PRESENTATION AT

IROS 3RD WORKSHOP ON ROBOT AVATAR

ROBOTIC DIGITAL TWIN OF DUAL-ARM TELEROBOTIC HOT CELL / GLOVEBOX FOR HAZARDOUS AND RADIOLOGIALC WASTE DISPOSITION

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Robotics and Remote Systems
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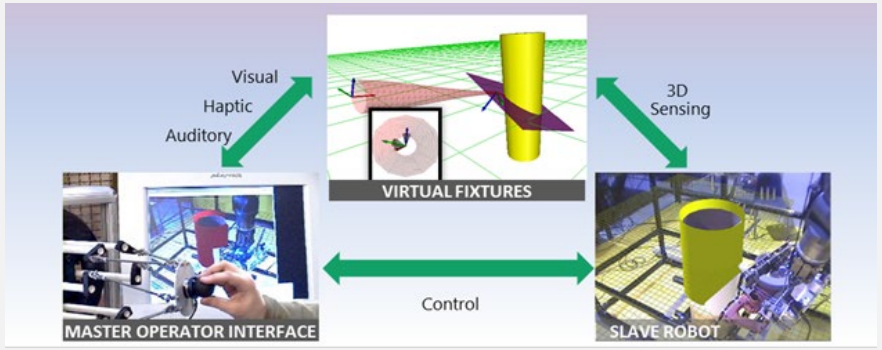
October 15, 2024

Robotics and Remote Systems Group at Argonne

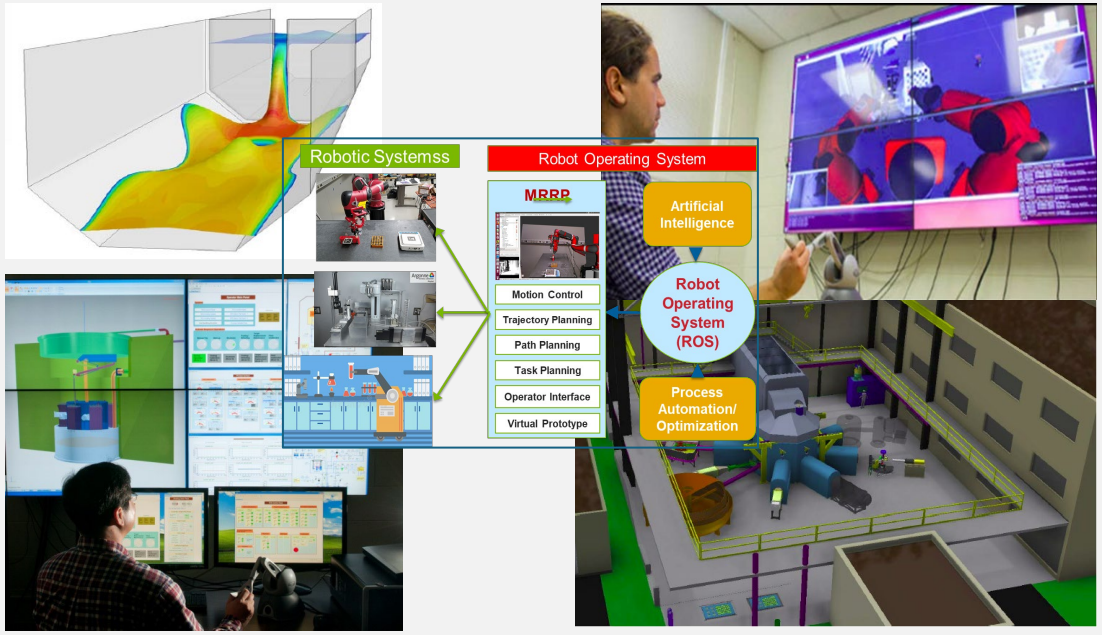
Enhanced Telerobotics Technology

- ANL Robotics and Remote Systems Program has developed various e nhanced telerobotics technologies for nuclear applications, including virtual fixtrues, teleautonomy, as well as artificial intelligence (AI) for process monitoring and diagnosis.



Robotic Digital Twin Platform

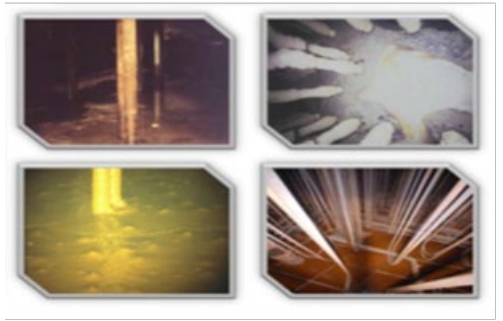
- ANL has pioneered adaptation of digital technologies (e.g. VR/AR, 3D sensing, IT, and AI) for nuclear applications.
- ANL is establishing Robotic Digital Twin testbed capability to support r obotic systems technology enhancement for field deployment in nuclea r applications.



ROBOTICS FOR UNSTRUCTURED, HAZARDOUS APPLICATIONS

DOE EM Nuclear Waste Cleanup Mission

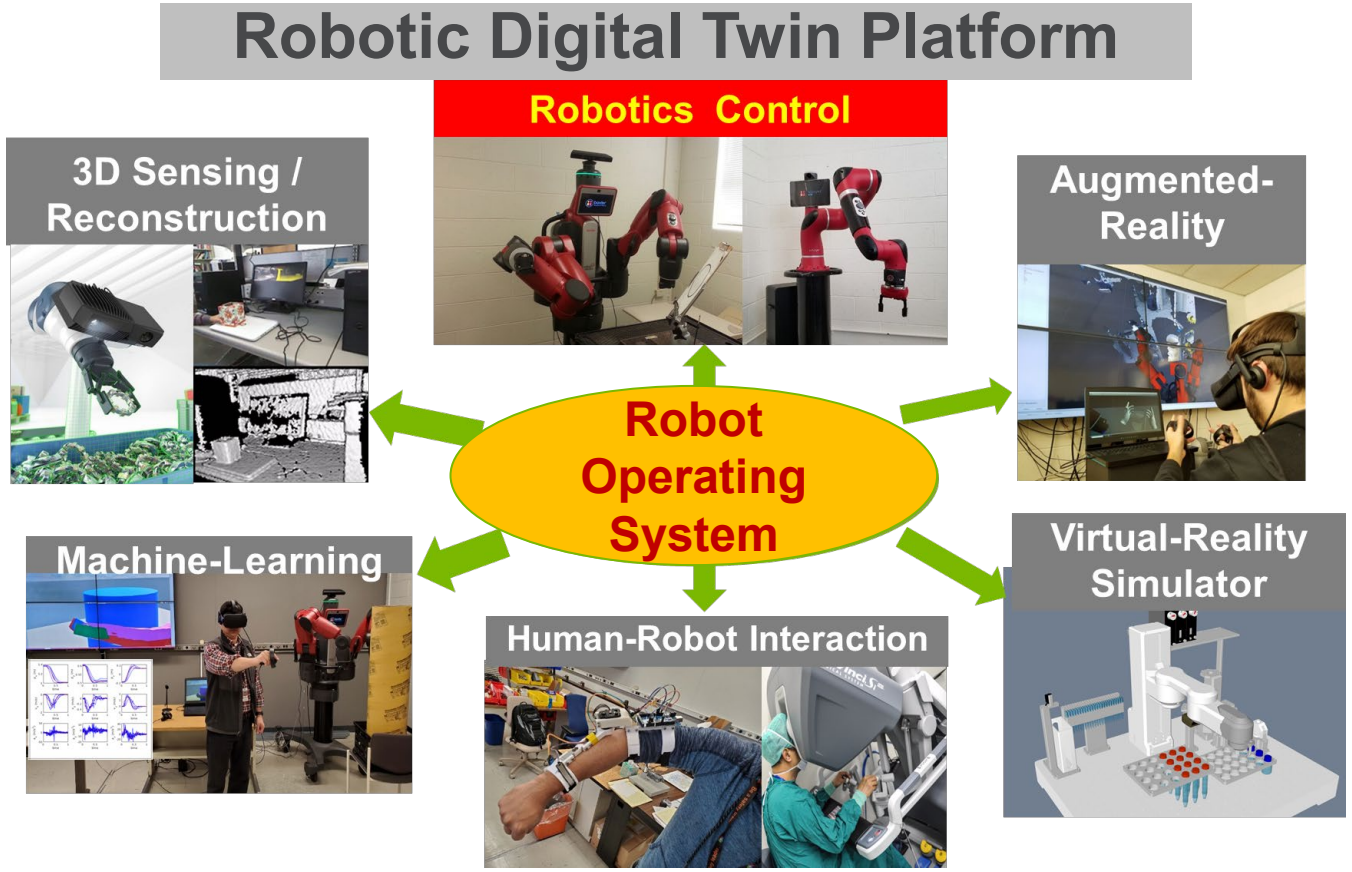
- Robotics and Remote Systems have potential to replace human workers to enhance safety in DOE Environment Management mission of safe cleanup of nuclear wastes
- Challenging task environments
  - Unstructured, Unpredictable, Hazardous
  - Limited access
  - Consequence of failure is significant
- Requirements (beyond industrial robotics)
  - Custom development of one-of-a-kind robotic solutions
  - Remote operation
  - Short-term deployment
  - Reliability



DIGITAL TRANSFORMATION OF ROBOTICS

Opportunities for Rapid prototyping of advanced robotic solutions for unstructured and hazardous applications

- Recent advances in Robotics technology
  - Falling robot prices
  - Collaborative robots
  - Robot Operating System
  - Digital twin
- Opportunities
  - Rapid Prototyping
  - Test and Verification
  - Accessible Talents



EM MISSION STATEMENT

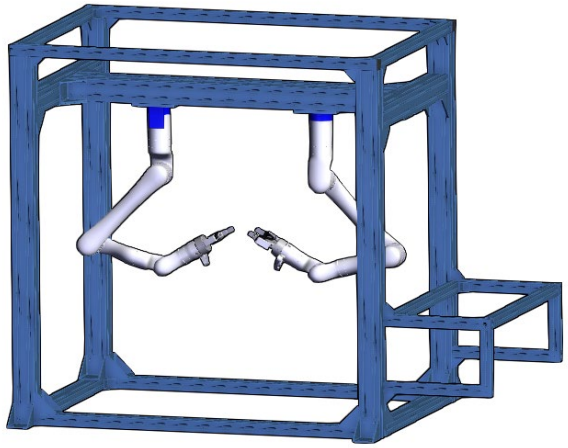
Waste Handling Needs at Oak Ridge Site

- For ORNL 3517 and Y-12 facilities radiological and hazardous materials to be disposed by human workers, thus incurring safety and health hazards. Robotic systems can benefit the process which can contain the hazardous waste for disposition.

OBJECTIVES

To develop low-cost Mobile Robotic Hot Cell/Glovebox platform that can be easily deployed for Hazardous and Radioactive Waste disposition at EM sites.

1) **Dual-arm collaborative robot** capable of human-like complex and dexterous manipulation to meet the diverse material handling needs
2) **Mobile hot cell** that can provide mobility and collaborative operation with internal and external robotic/remote systems, as well as the normal hot cell capabilities of shielding and monitoring
3) **Robotic digital twin** platform integrating VR, AR, hardware control technologies in support of all phases of the remote operation system: design, training, operation, and analysis



TEAM

ANL
(Telerobotics, Digital Twin)

- Northwestern Univ.
- Univ. Texas - Austin
- Northern Illinois Univ.
- KAIST
- Seoul National Univ.
- Novatech*

DOE-EM TDO / IAA

OREM

UCOR

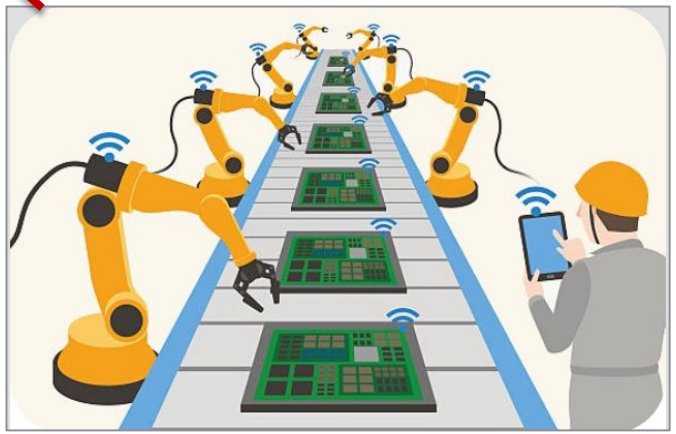
Planning and Approval for Hot test / Site Application & Metric

Y-12 site

ORNL Hot Cell

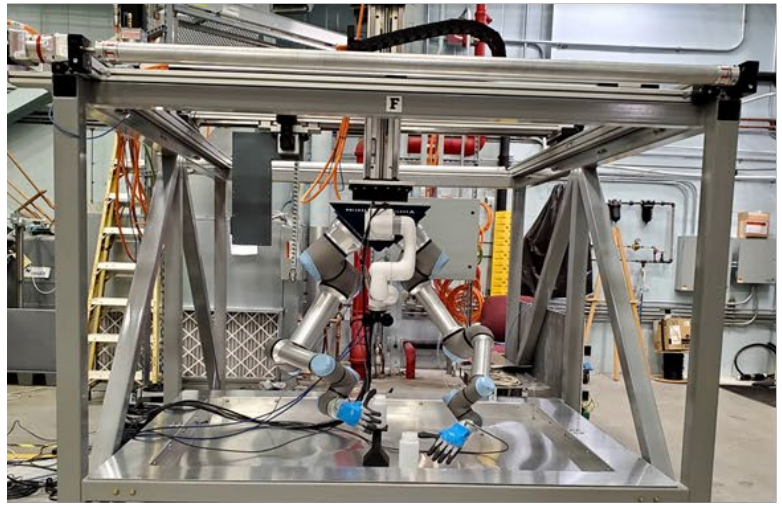
ORNL
(Remote Systems)

UIC
*MSIPP (Automation)



