Collaborative Autonomous Surgical Assistant Arm

Chetan Reddy Narayanaswamy
Joonwon Kang

Alaa Eldin Abdelaal
Allison Okamura

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Stanford University

Motivation

- **Existing System:**
  - Surgeon teleoperates with two arms
  - cannot simultaneously use all 3 arms

- **Opportunity:**
  - Can the 3rd arm be used to autonomously assist the surgeon
  - Data driven imitation learning approach

- **Advantages:**
  - 3 Armed/Multi Armed Surgeon!
  - Better Efficiency
  - Greater Ease
  - Expands Surgical Capabilities

AI Generated

Data Collection Pipeline

Surgeon Arm 1
Teleop

Surgeon Arm 2
Teleop

Assistant Arm 3
Teleop

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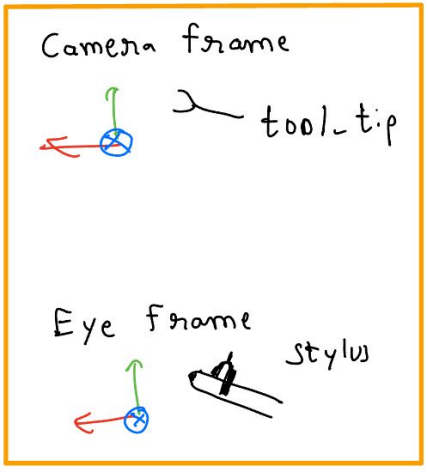
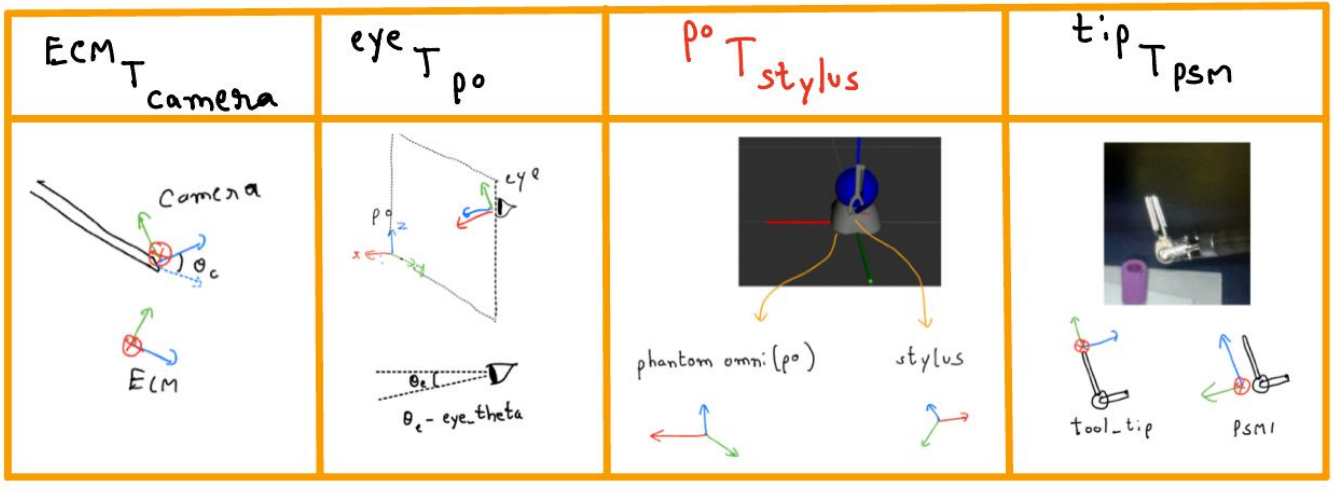
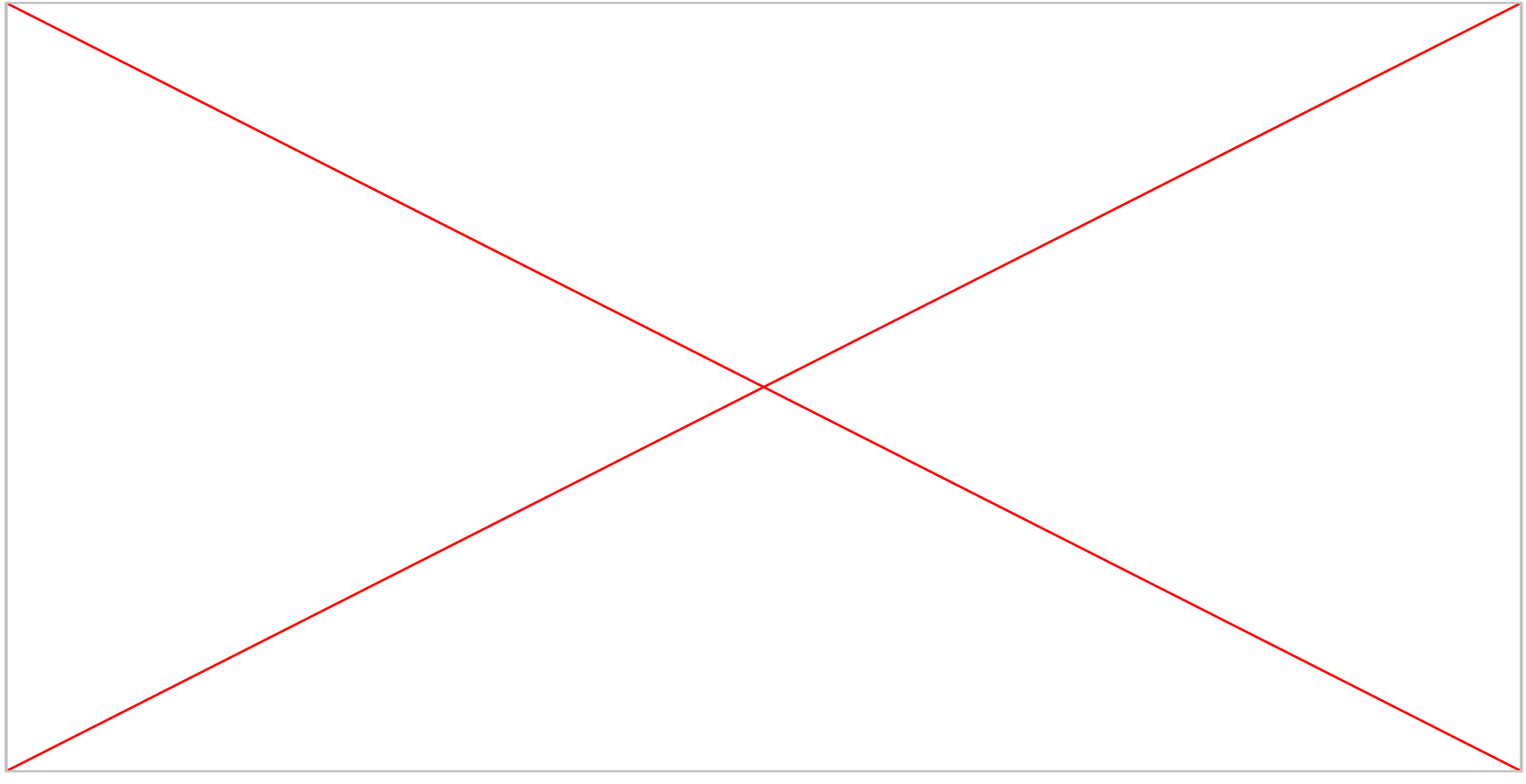
Phantom Omni Teleop

