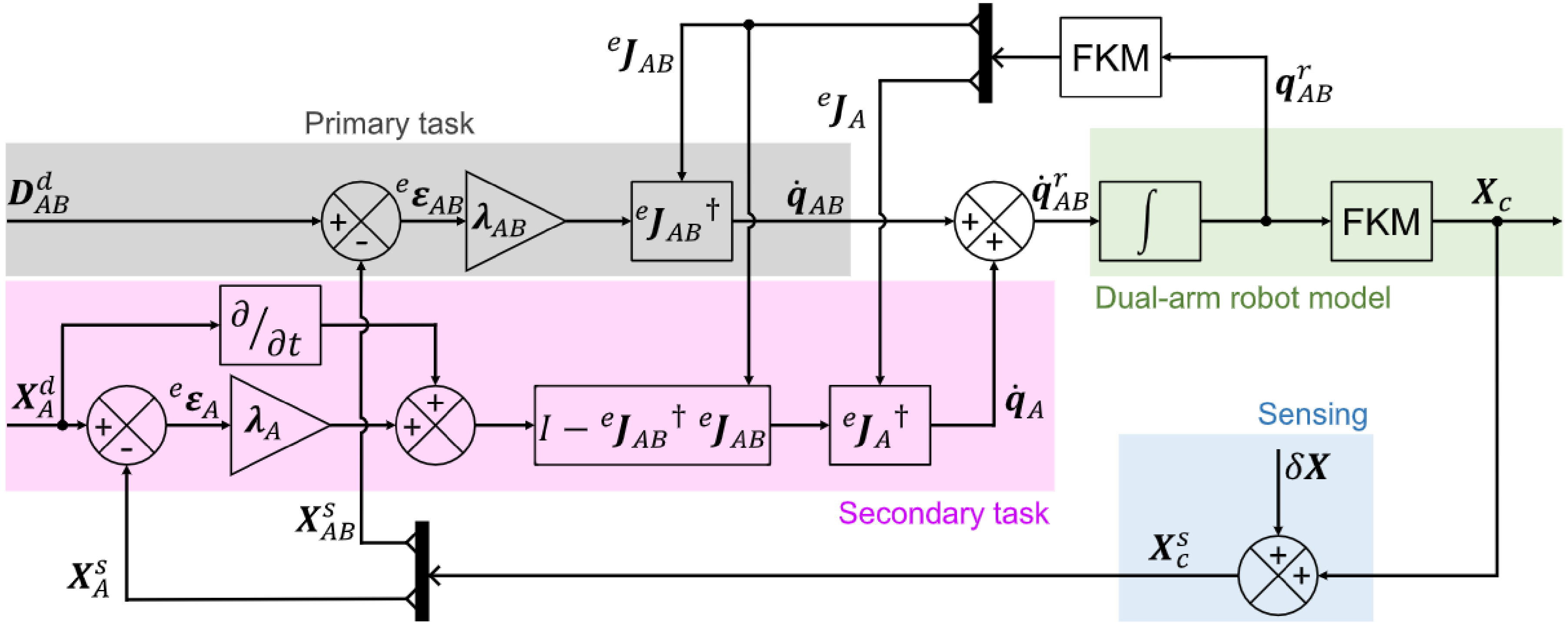
Control Scheme

Past Work (Detailed)



[Chikhaoui et al., RAL, 2018, Towards Motion Coordination Control and Design Optimization for Dual-Arm Concentric Tube Continuum Robots]