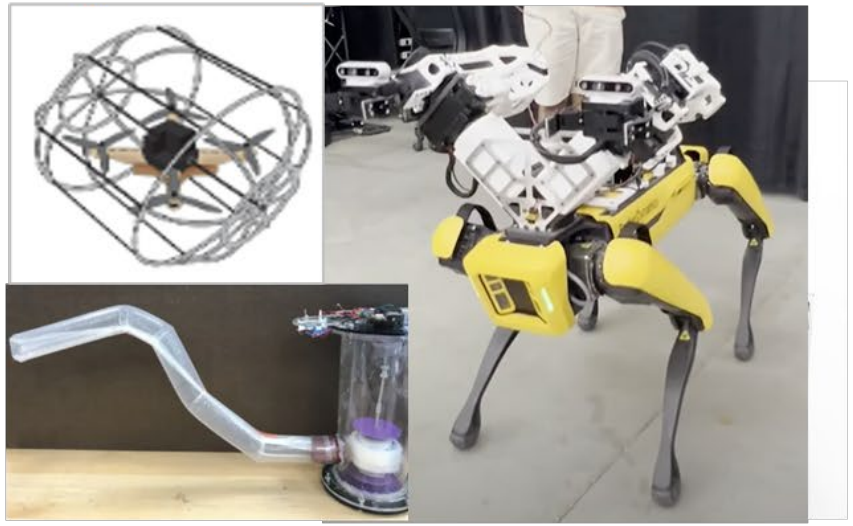
Project Overview

Waste Handling



Robotic Digital Twin Platform

Inspection / Decontamination



Dismantling

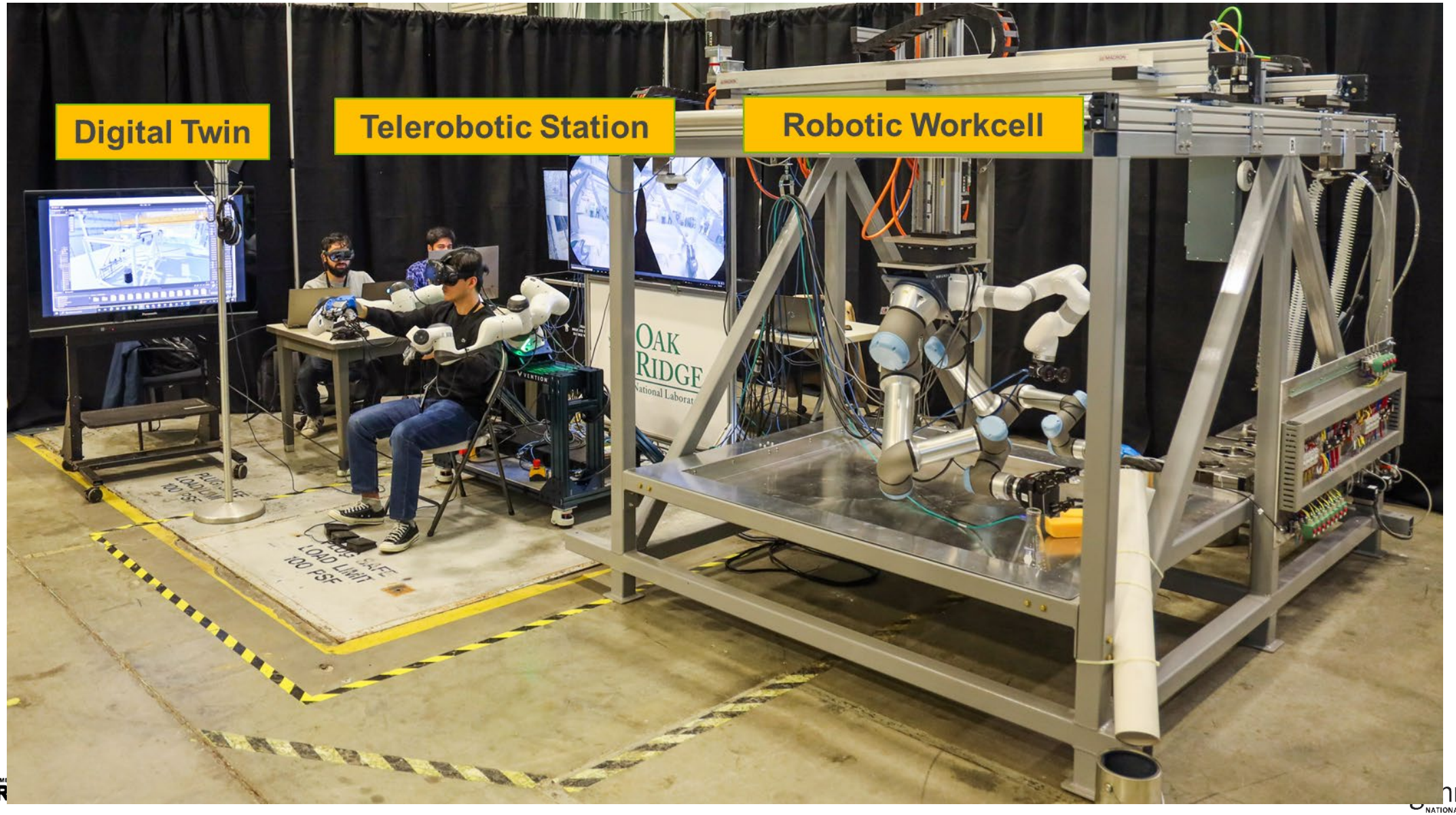
Repair

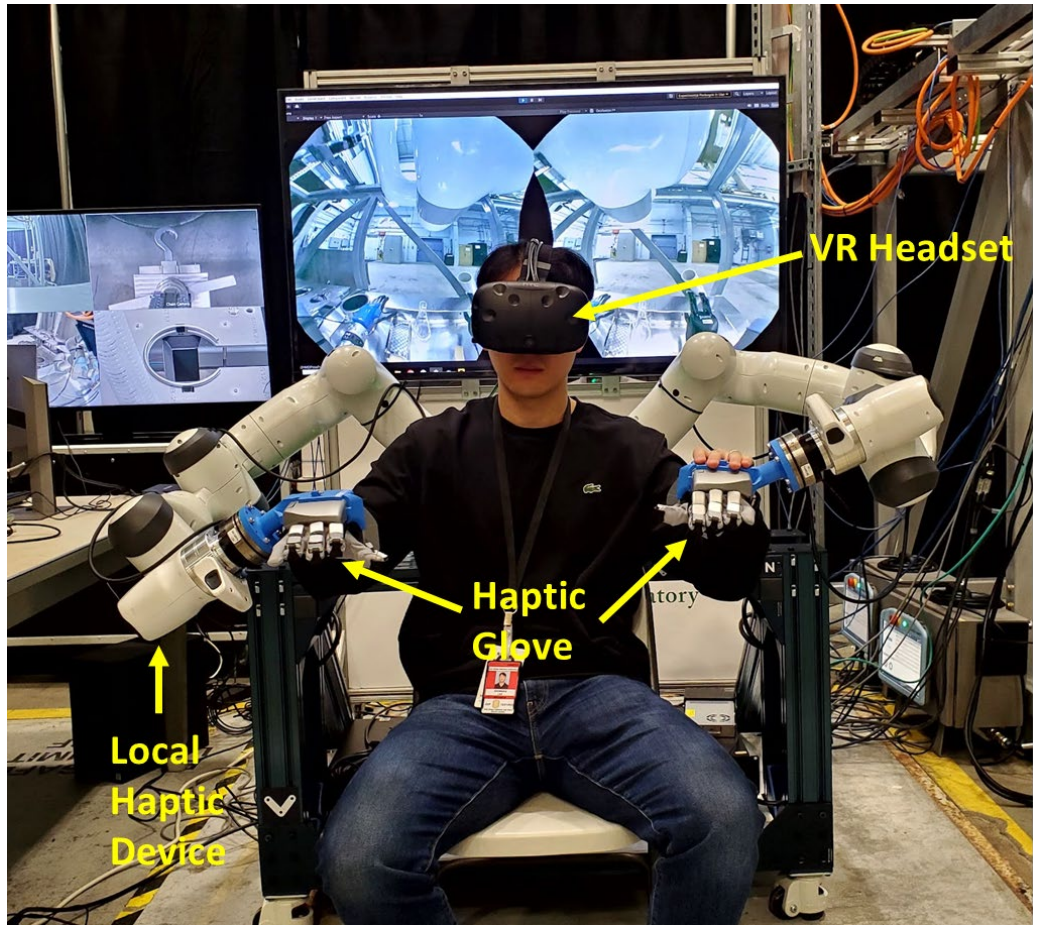
Mobile Robotic Work Cell

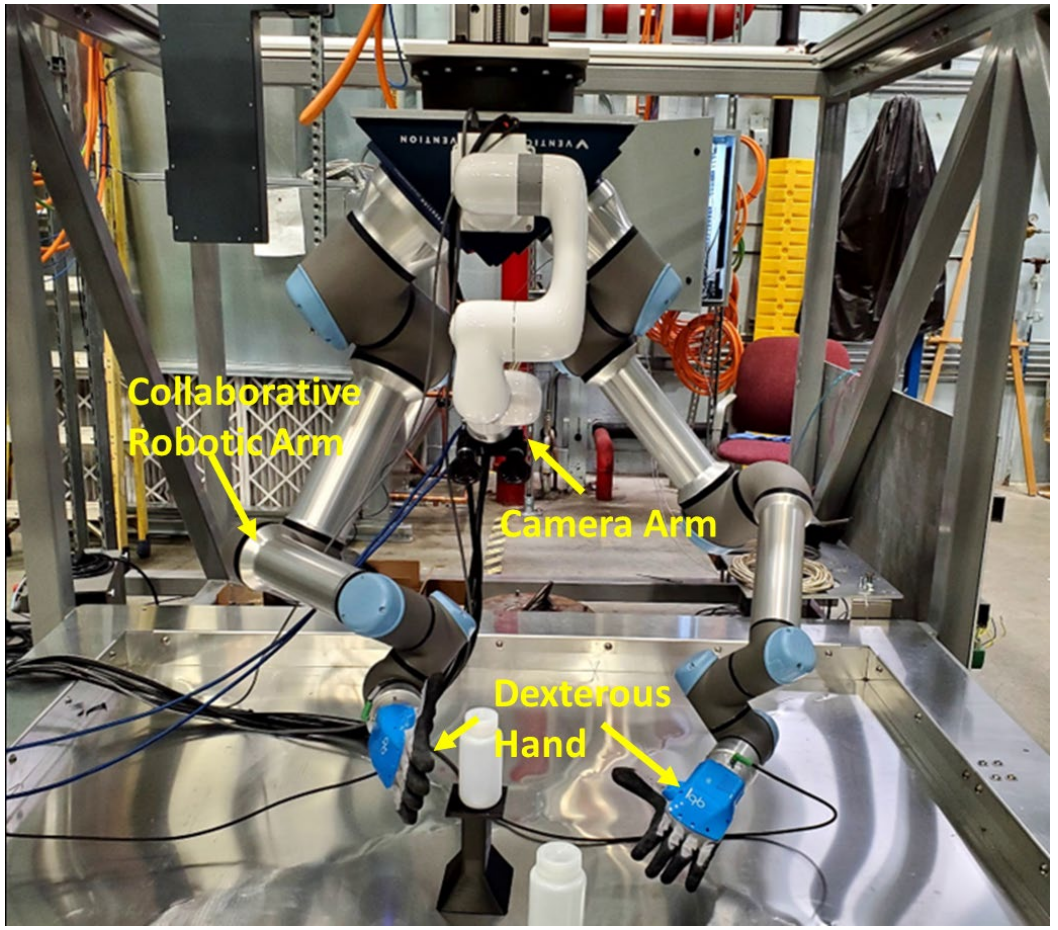
- **Rapid Prototyping**: For ORNL 3517 and Y-12 facility cleanup missions, the **Robotic Work Cell** will provide a remotely deployable hot cell/glovebox environment that can perform remote handling and packaging of radiological and hazardous materials, thus save human workers from the harm's way.
- **On-site Demonstration**: Interrogate and classify canisters containing radioactive material and transfer any material in them to a DOT certified container. All operations are performed remotely thus minimizing any potential contamination or radiation exposure to workers
- **Technology Adaptation (Robotic Digital Twin)**: Develop robotic digital twin testbeds with hardware-in-the-loop simulation capabilities to demonstrate technology adaptation for broad D&D operations.