- ${}^{camera}T_{tool\ tip} = {}^{eye}T_{stylus}$
- ${}^{\mathbf{ECM}}\mathbf{T}_{\mathbf{PSM}} = {}^{ECM}T_{camera}\ {}^{eye}T_{po}\ {}^{\mathbf{po}}\mathbf{T}_{\mathbf{stylus}}\ {}^{tip}T_{PSM}$





Demo on the Da Vinci Robot in SRC



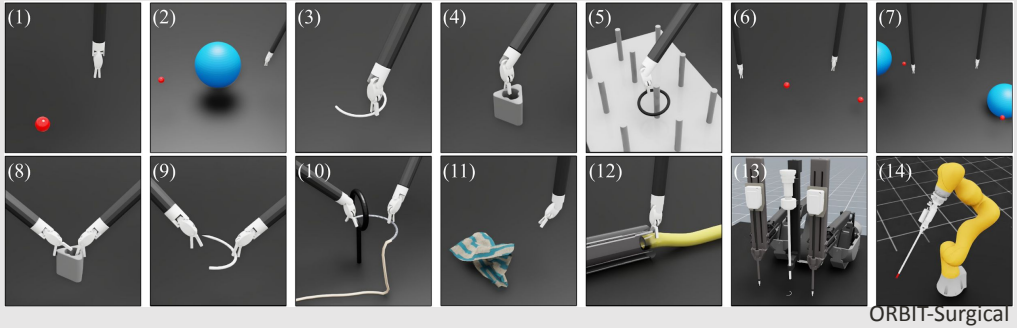
Using Simulation for Robot Learning

- Overcome Physical Limitations
- Safety
- Efficiency

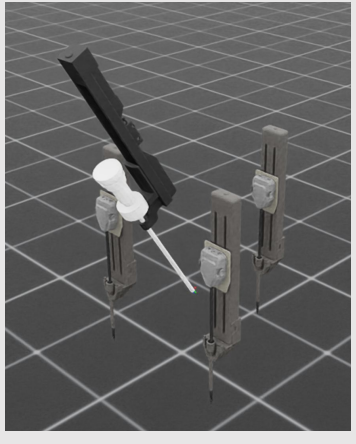
SRC dVRK

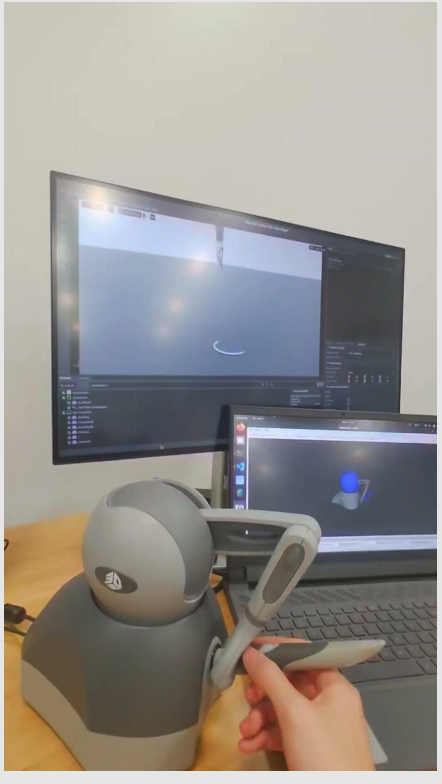
Simulator - Isaac Sim + ORBIT-Surgical

- Realistic Visualization
- GPU accelerated Physics Engine
- Specified Assets and Environments for dVRK
- Customizability