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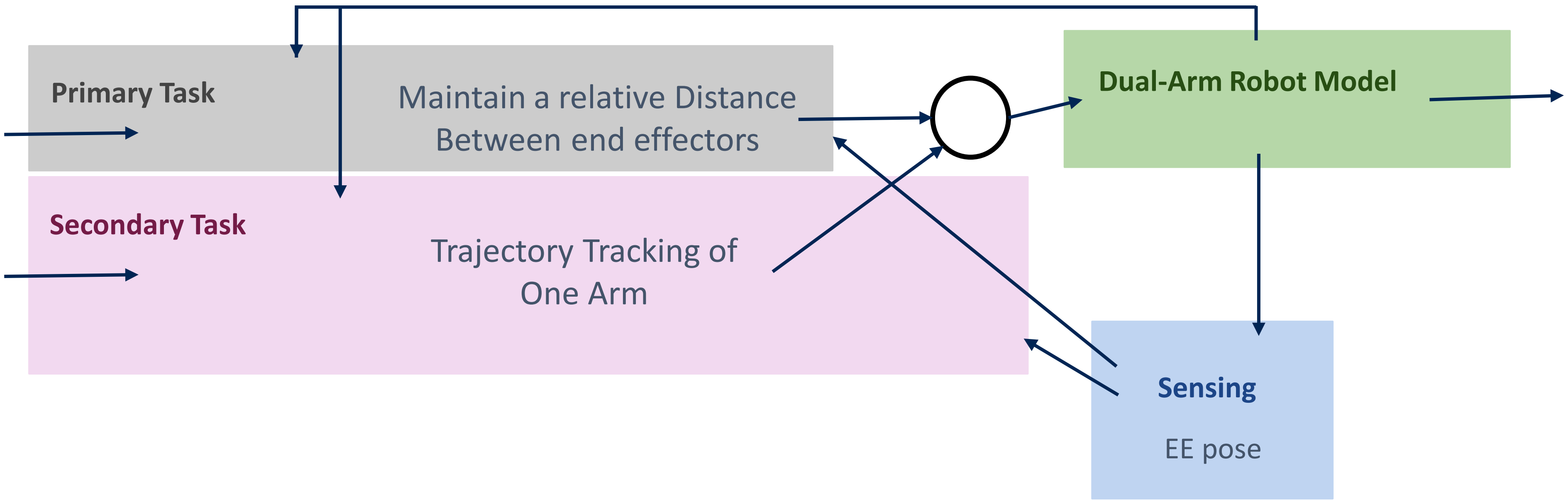
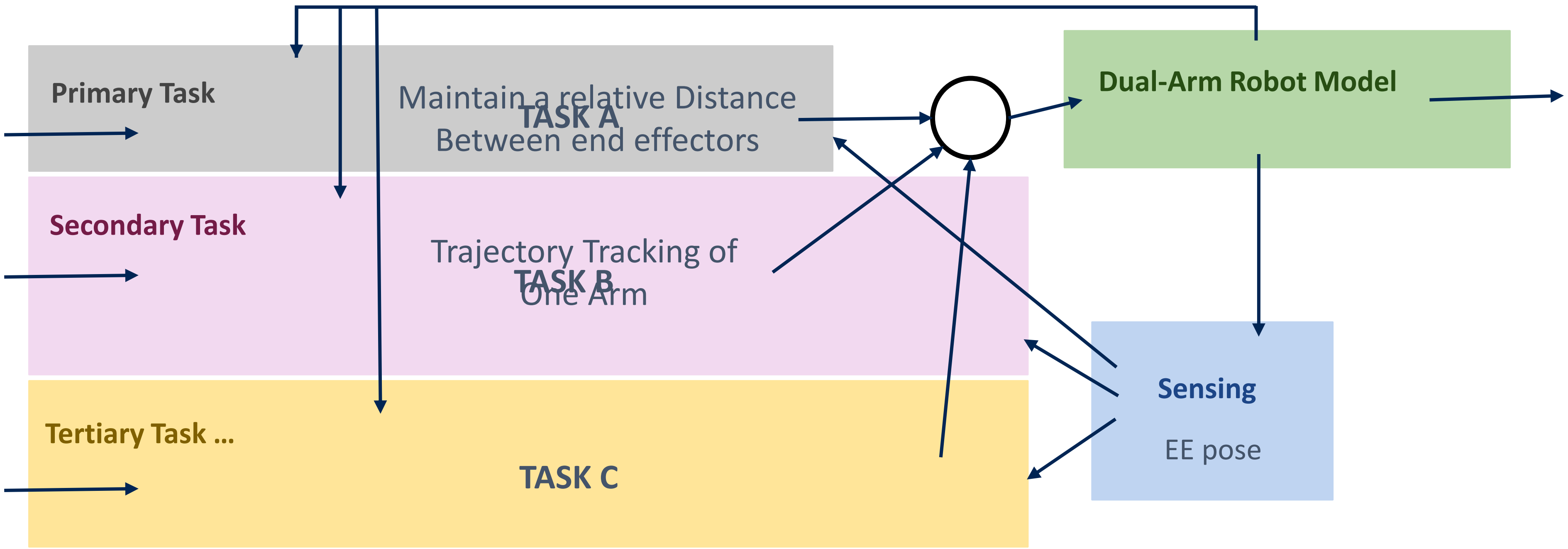
Past Work (Simplified)



[Chikhaoui et al., RAL, 2018, Towards Motion Coordination Control and Design Optimization for Dual-Arm Concentric Tube Continuum Robots]

Proposed Method



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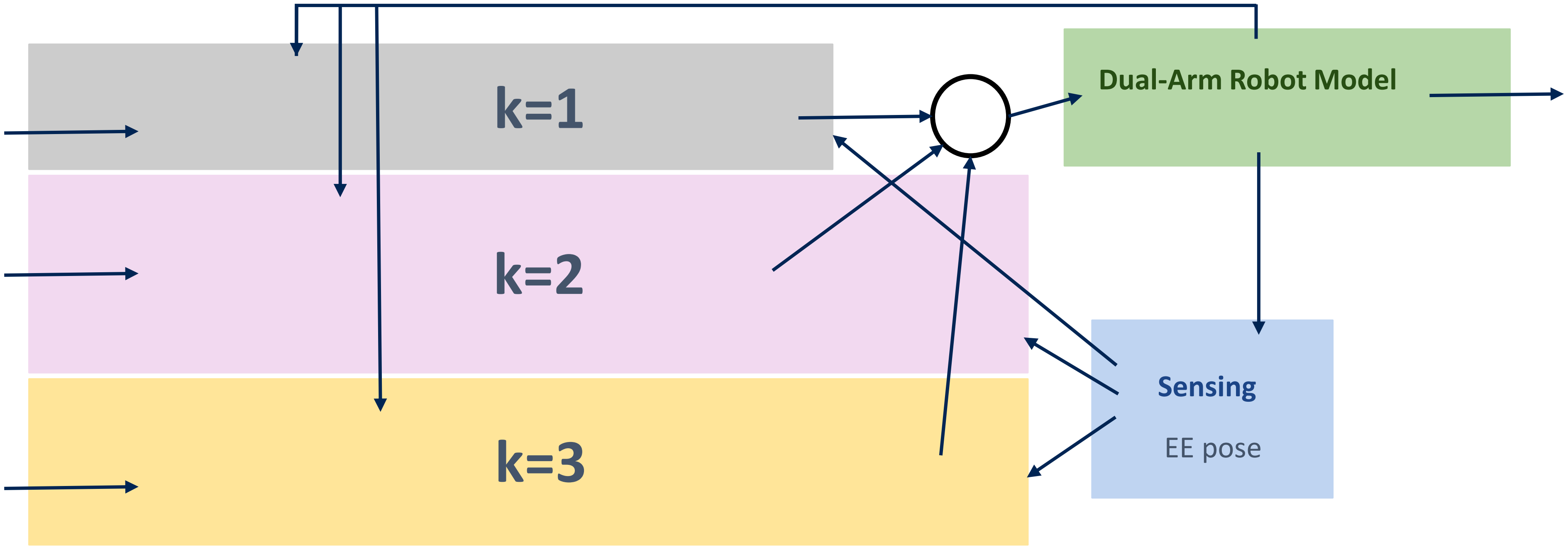
Task Prioritization

$$\mathbf{P}_k = \mathbf{P}_{k-1} - (\mathbf{J}_k \mathbf{P}_{k-1})^{\dagger} (\mathbf{J}_k \mathbf{P}_{k-1})$$