RAPID PROTOTYPING (MOBILE ROBOTIC WORK CELL)

RAPID PROTOTYPING

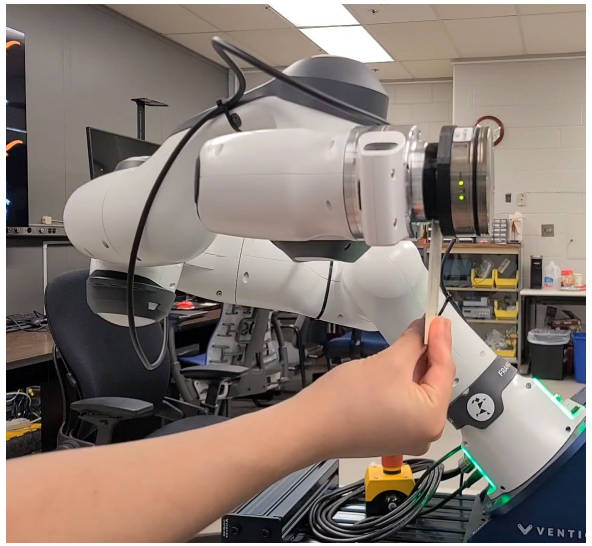



VR Headset
Haptic Glove
Local Haptic Device


Collaborative Robotic Arm
Camera Arm
Dexterous Hand

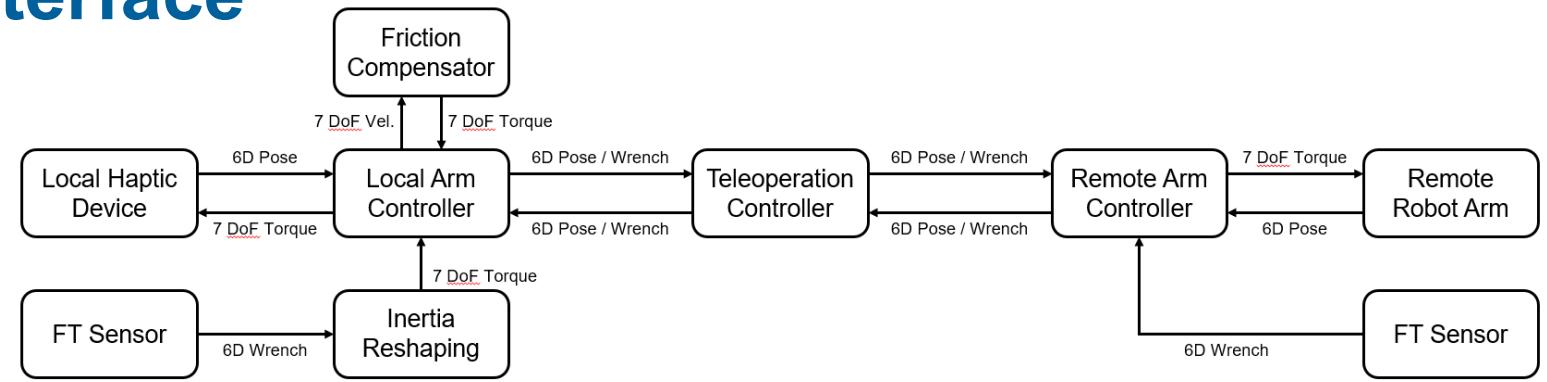
Telerobotic Operator Interface

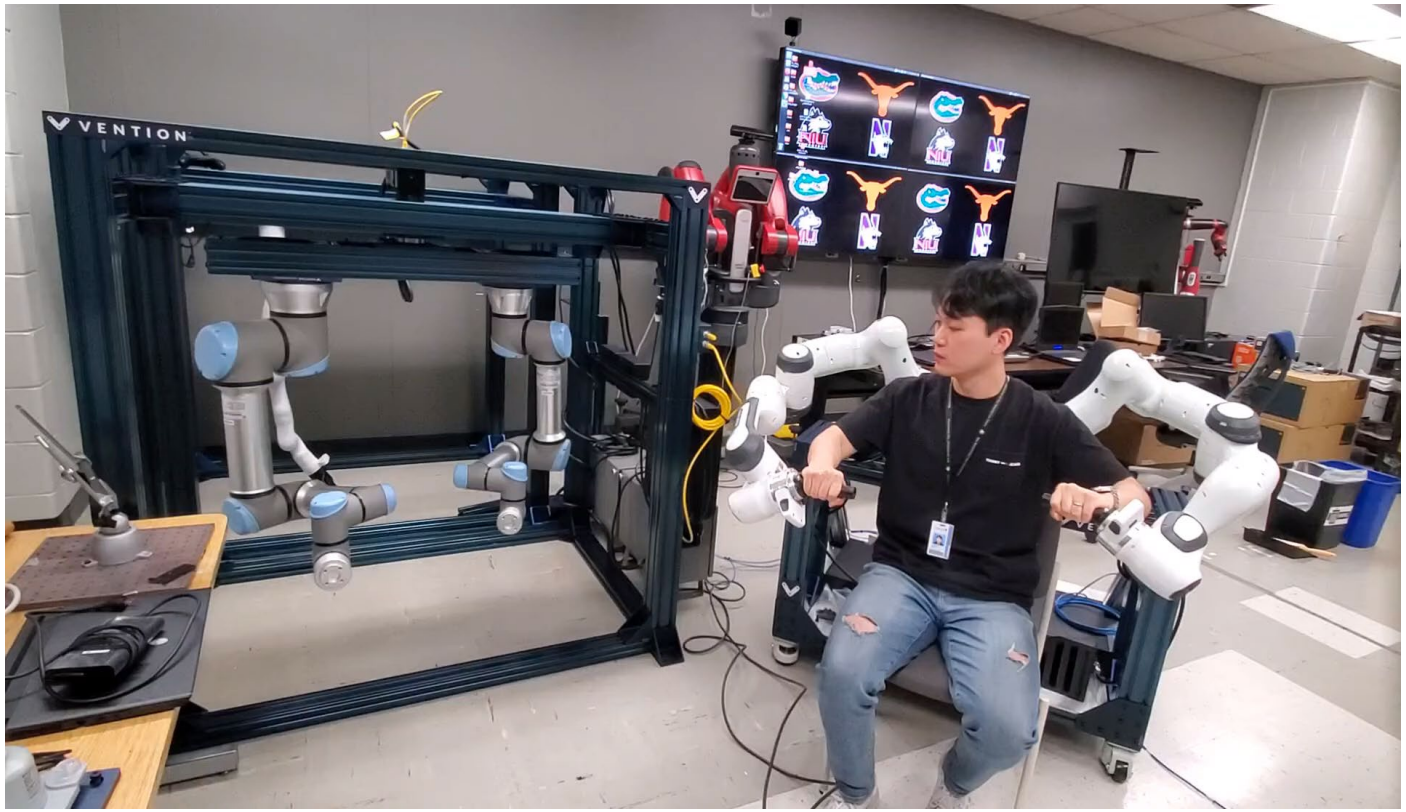
- Friction/Inertia Compensation



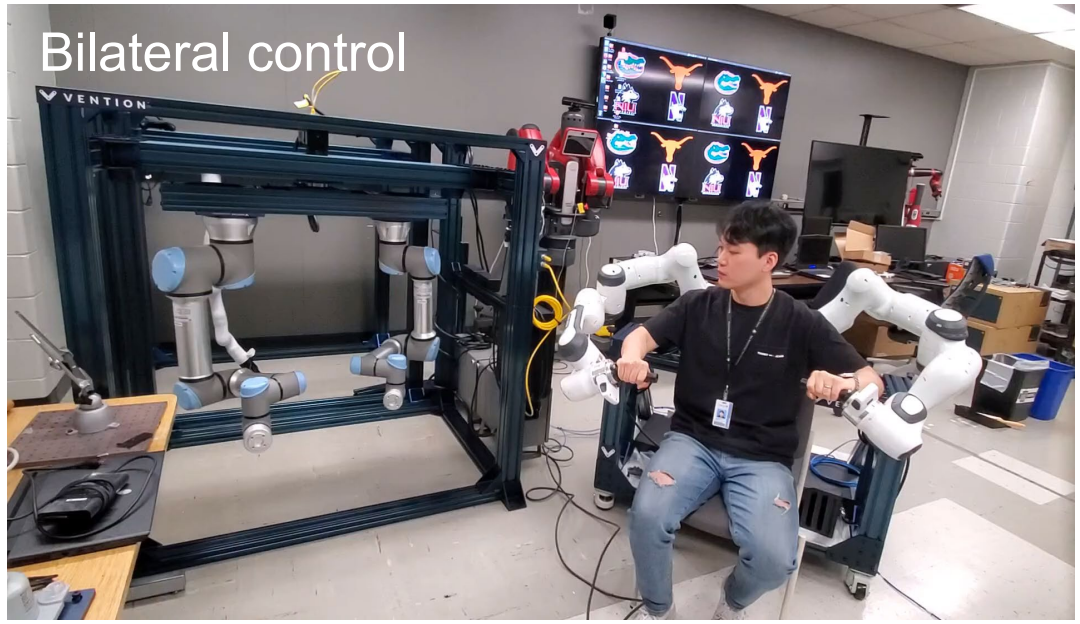
Without compensation

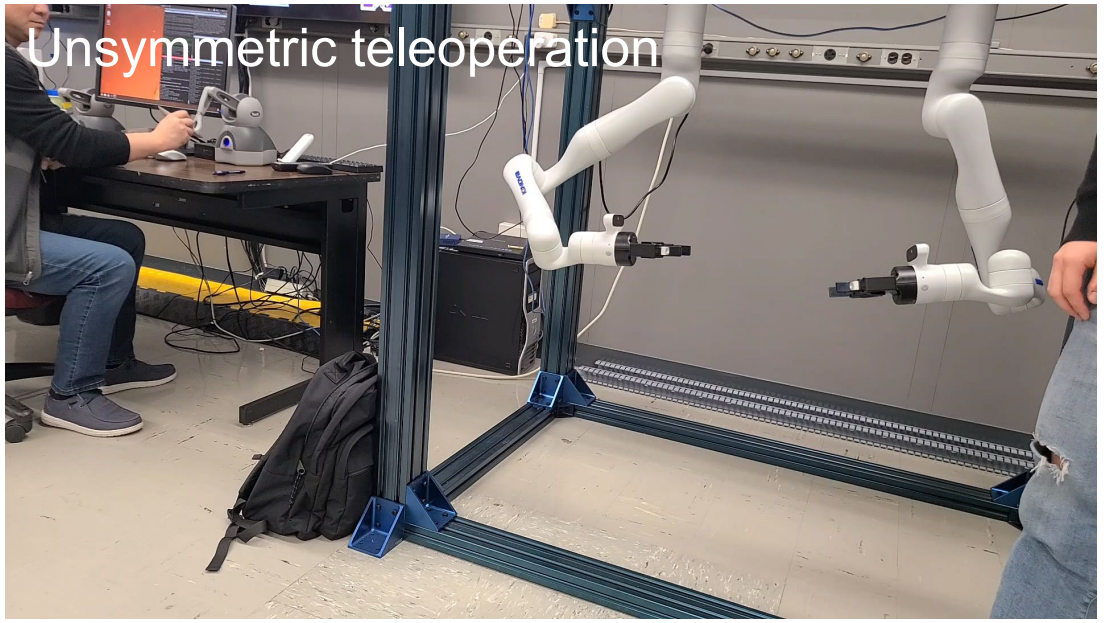
With compensation

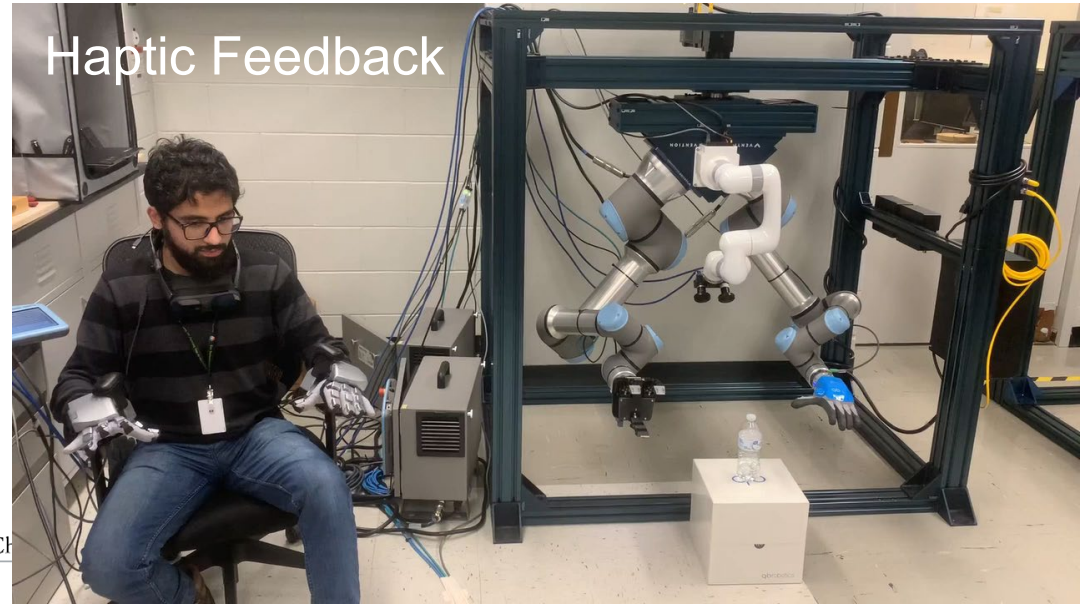


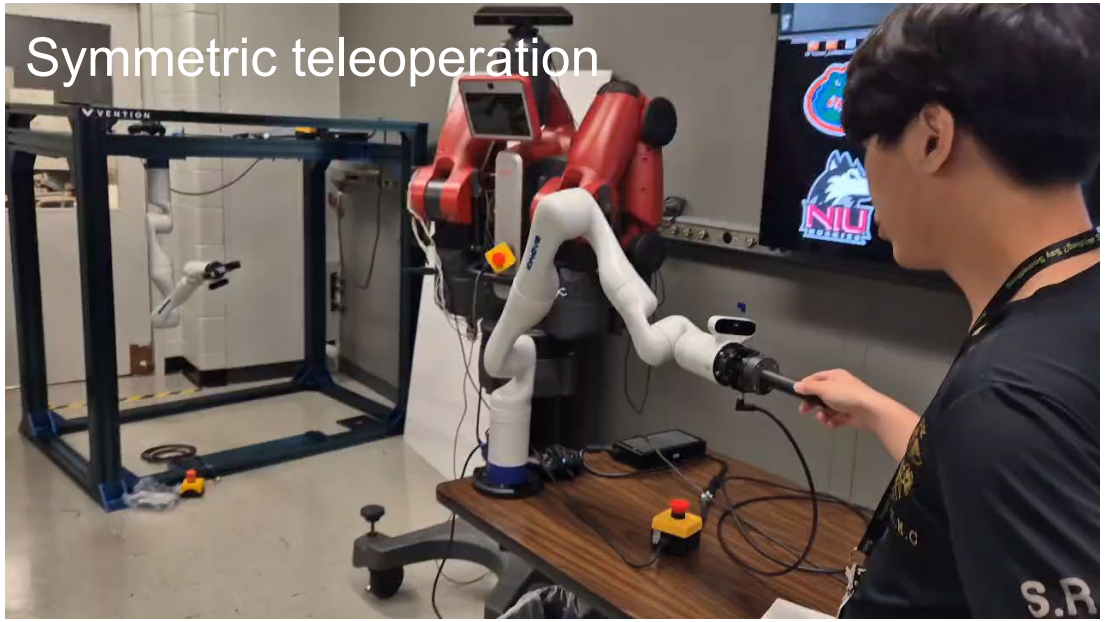