ORBIT-Surgical

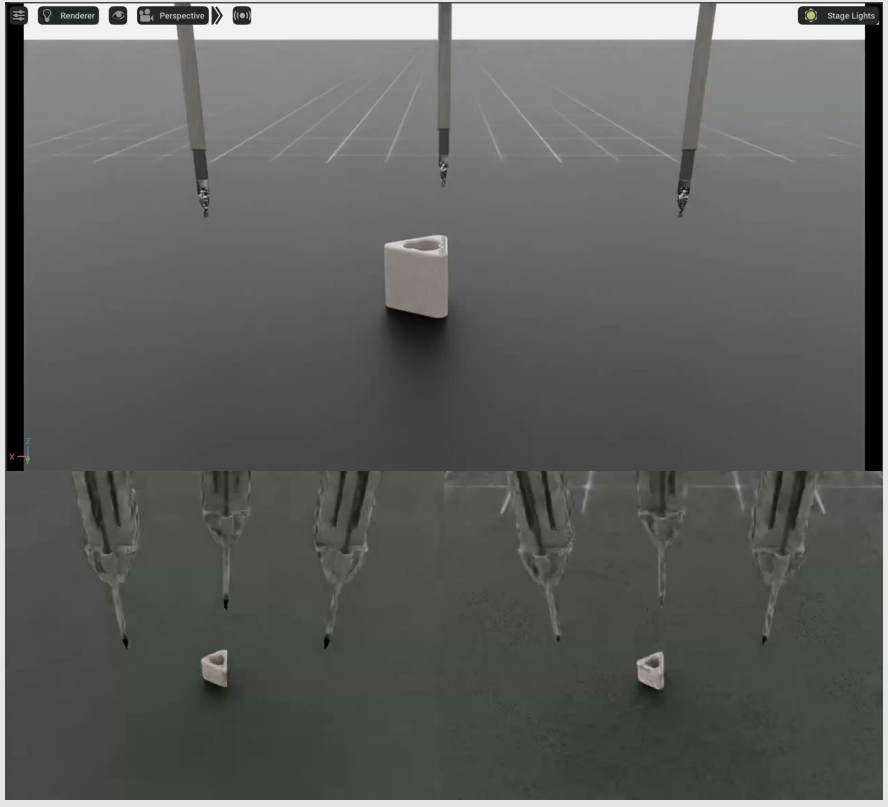




Input and Output in Simulation

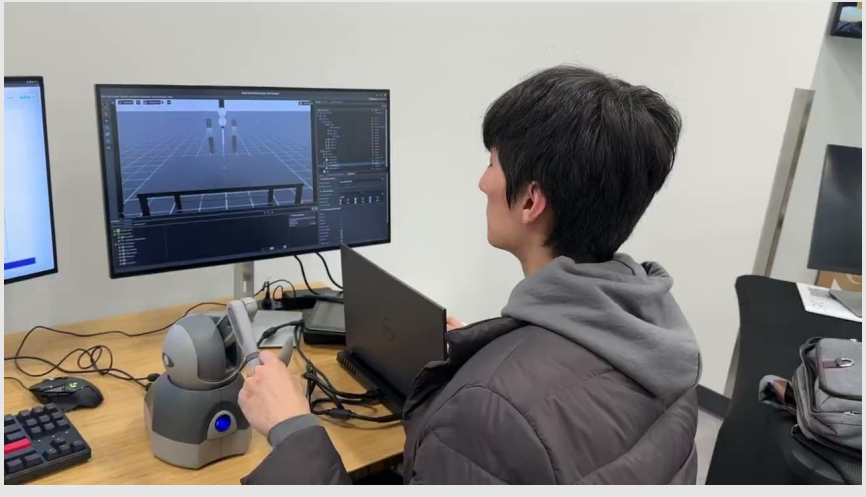
- Control Input:
  - Joint State
  - Tip Cartesian Point relative to the previous tip frame/ base frame

- Output:
  - Joint State
  - Cartesian Point of each link
  - Camera Output



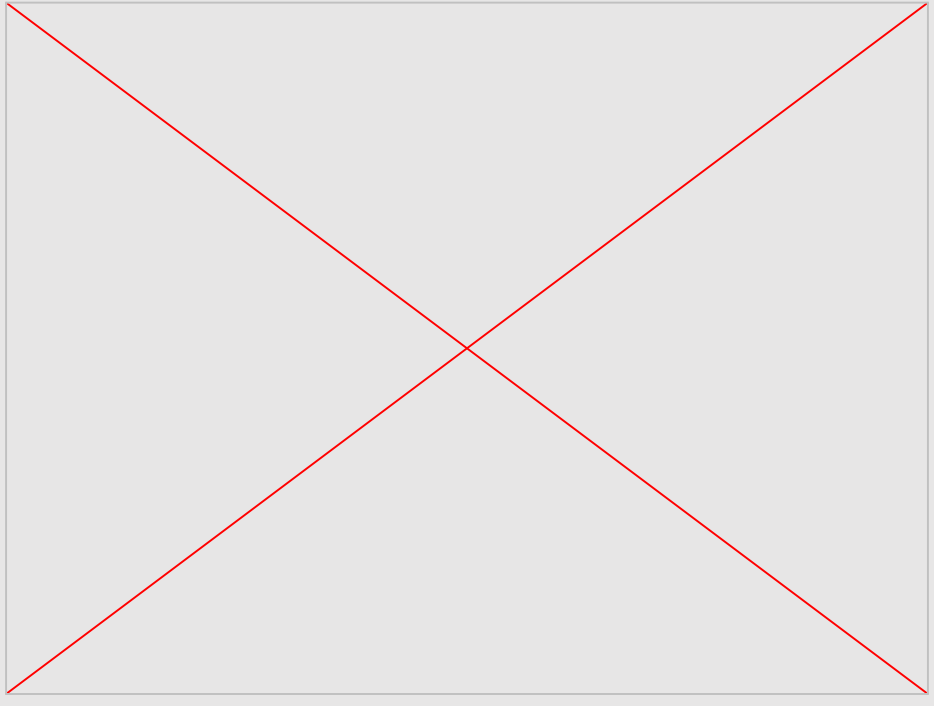
Adding Teleop Interface in Simulation

Same principle, apply additional transformation



MTM + PO Teleop in Simulation

Teleoperation Interface for both MTM and Phantom Omni in SImulation



What to Do Next

- Data Collection and Network Training
  - Surgeon: MTM teleop, move two PSMs
  - Assistant: Phantom Omni teleop, move one PSM
  - Imitation Learning using Action Chunking Transformer
  - Learning methods used in HRC (eg. GAIL)