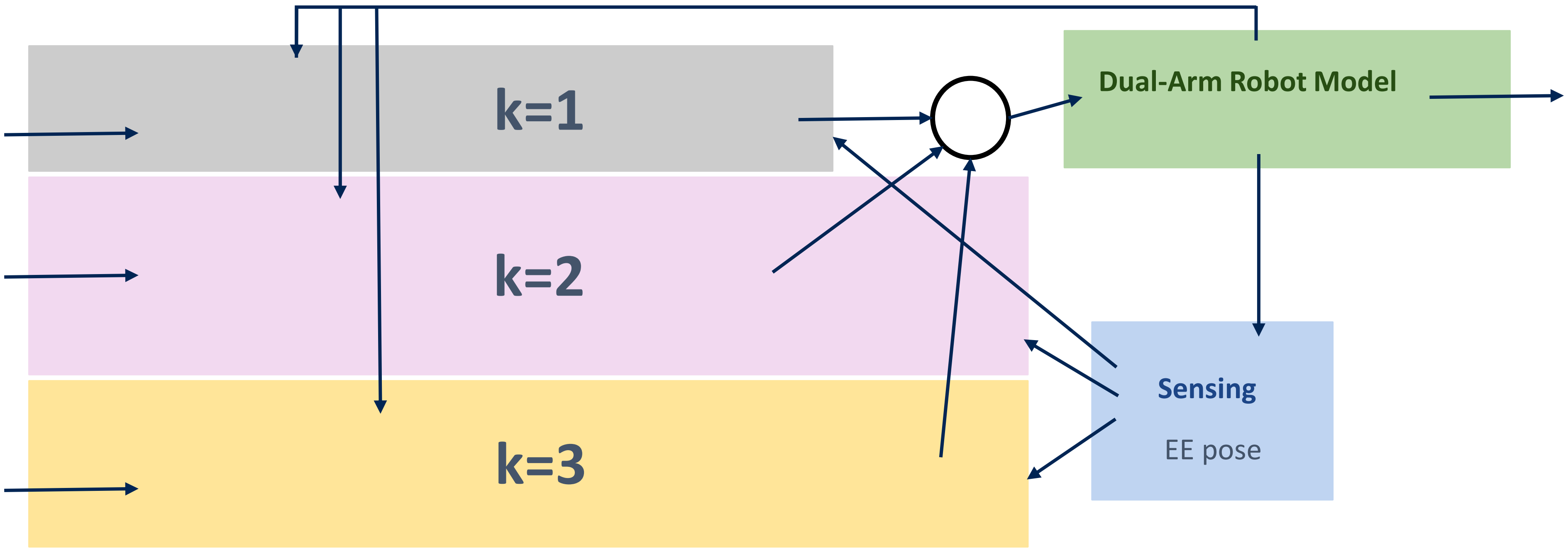
Nullspace Projection



<u>Recursive projection</u> to the nullspace of the prior task Jacobian.

$$\nabla \boldsymbol{\eta}_k(\mathbf{q}) = \begin{cases} \mathbf{J}_k^{\dagger} \boldsymbol{\epsilon}_k(\mathbf{q}), & \text{for tasks errors} \\ \nabla \mathbf{f}_k(\mathbf{q}), & \text{for task gradients} \end{cases}$$