Telerobotics







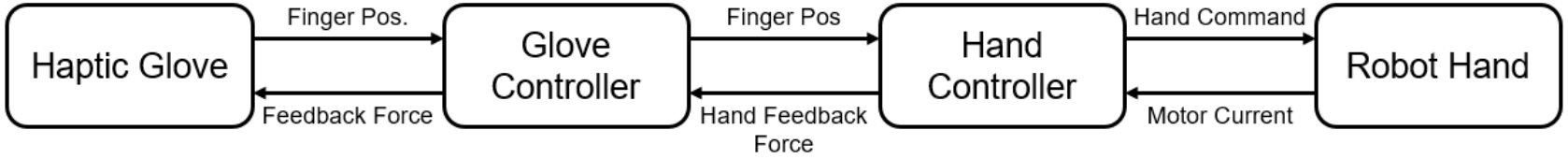


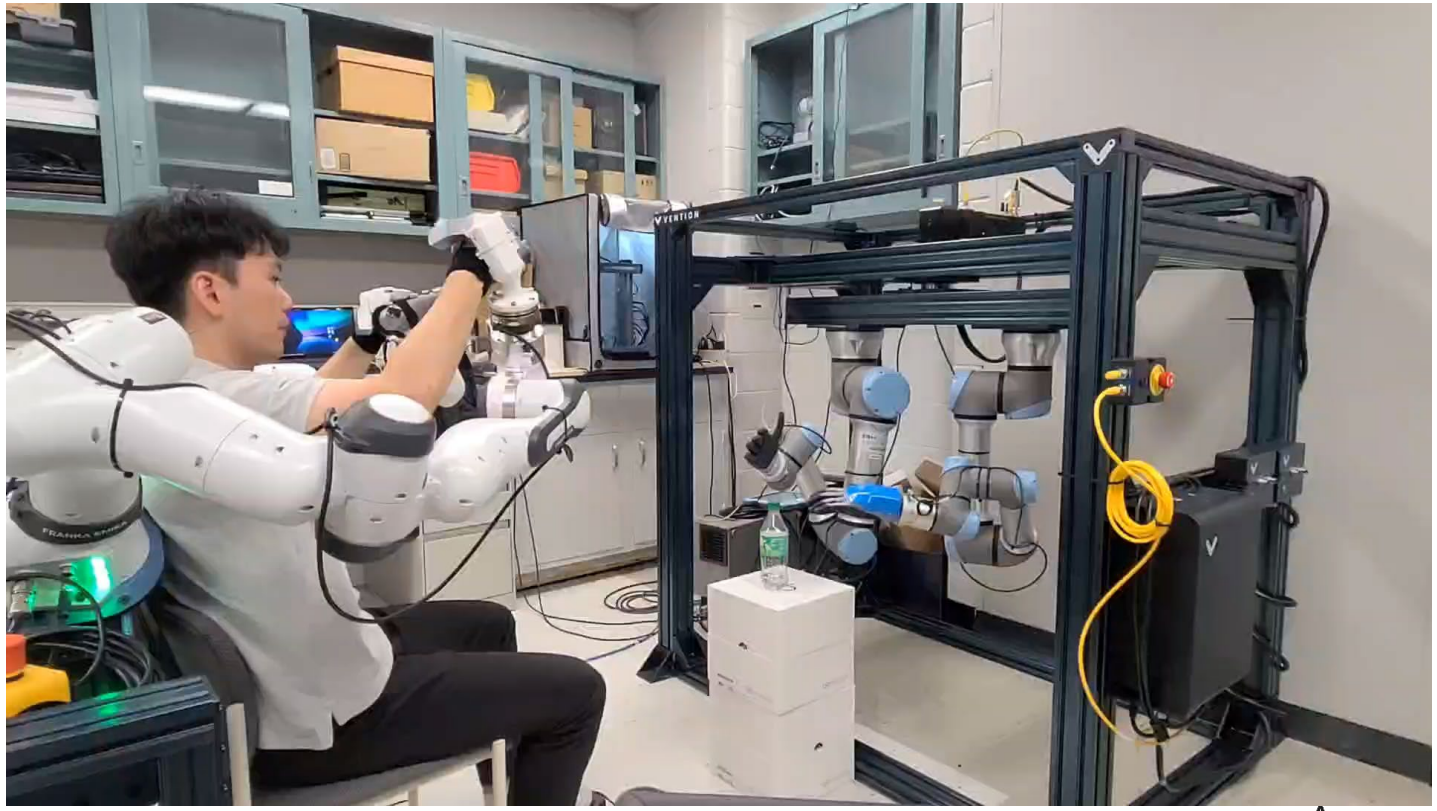
Dexterous Manipulation

Grasp motion mapping

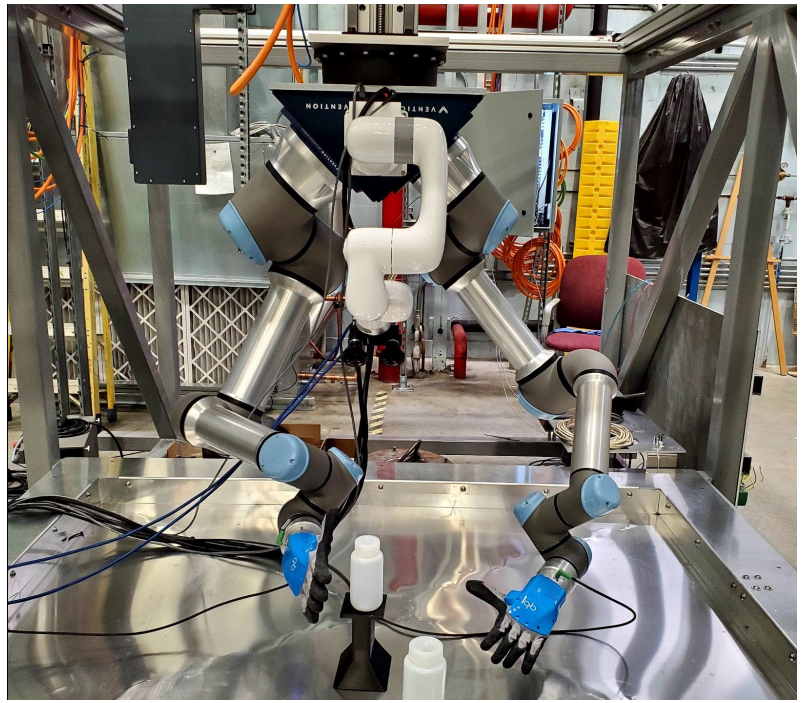
Haptic Feedback

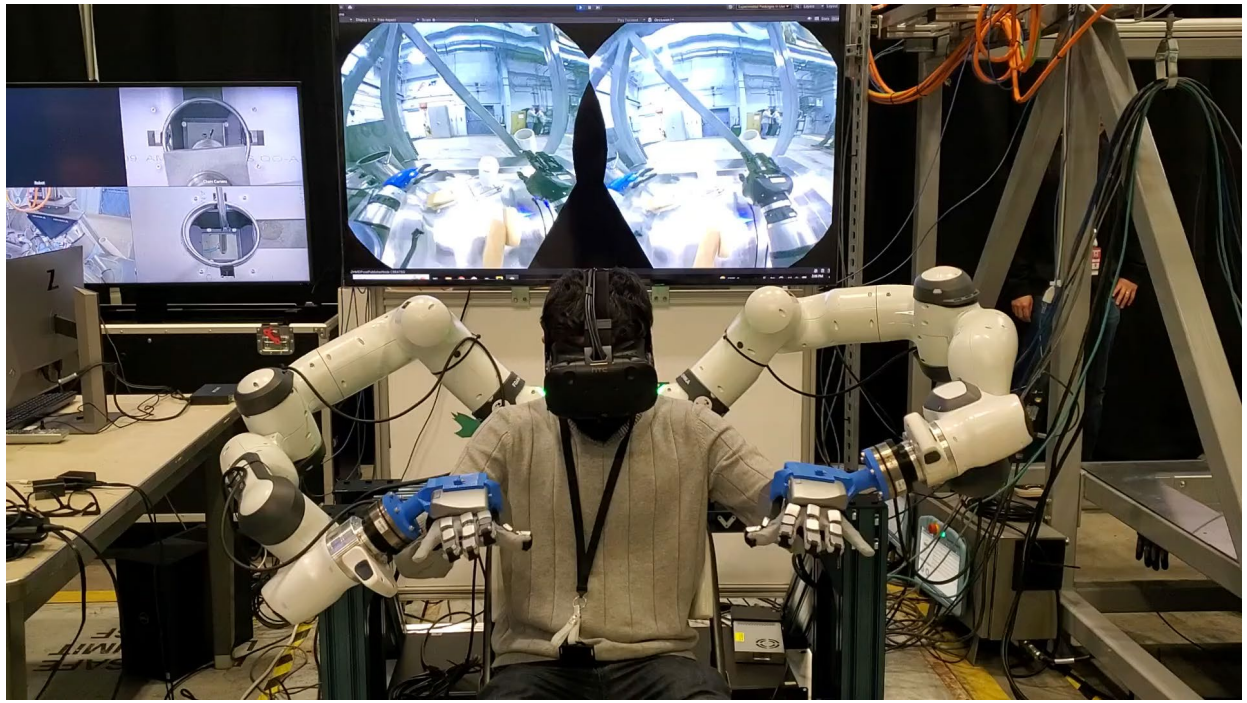
- Hand Control

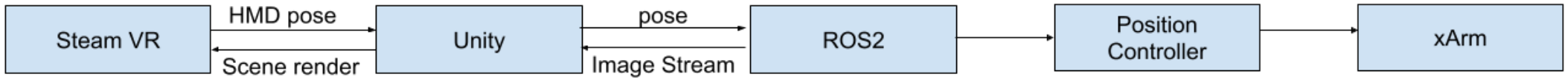




Hand-Eye Coordination

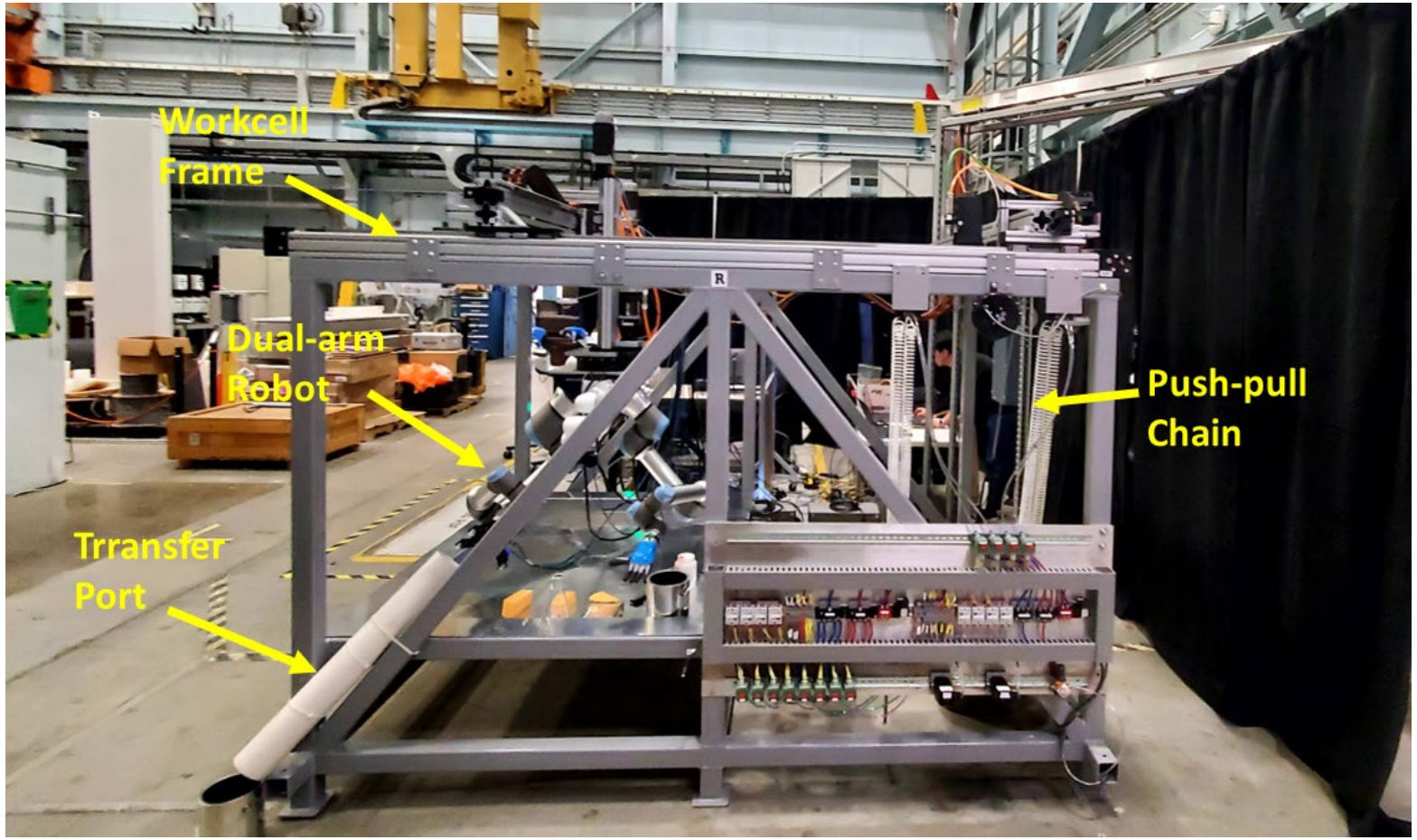


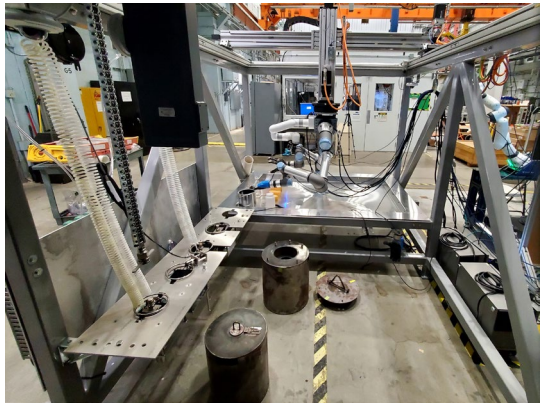




COLD DEMONSTRATION

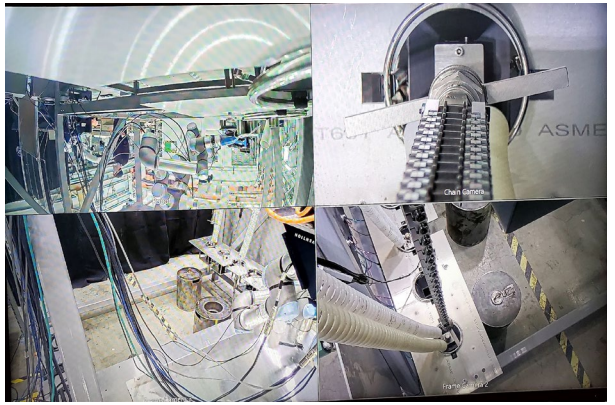
Remote Handling of Waste Cask with Push-Pull Chain