- Future Research Questions
  - Role of human and robot in surgical robotics
  - Effective method to convey intentions
  - Fully automated multi-arm surgical robot

Collaborative Autonomous Surgical Assistant Arm

Presented by:
Chetan Reddy Narayanaswamy
Jiaqi Shao

Mentored by:
Alaa Eldin Abdelaal
Allison Okamura

Date:
Jun 4, 2025

Stanford University

Motivation

- **Existing Da Vinci System:**
  - Surgeon uses 2 hands to teleoperate 2 arms
  - Cannot use all 3 simultaneously

- **Opportunity:**
  - Can the 3rd arm be used to autonomously assist the surgeon
  - Data driven imitation learning approach

- **Advantages:**
  - 3 Armed/Multi Armed Surgeon!
  - Better Efficiency
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  - Expands Surgical Capabilities

Source: [Link]

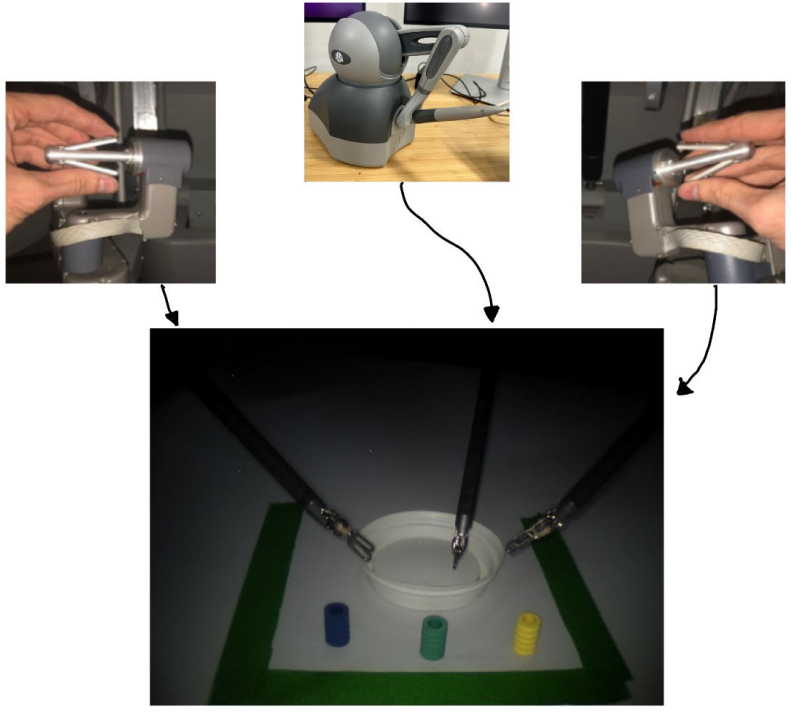
AI Generated

Data Collection Pipeline

Recorded Data

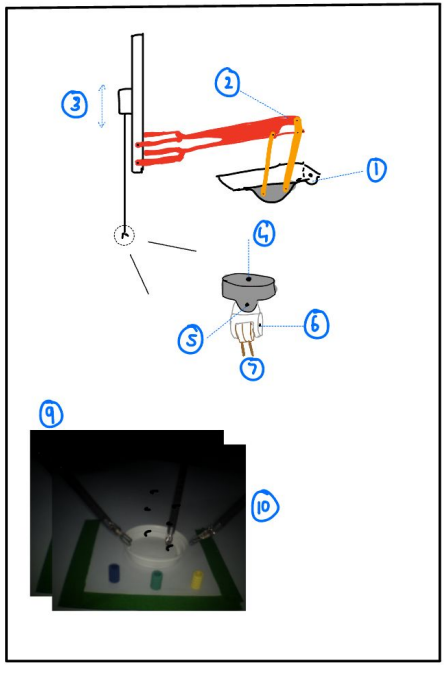
- Kinematic Data
  - 6 Joint Values
  - Jaw Angle
  - X,Y,Z Values of Tool Tip
  - Orientation Matrix of Tool Tip