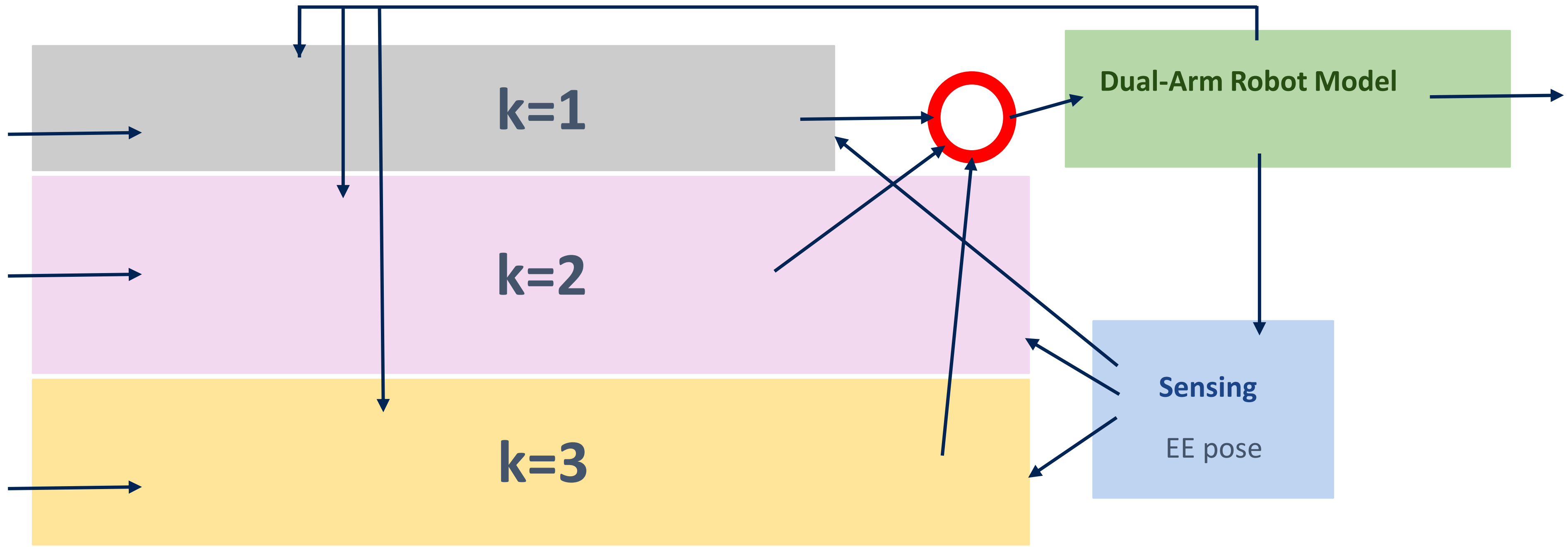
Contribution of Tasks



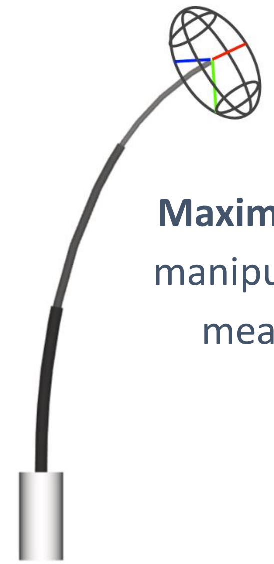
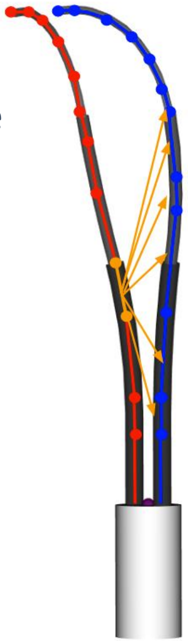
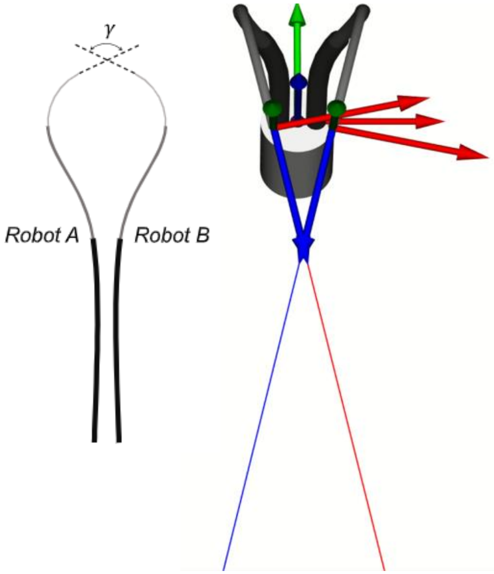
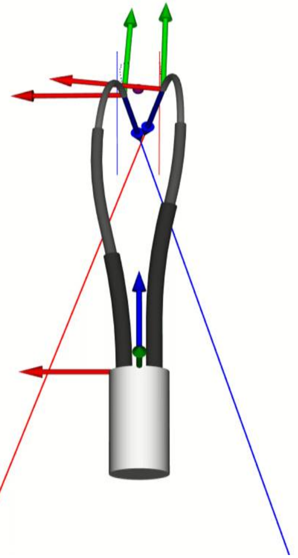
$$\mathbf{J}_k^{\dagger} = \mathbf{J}_k^T (\mathbf{J}_k \mathbf{J}_k^T)^{-1}$$

$$\dot{\mathbf{q}}_D = \sum_{k=1}^{t} \lambda_k \mathbf{P}_{k-1} \nabla \boldsymbol{\eta}_k(\mathbf{q})$$

Weighted Sum of All Tasks



Task Formulation

Manipulability Maximization	Body Collision Avoidance	Triangulation to a Relative Angle	Triangulation to a Point
 **Maximize** the manipulability measure $m = \sqrt{\det\left(J(q)J(q)^\top\right)}$	**Maximize** the collision cost ⇒ the distance between the closest 2 backbone segments 	 **Minimize** the triangulation angle error	**Minimize** the distance from the line of sight ray to the desired triangulation point 

Control task gradients are computed using finite differences.