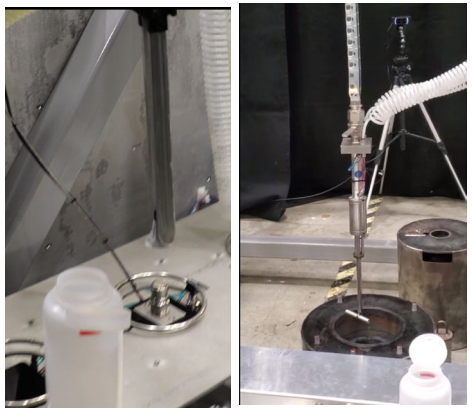


Remote Handling System

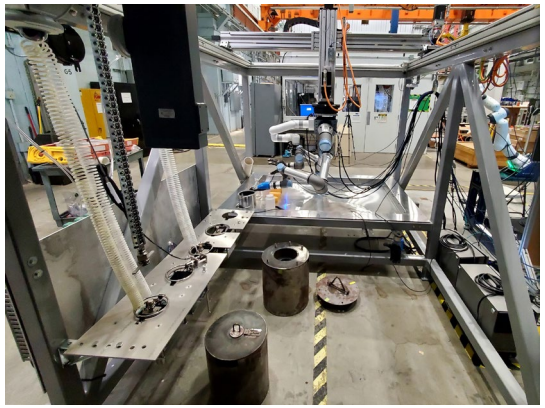
Remote Operator Station



Operator Interface Screen

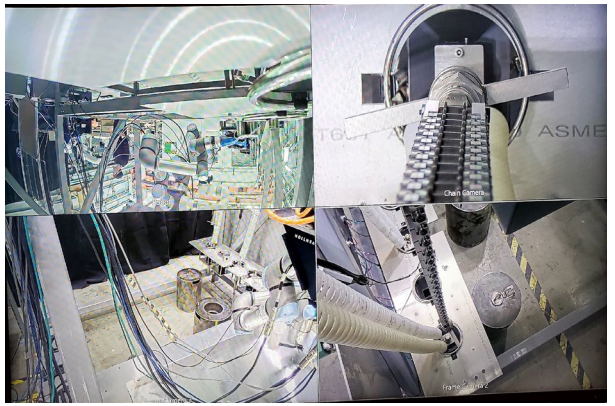


Smear and waste removal

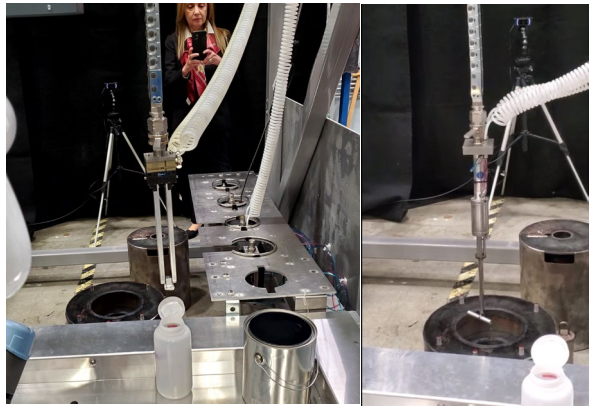


Remote Handling System

Remote Operator Station



Operator Interface Screen

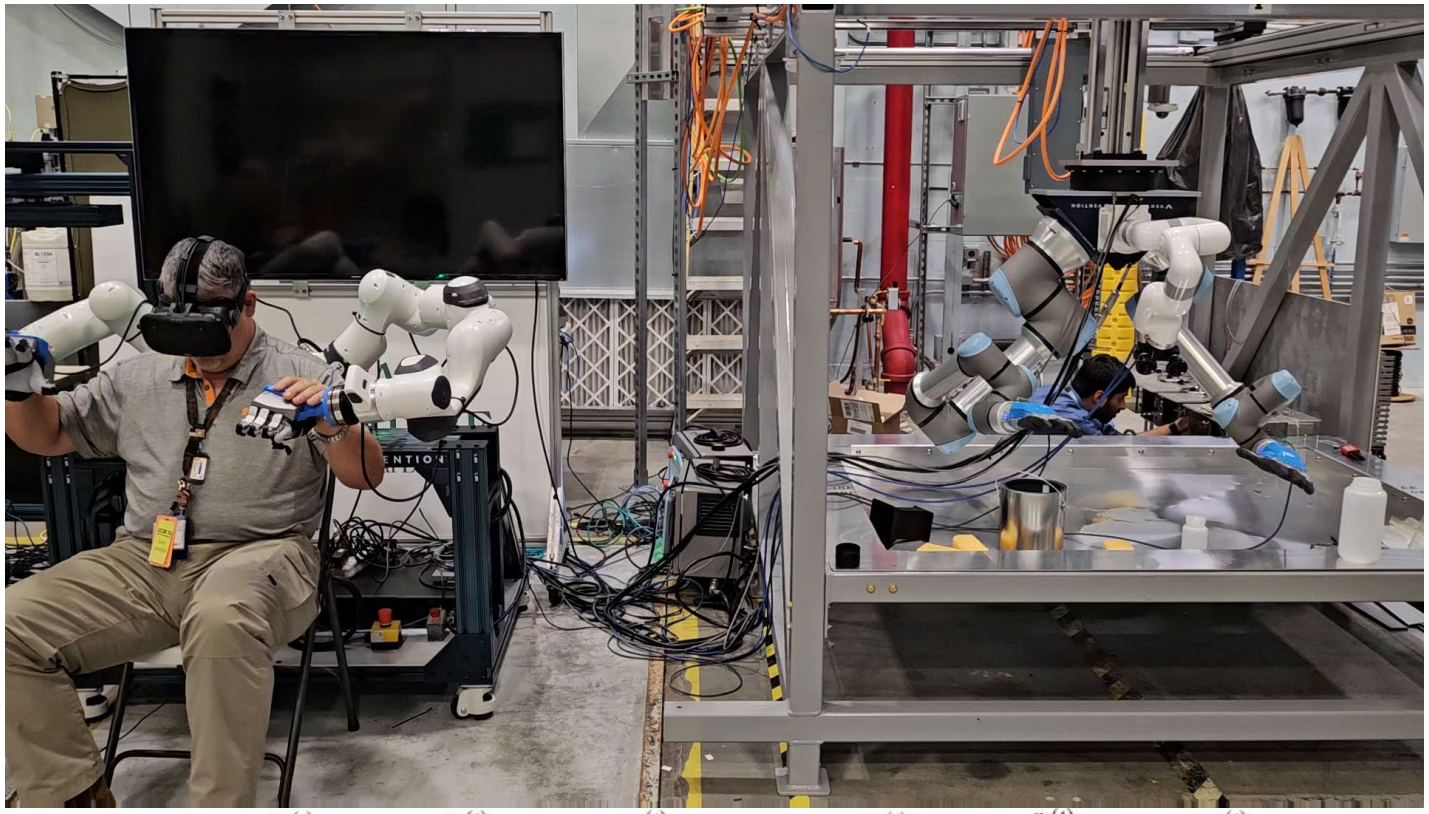


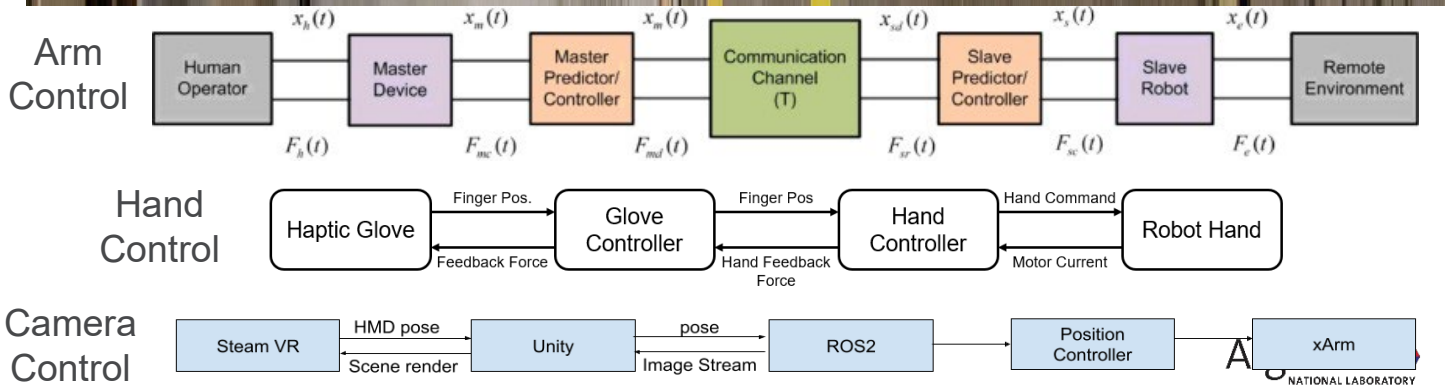
Smear and waste removal

COLD DEMONSTRATION

Dual-arm Telerobotic Operation

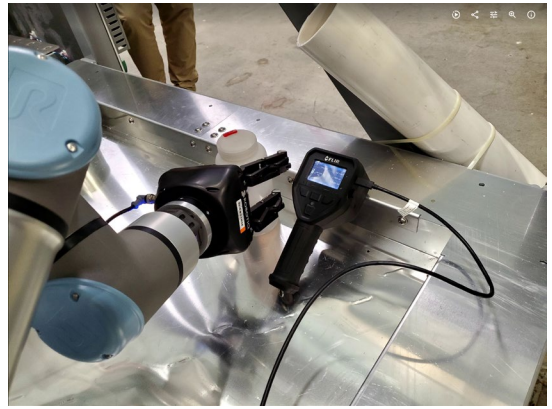
- US DOE-EM has many facilities that require nuclear waste handling



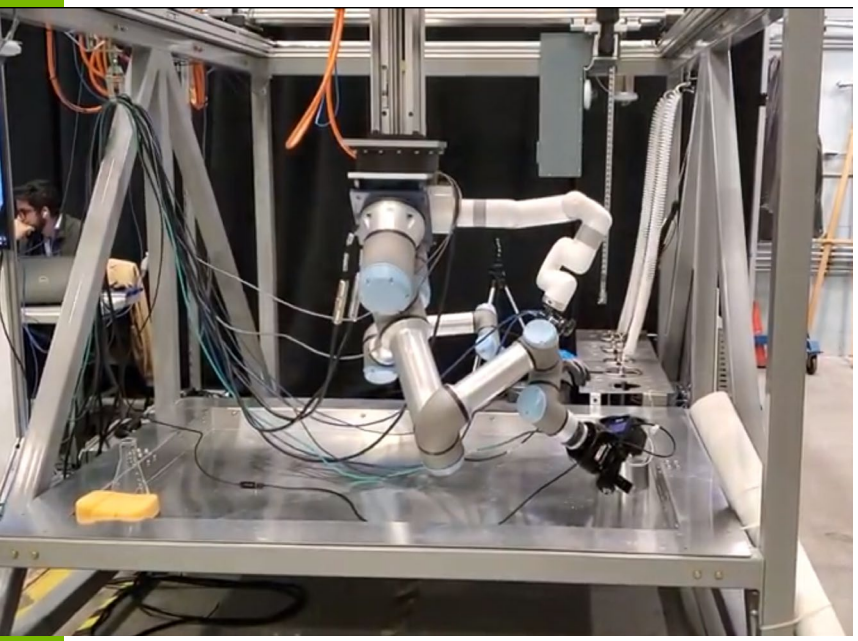


Pick up sample bottle (Task 1)

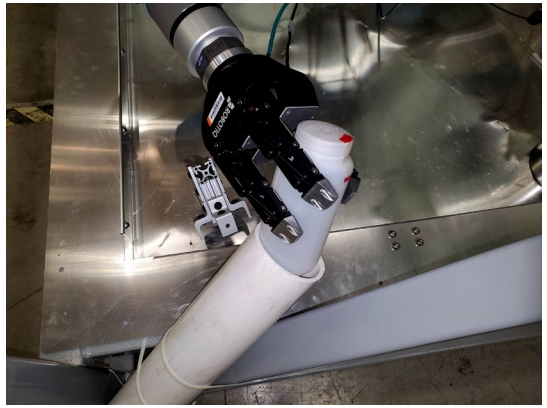
Close cap (Task2)



Radiation detection (Task 3)



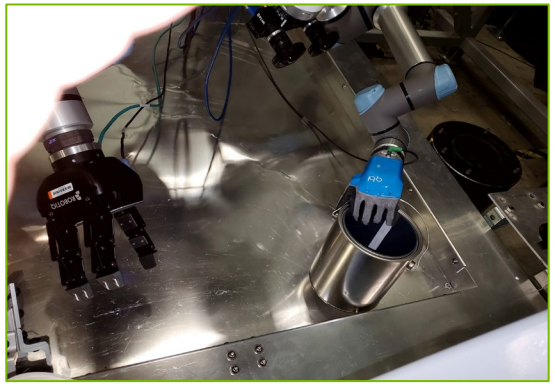
Dual-arm Robotic Work Cell



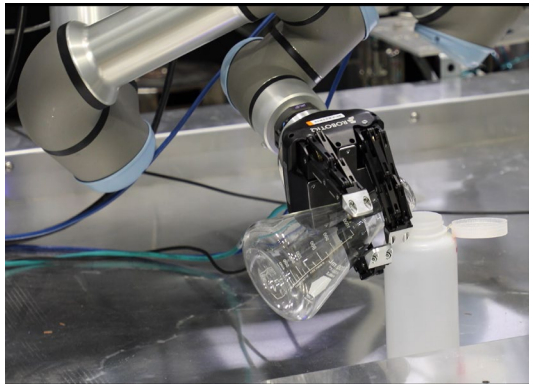
Transfer sample (Task 4)