- Vision Data
  - Left Camera Image
  - Right Camera Image



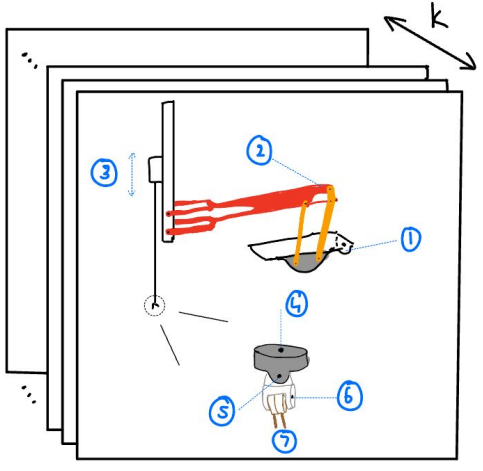
Teleoperation Connections

Model



Input Data from the 3 Arms

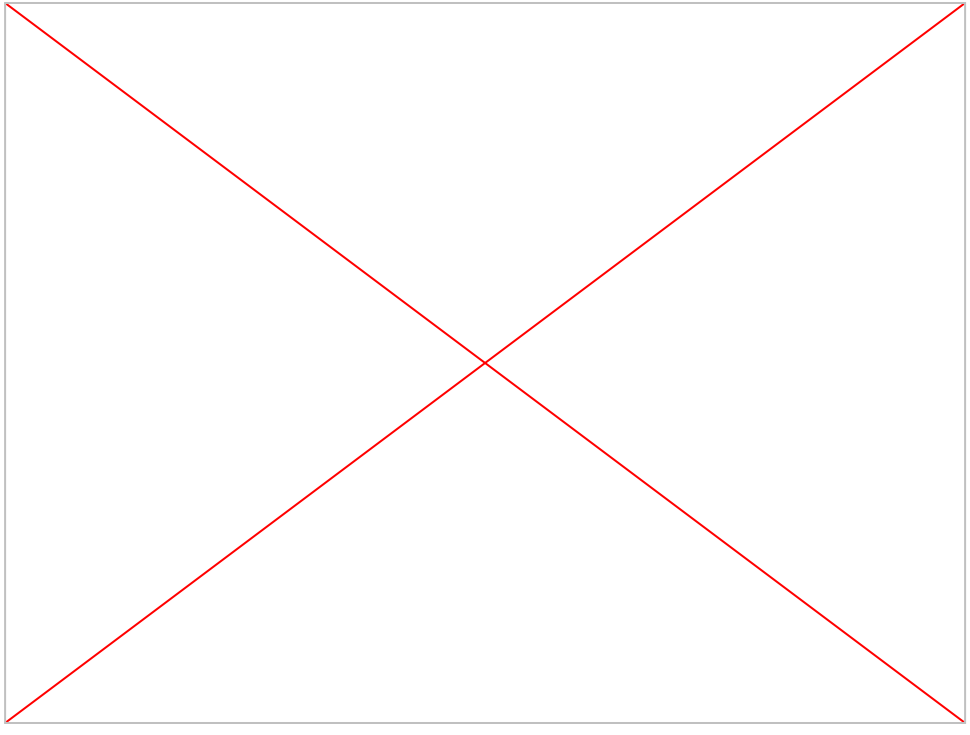
Action Chunking with Transformers (ACT) Model



Output Target Joint Angles over the next k steps

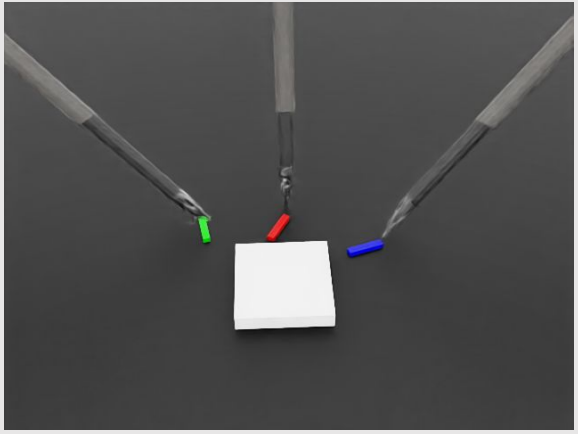
- Model was trained on 100 Demonstrations for the 2 handed Task
- Model was trained on 70 Demonstrations for the 3 handed Task

Results/Demo - Two Handed Task



Simulation Goal

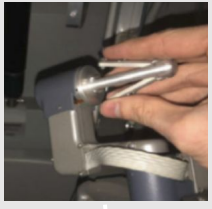
- Automate three handed task in Isaacgym simulation environment
- Use the ACT (Action Chunking Transformer), same model employed on the real robot, to achieve.
- Ultimate Goal: Train the third arm to help surgeon during operation