Experimental Evaluation

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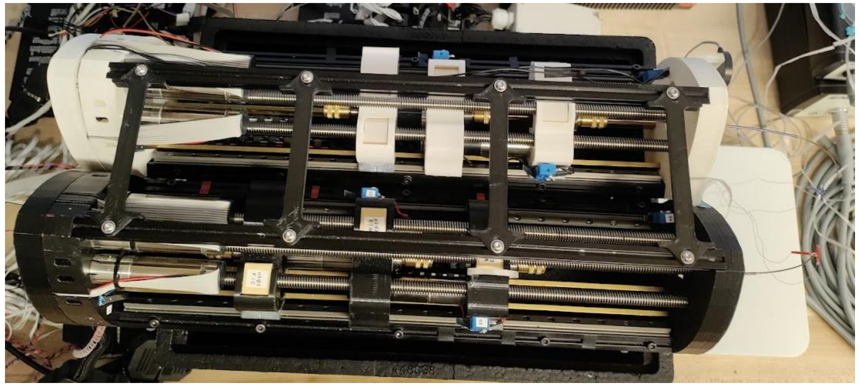
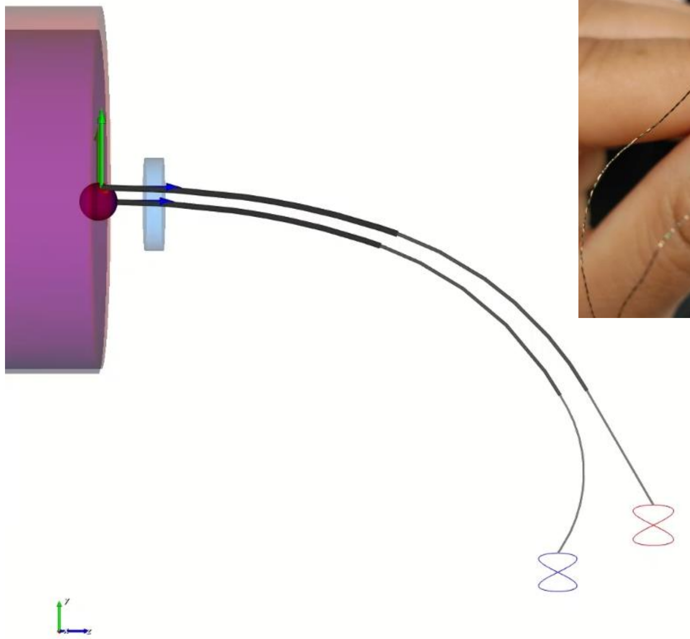
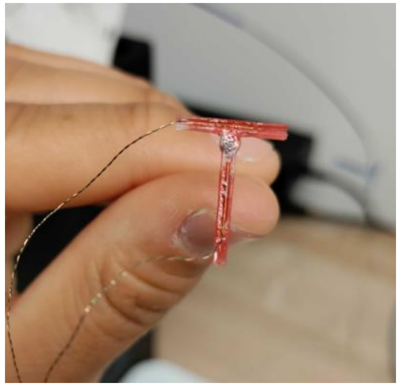
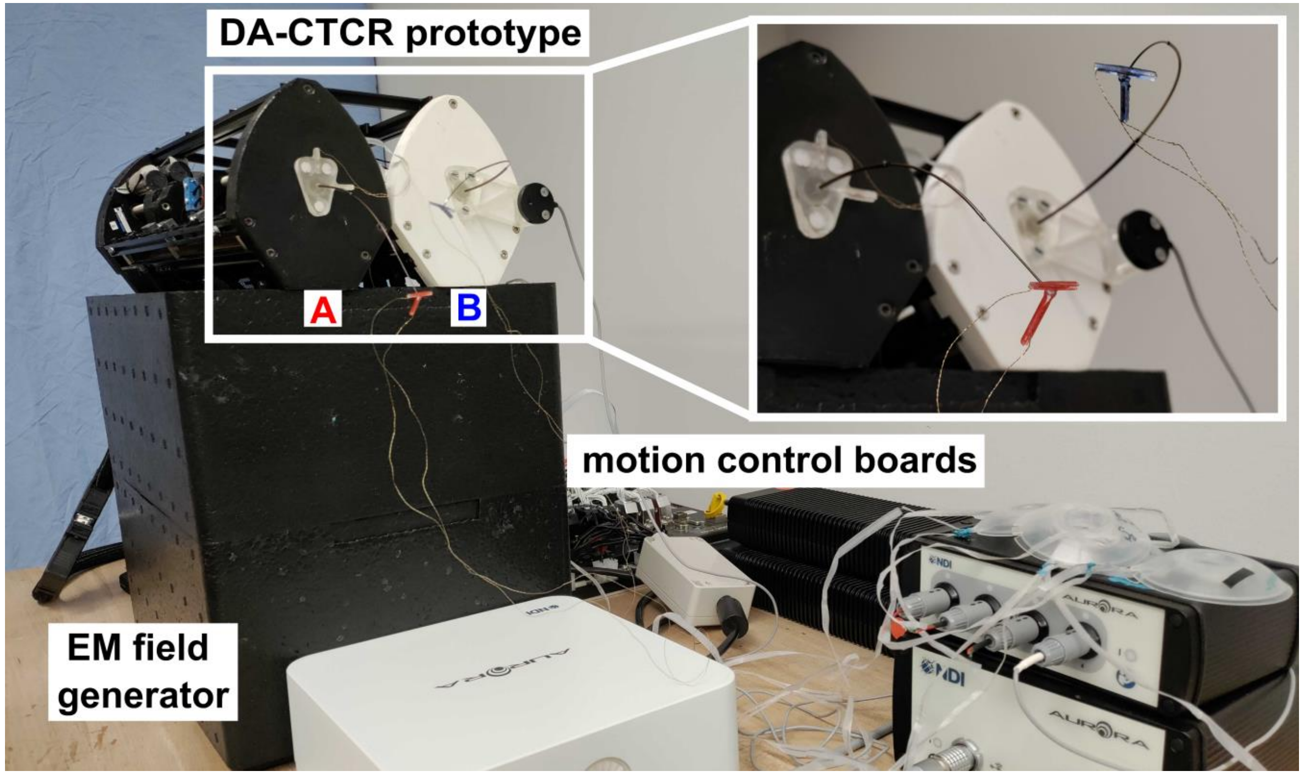
Physical Setup