Pickup waste can (Task 5)

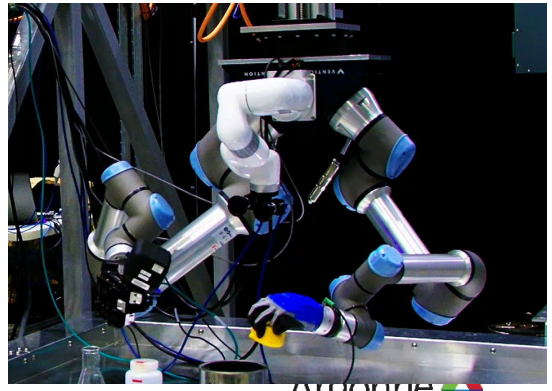
Radiation detection (Task 6)



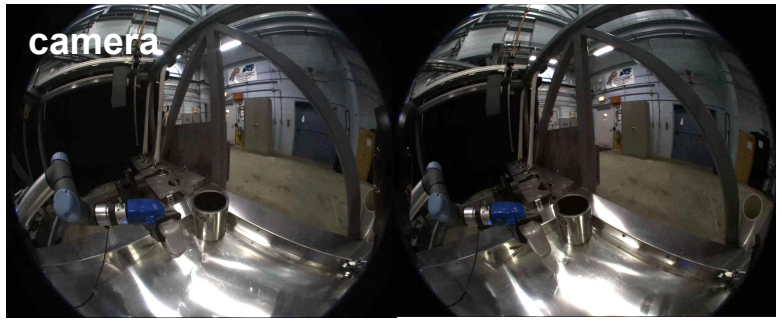
Put away waste can (Task 7)



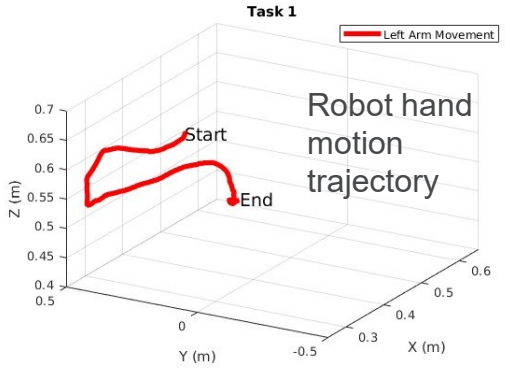
Pouring liquid waste (Task 8)

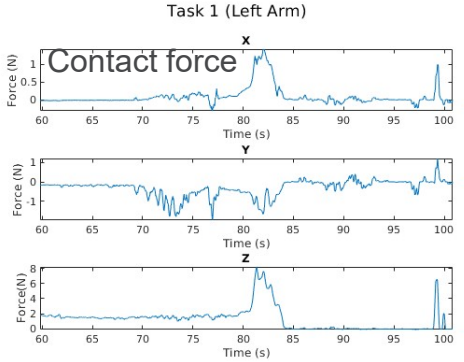


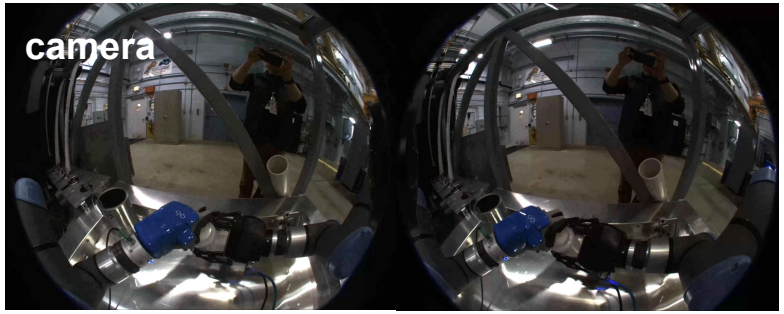
Collection, sorting (Task 9)



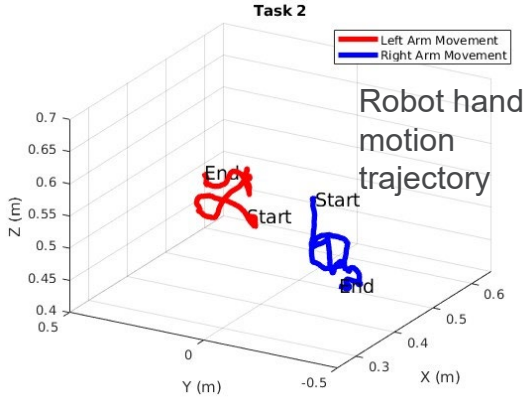
Task 1: Moving the bottle

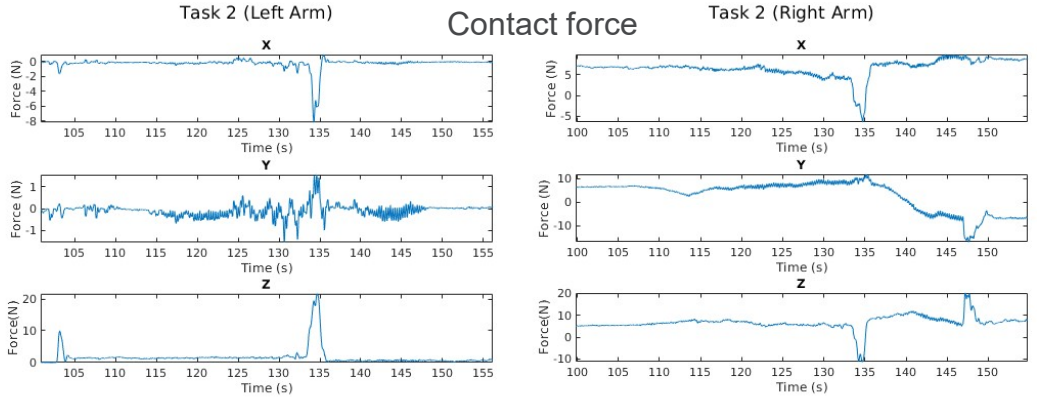


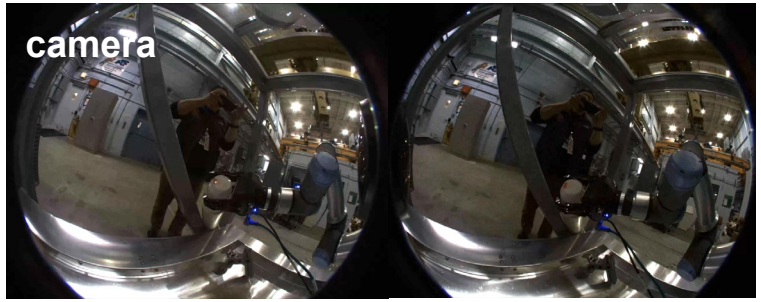




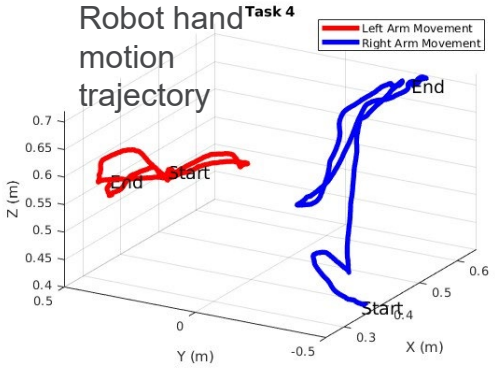
Task 2: Closing the bottle cap

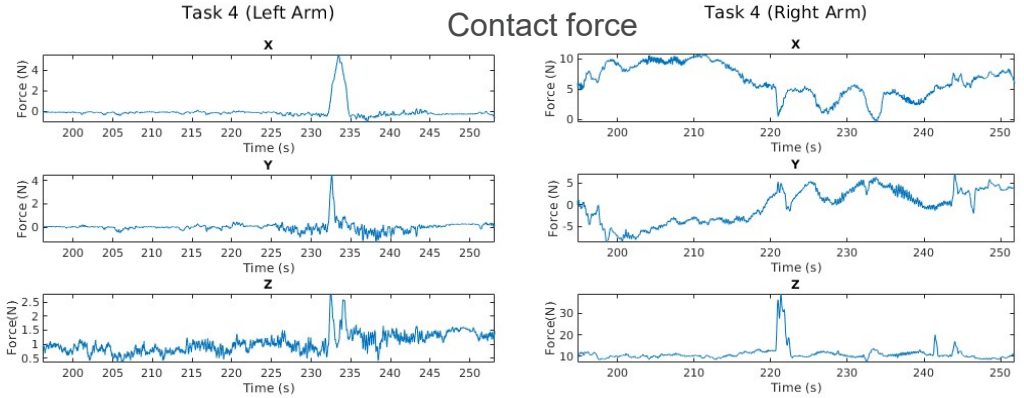






Task 4: Putting the bottle into port



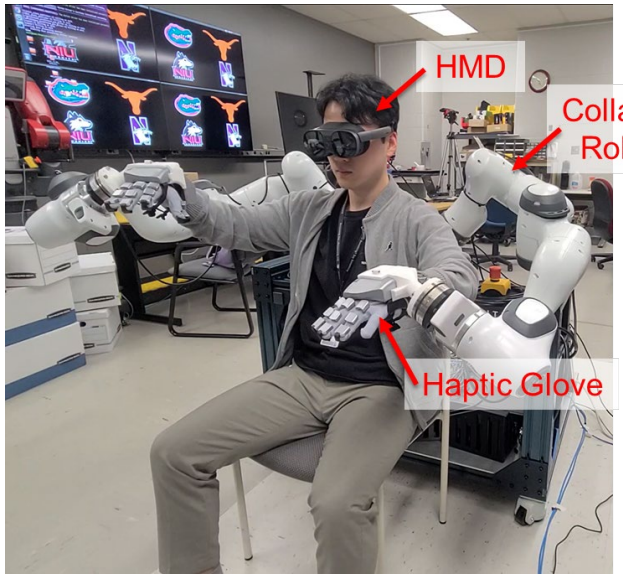


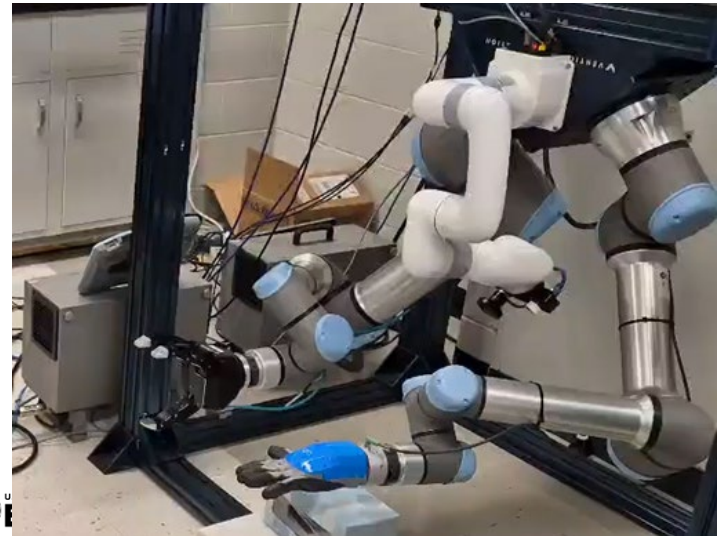
ON-SITE DEMONSNTRATION

ORNL 3517

ENHANCEMENT OF ROBOT SYSTEM

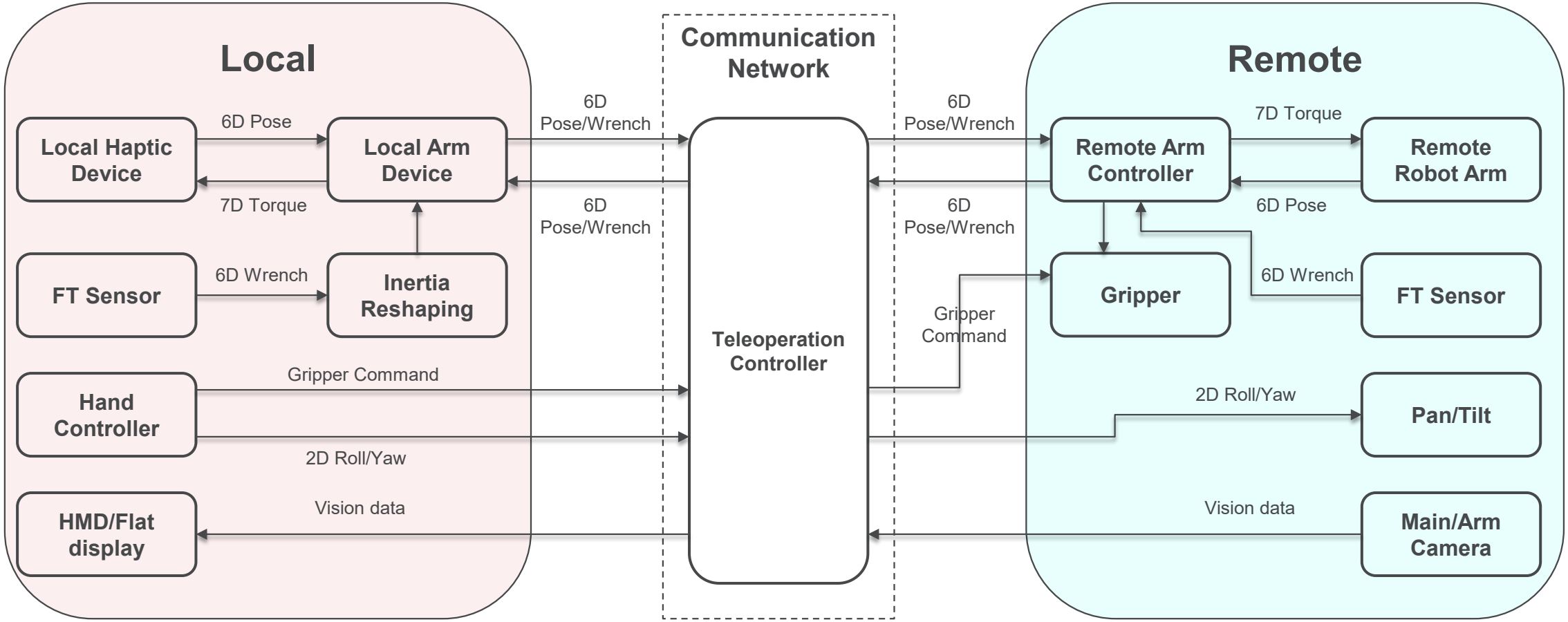
Objective: To enhance reliability for on-site deployment