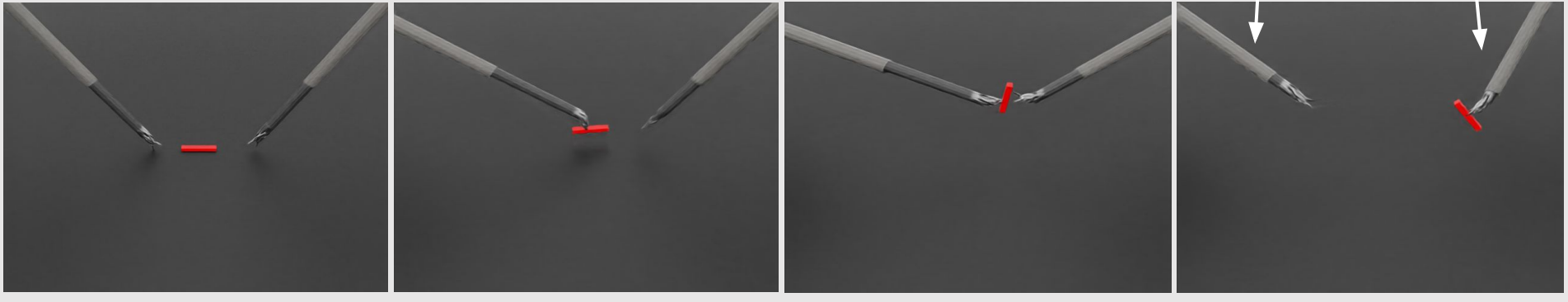


Human Demonstration

1st Task: Handover with but with different control interfaces

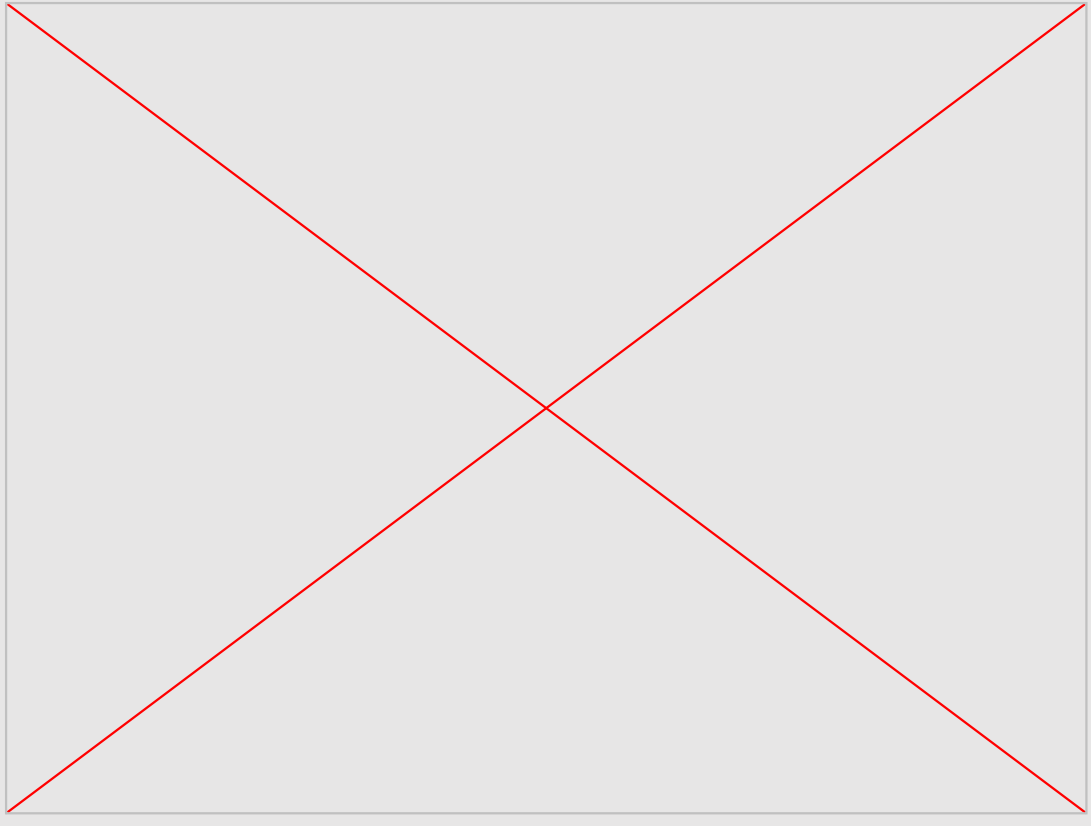
- Left PSM controlled by Phantom Omni;
- Right PSM controlled by right MTM