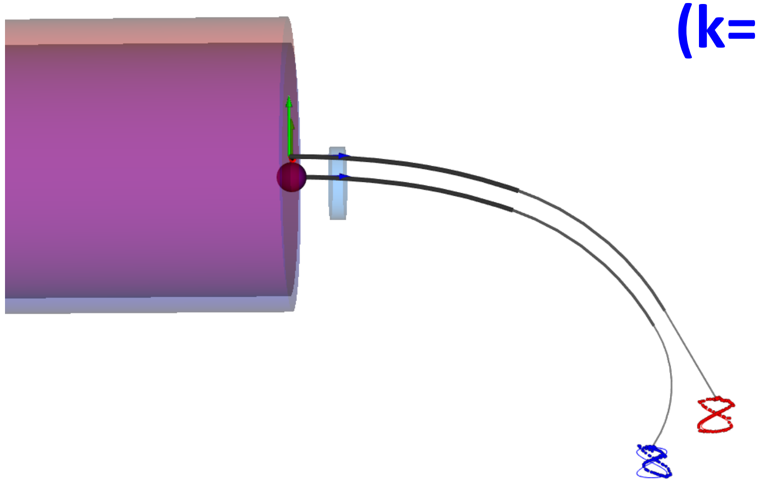


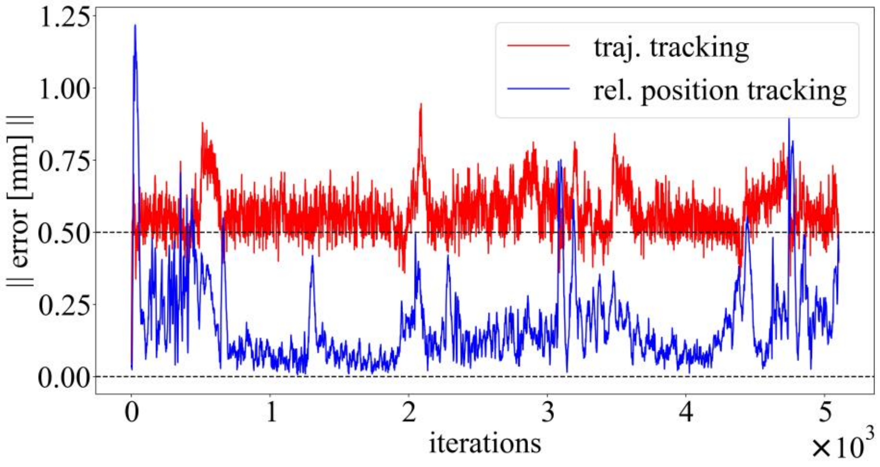


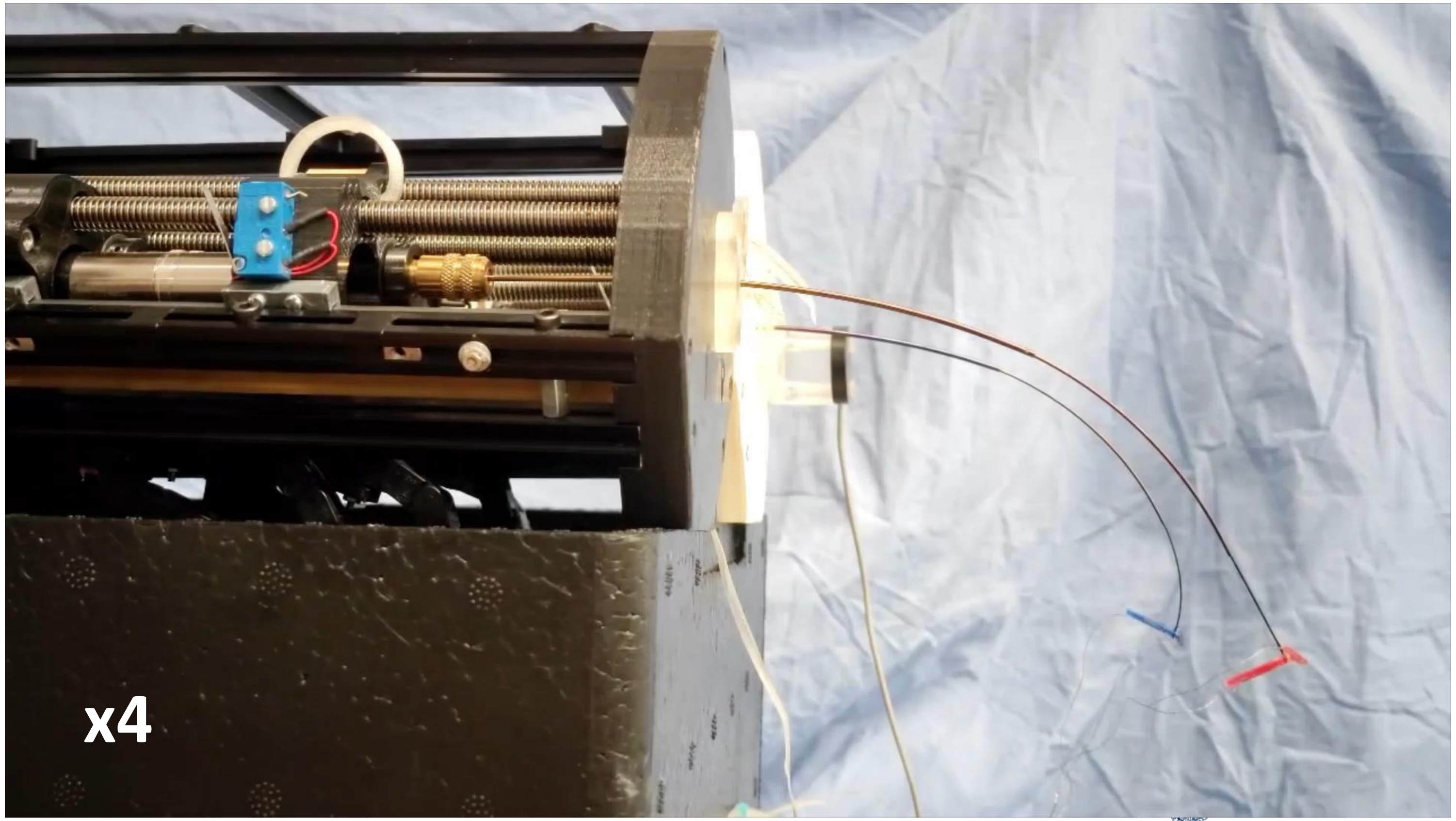
Follower

(k=2) Trajectory Tracking of One Arm

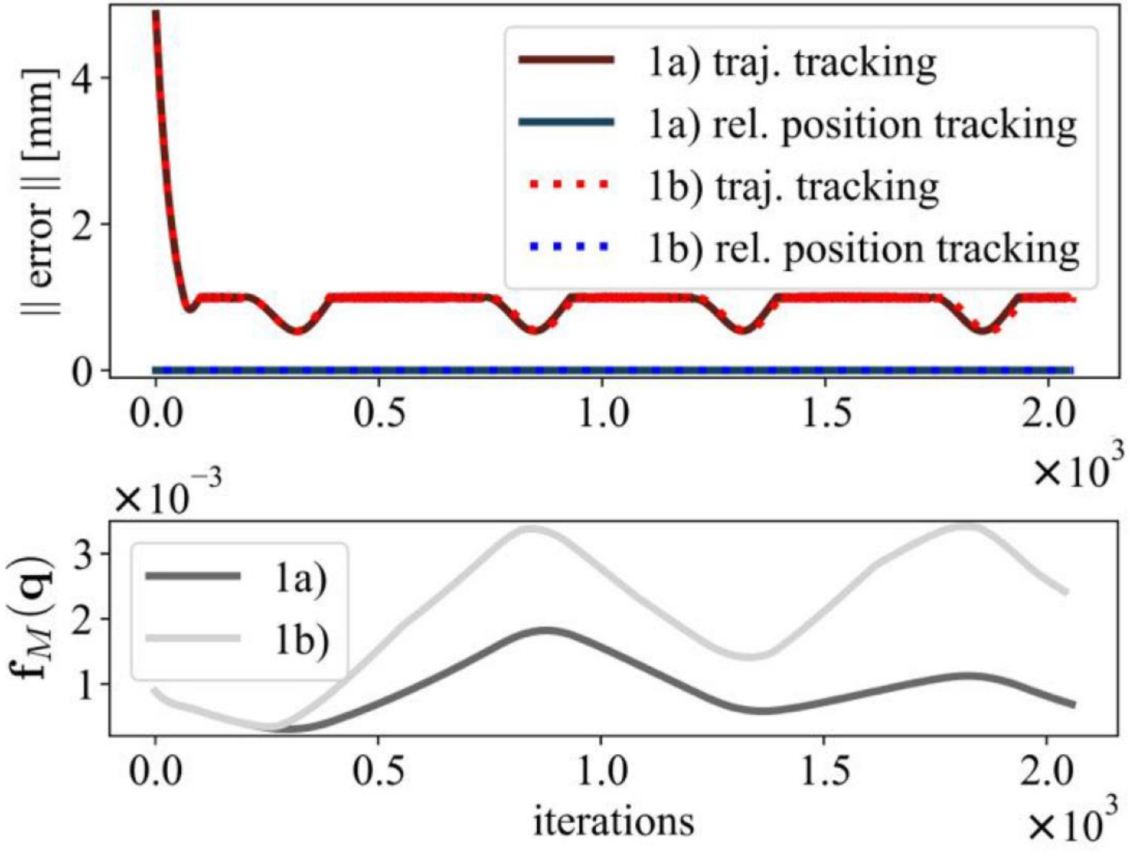
(k=1) Maintain a relative Distance Between End Effectors