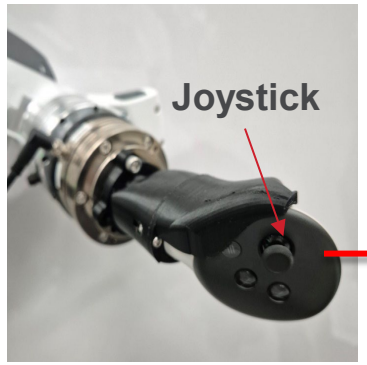
- Bilateral control tuning
- 6 dof arm → 7 dof arm
- Multi-finger gripper → 2-finger gripper
- Camera arm → Pan/tilt device
- HMD → Flat screen
- Haptic glove → Hand controller
- Camera head tracking → joystick control

Telerobotic Control System

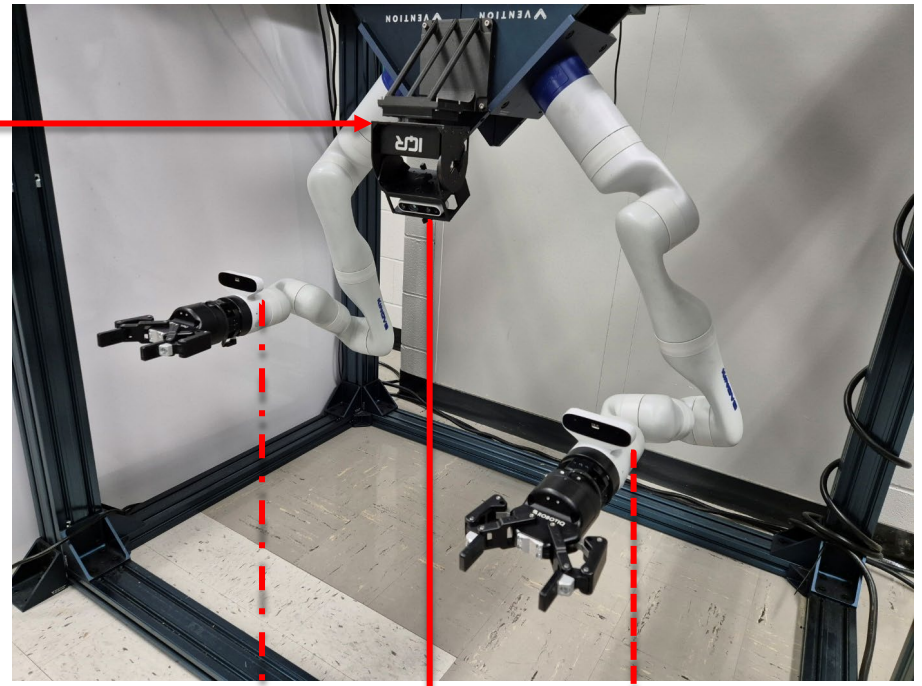


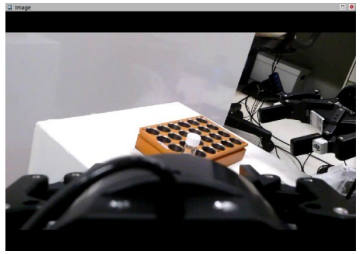
TASK 9: ENHANCEMENT OF THE ROBOT SYSTEM

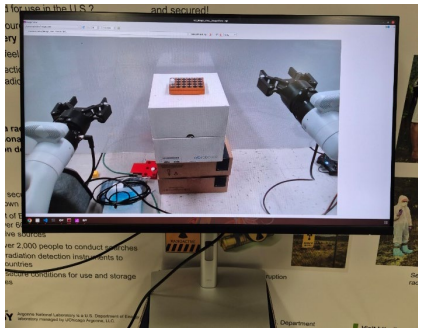
Vision System

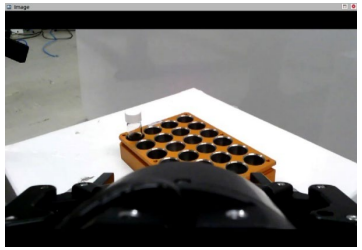


Pan/Tilt command









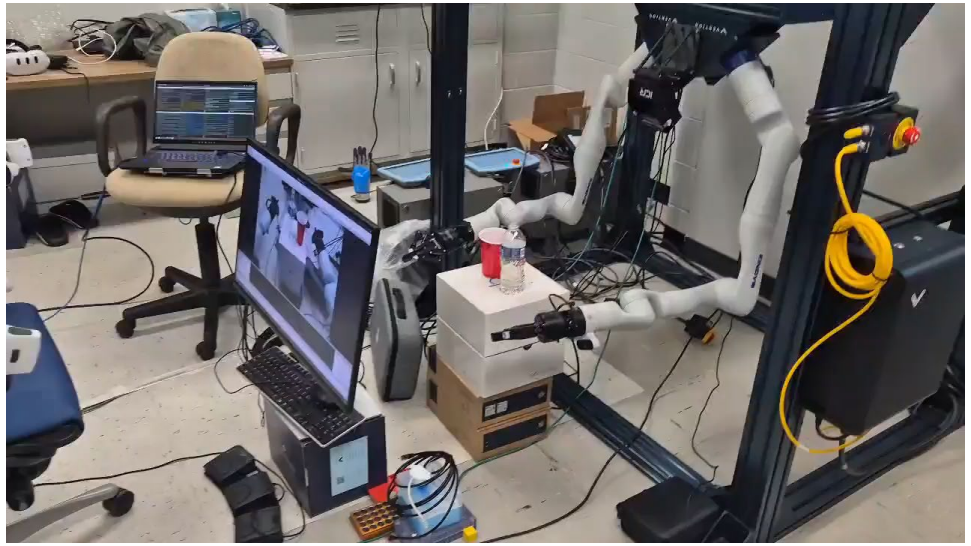
Left arm camera

Main camera

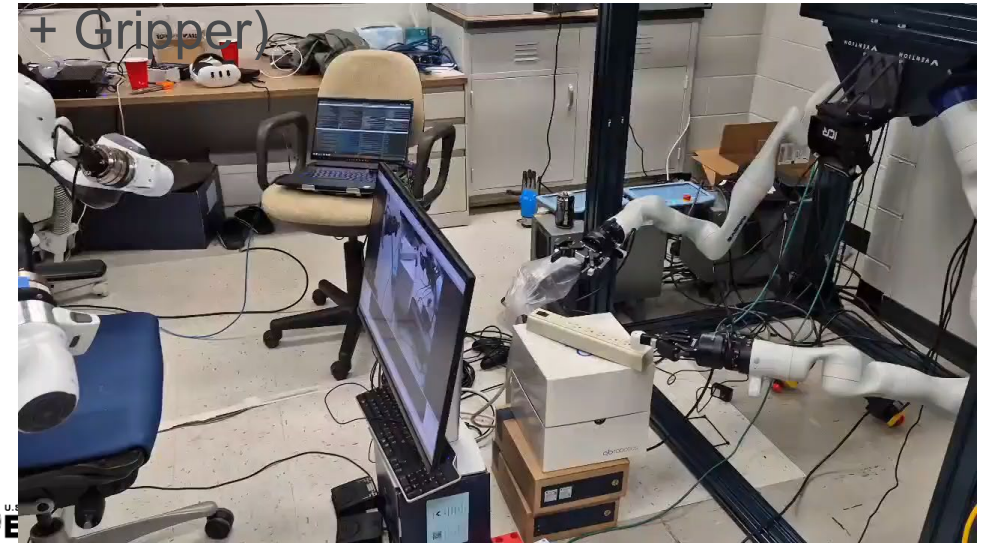
Right arm camera

Experimental videos

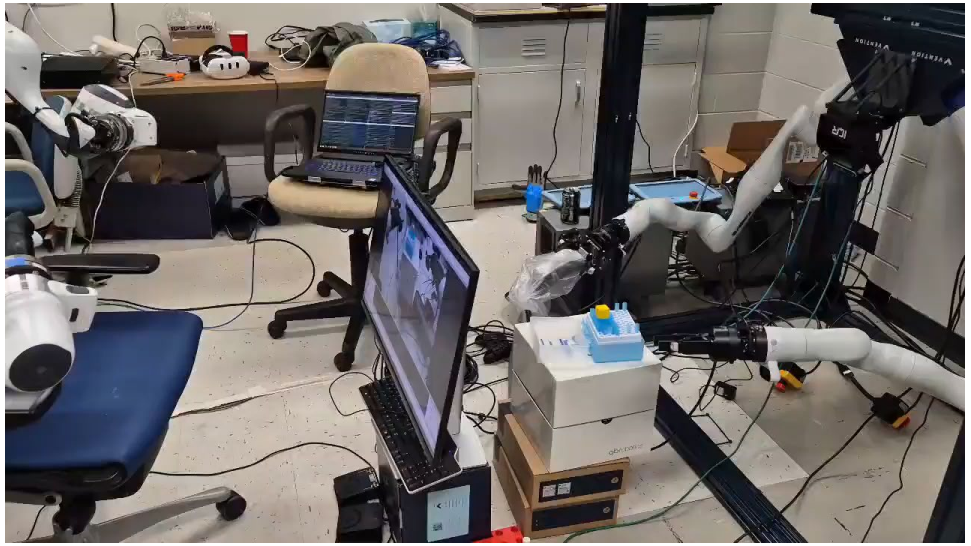
- Pouring liquor (Free motion + Gripper)



- Plug-off & plug-in (Precise interaction + Gripper)

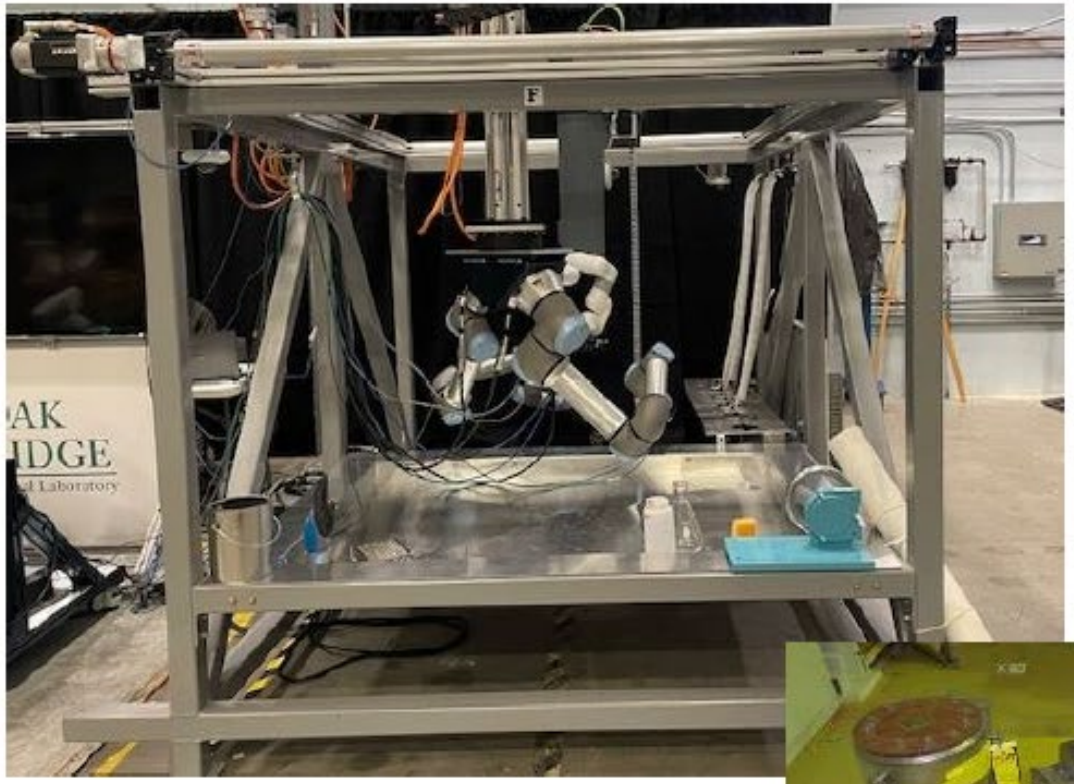


- Placing reagent storage (Free motion + Interaction + Gripper)