Model Rollout (2 arm task & Half Autonomous)

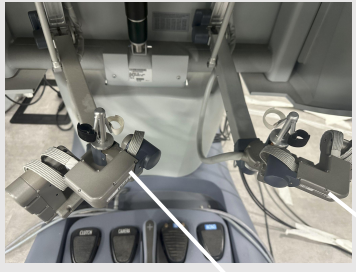
- Model was trained on 50 demos
- Left PSM: Teleoperated
- Right PSM: Automated

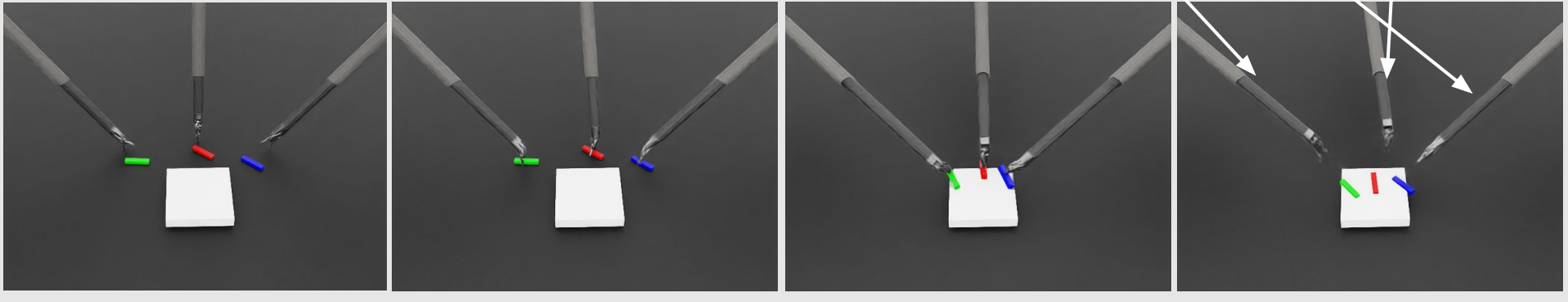


Human Demo

2nd Task: Pick up 3 objects and place to common area

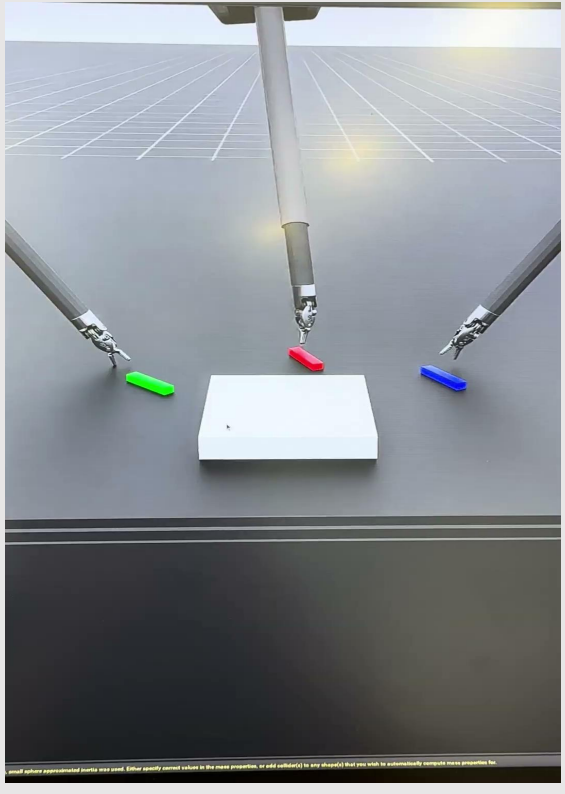
- Left PSM controlled by left MTM;
- Right PSM controlled by right MTM;
- Extra PSM controlled by Phantom Omni





Model Rollout (3 arm task & Half Autonomous)

- Model was trained on 50 demos
- Left & Right PSM: Teleoperated
- Central PSM: Automated



Takeaways

- ACT model could be used not only fully 2-arm autonomous tasks, but also 3-arm human-robot collaborative tasks!

- For Future work:

  1. Compare the performance of three arm task when fully autonomous/fully teleoperation/collaborative.

  2. Try more complicated tasks for three arm.