Follower + Manipulability Maximization



1b)

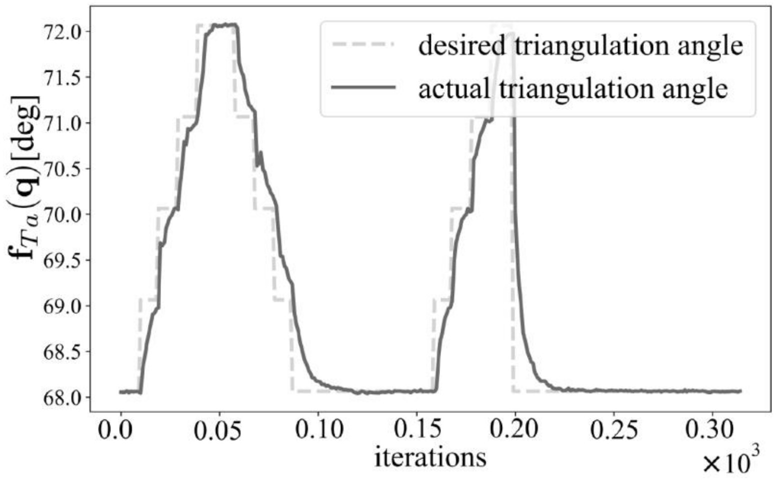
1a) **(k=3)** Manipulability Maximization

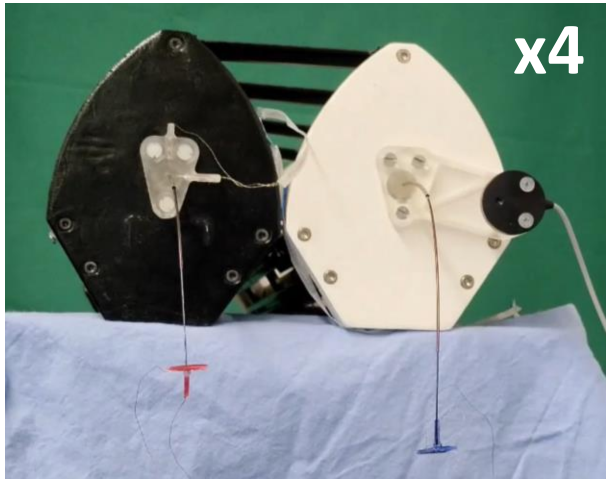
(k=2) Trajectory Tracking of One Arm

(k=1) Maintain a relative Distance Between End Effectors

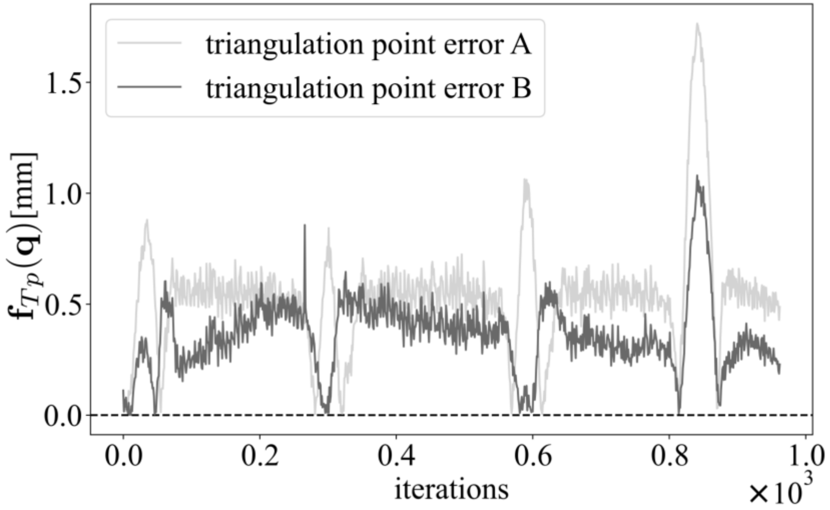
Triangulation to …

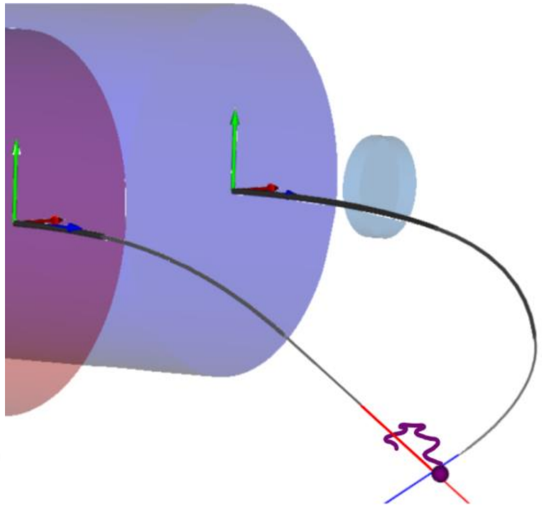
a relative angle

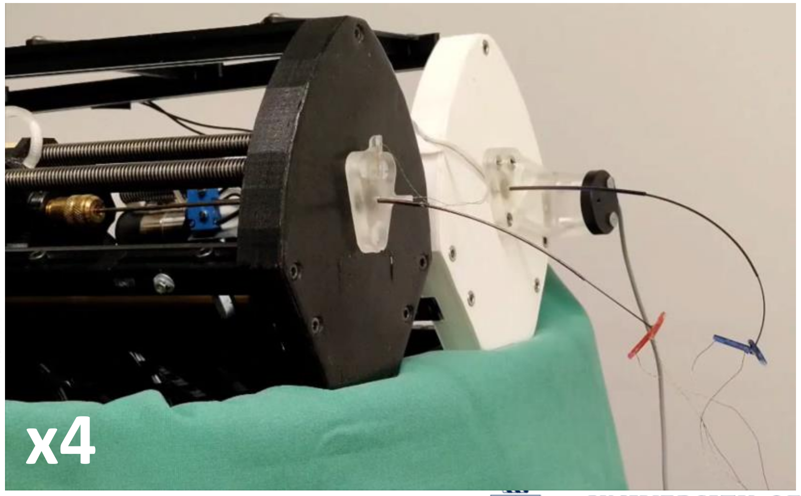




a point







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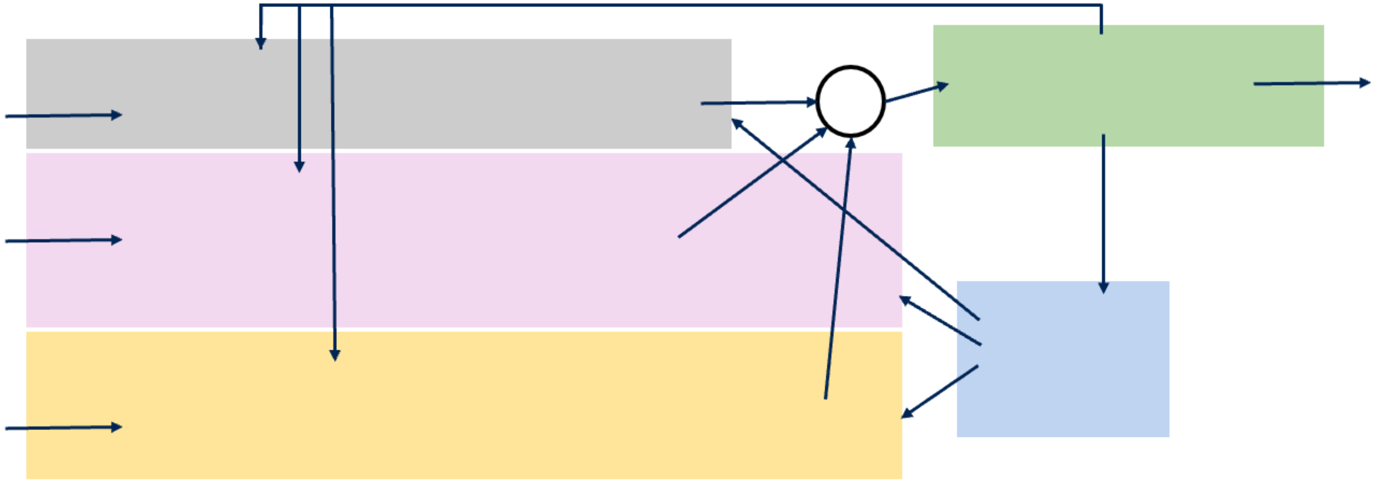
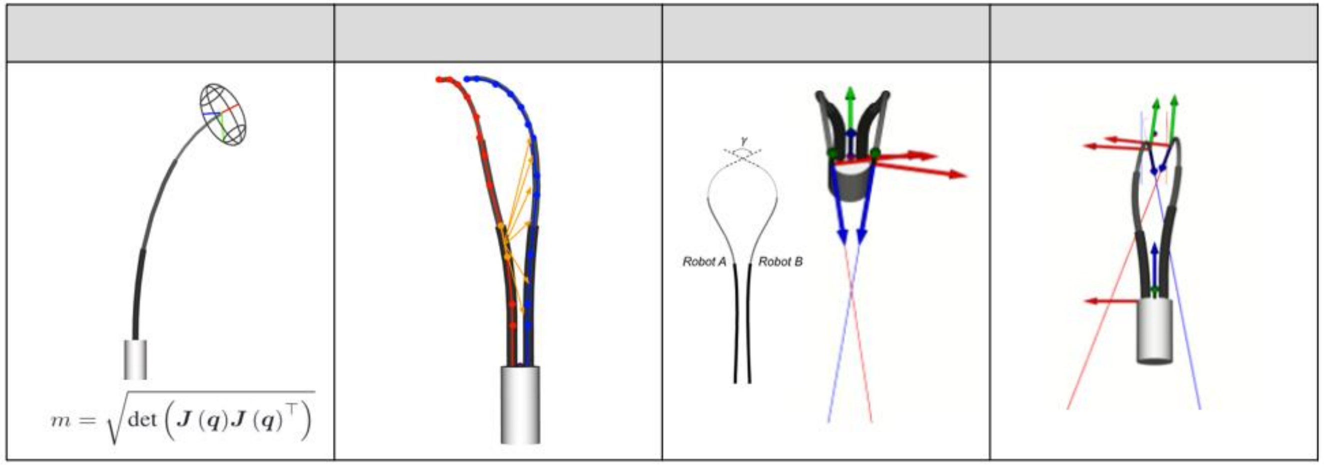
Conclusion

Summary



Controller is versatile, can prioritize a variety of tasks

→ Can optimize over other quantitative performance indices during control of DA-CTCR



Limitations:

- Finite differences is a local approximation method
- Number of nullspace projections is limited

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