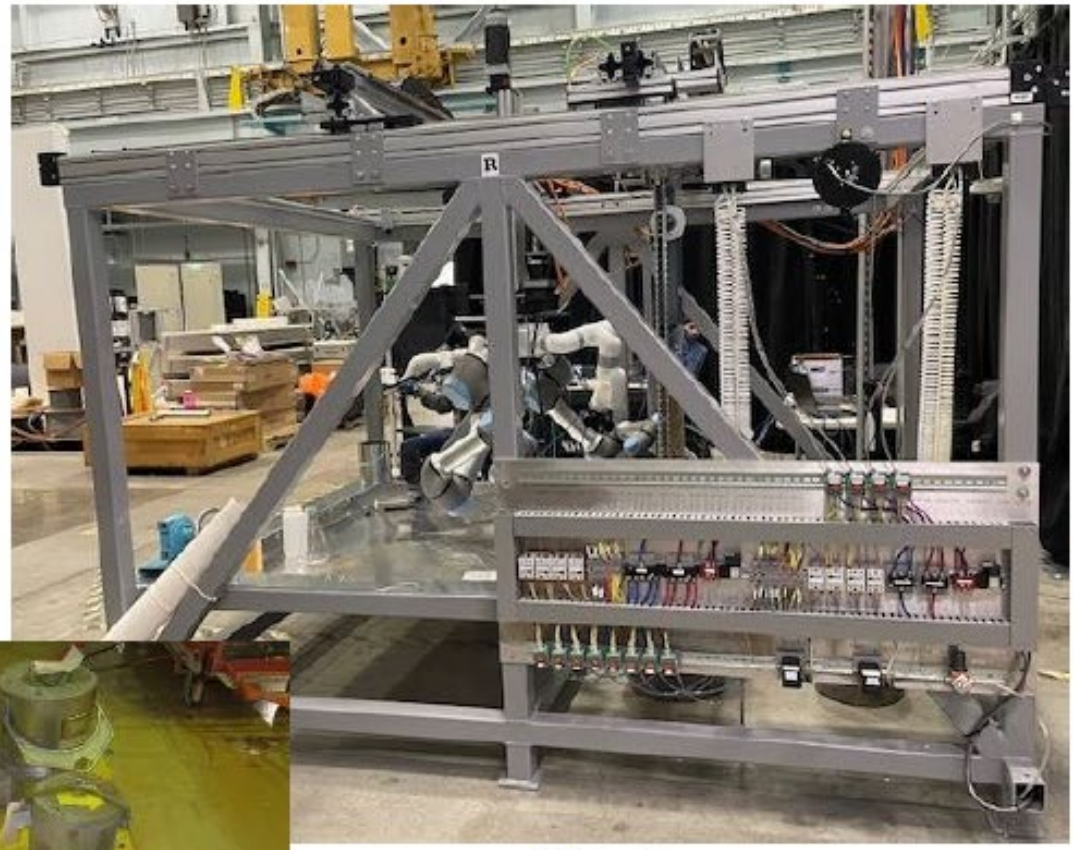


  - Weigh handling (Two-arm cooperative work)
  - T

ROBOTIC WORK CELL



Front View



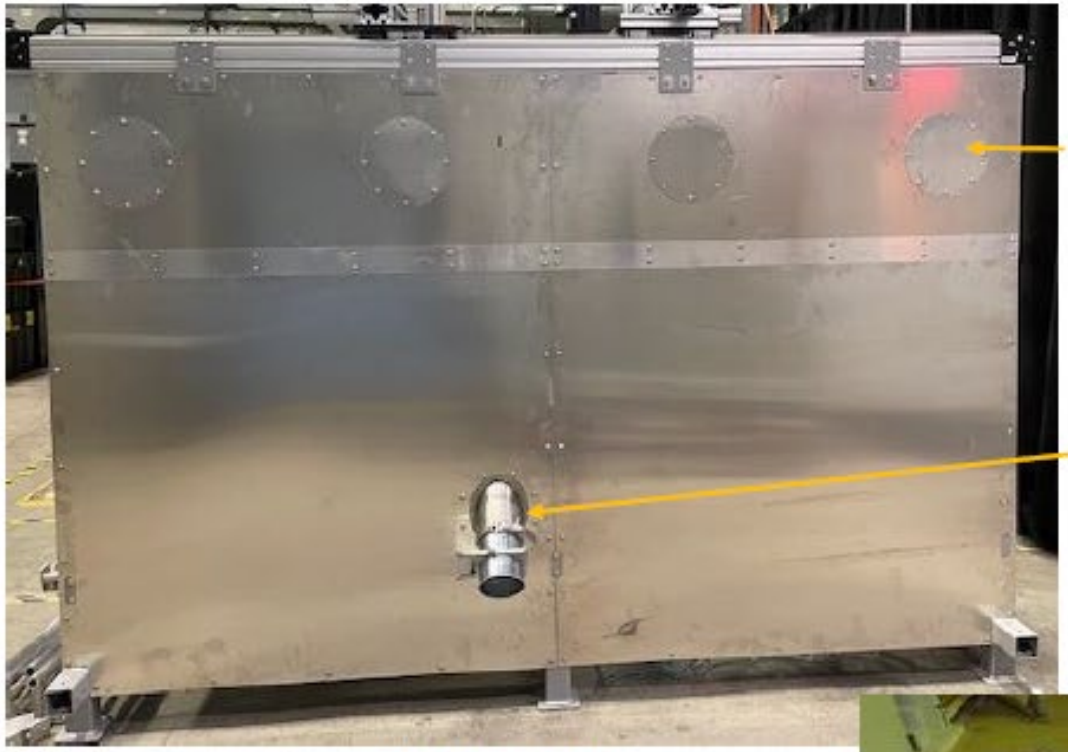
Side View

Canisters to Interrogate

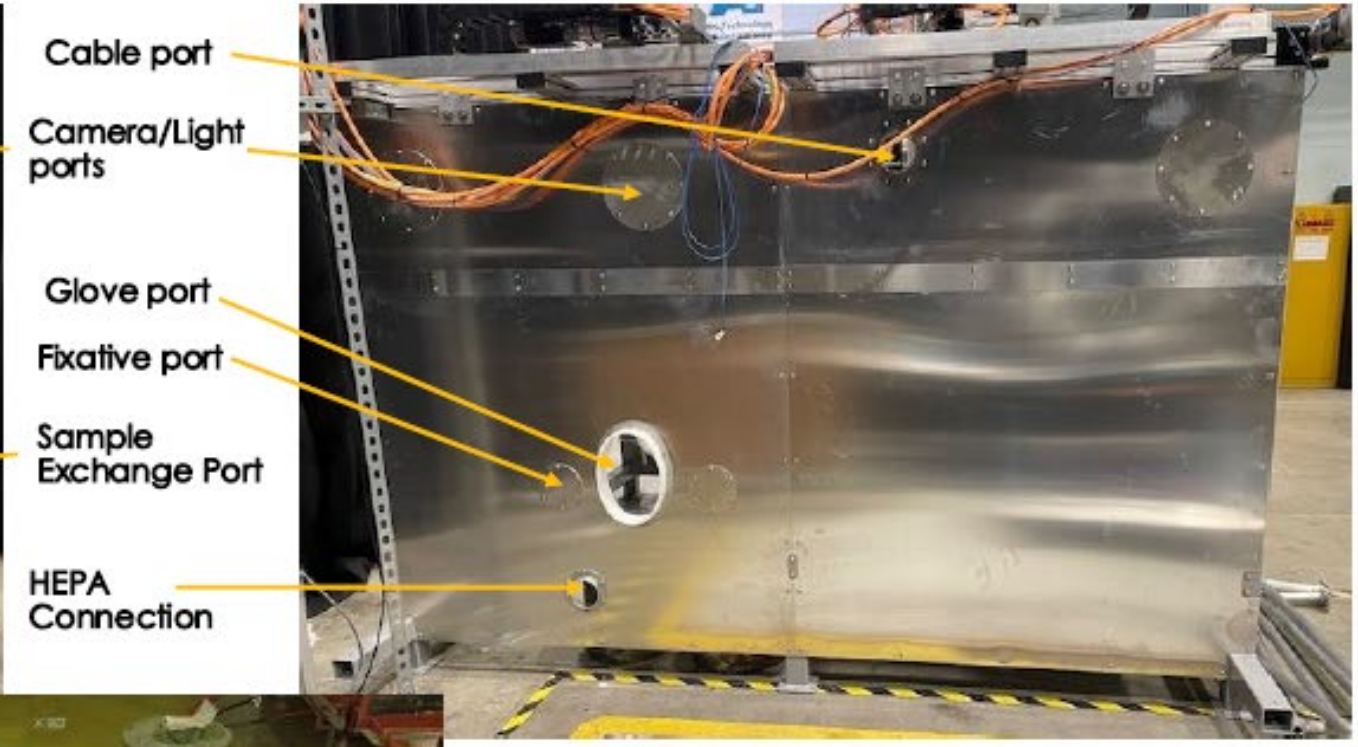
OAK RIDGE National Laboratory

Open slide master to edi

WORK CELL AT ORNL



Right side View



Left side View

Canisters to Interrogate

HEPA Filter + Rad Detector

HEPA Filter

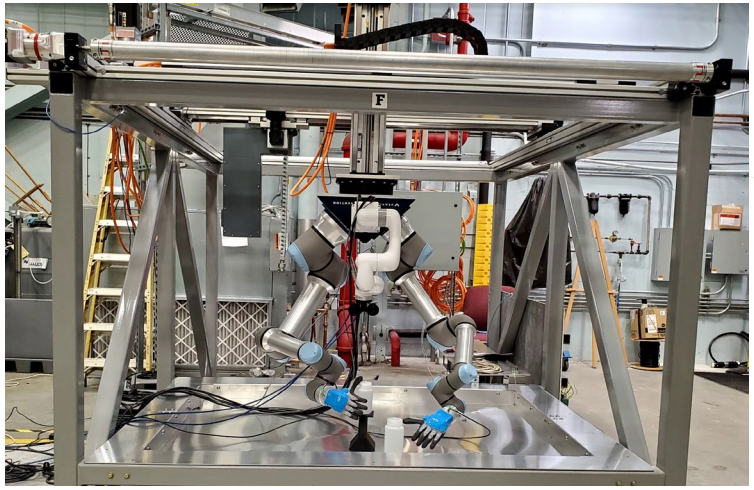
Radiation Detector

Fixative: Decon Gel 1128; Still identifying the correct sprayer

TECHNOLOGY ADAPTATION (ROBOTIC DIGITAL TWIN)

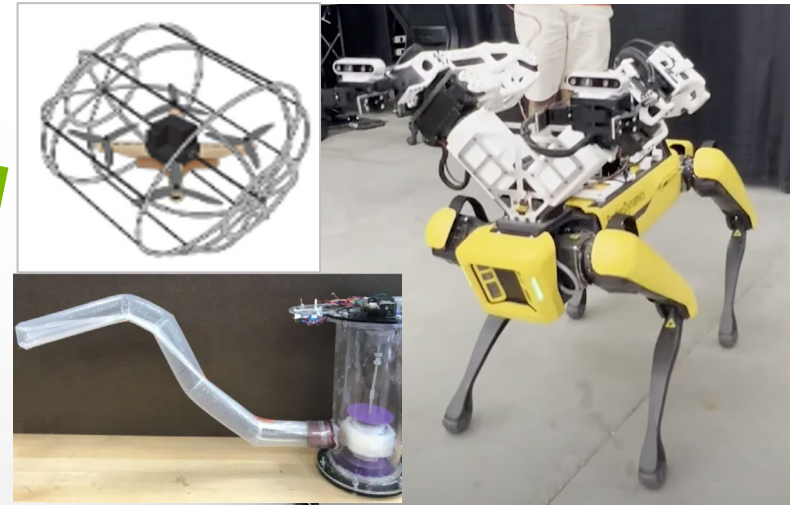
ROBOTIC DIGITAL TWIN TESTBED FOR DOE-EM

Waste Handling

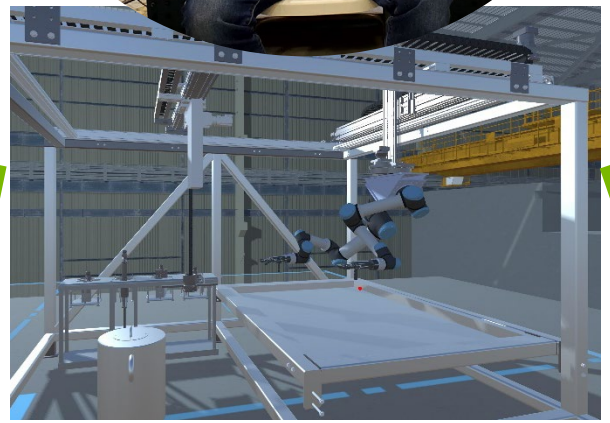


Robotic Digital Twin Platform

Inspection / Decontamination



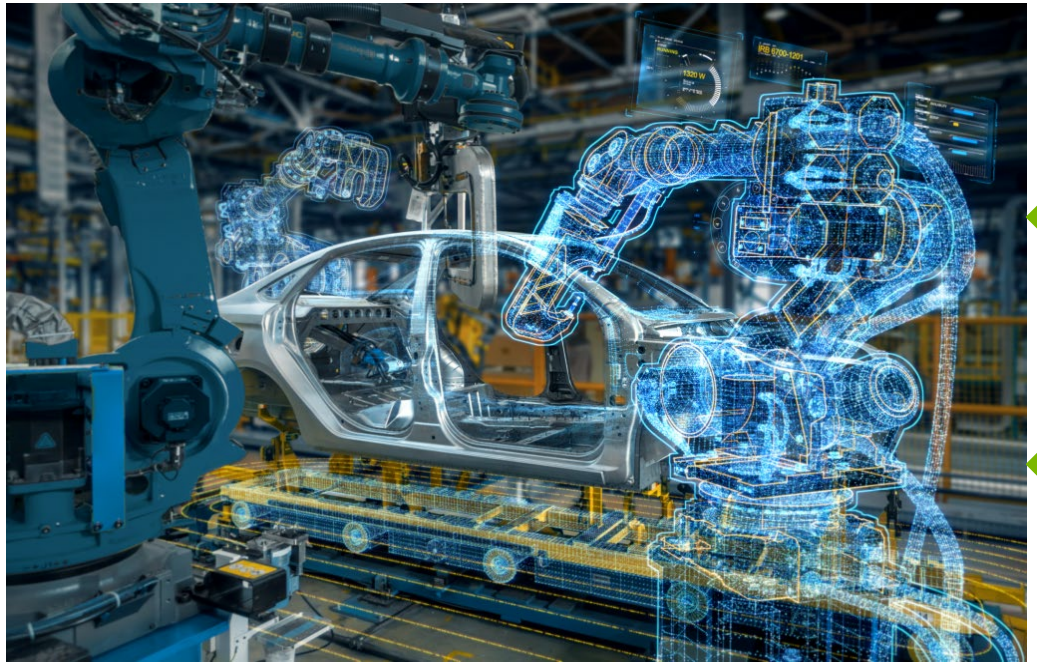
Dismantling



Repair

“Robotic Digital Twin” - Next generation robotics

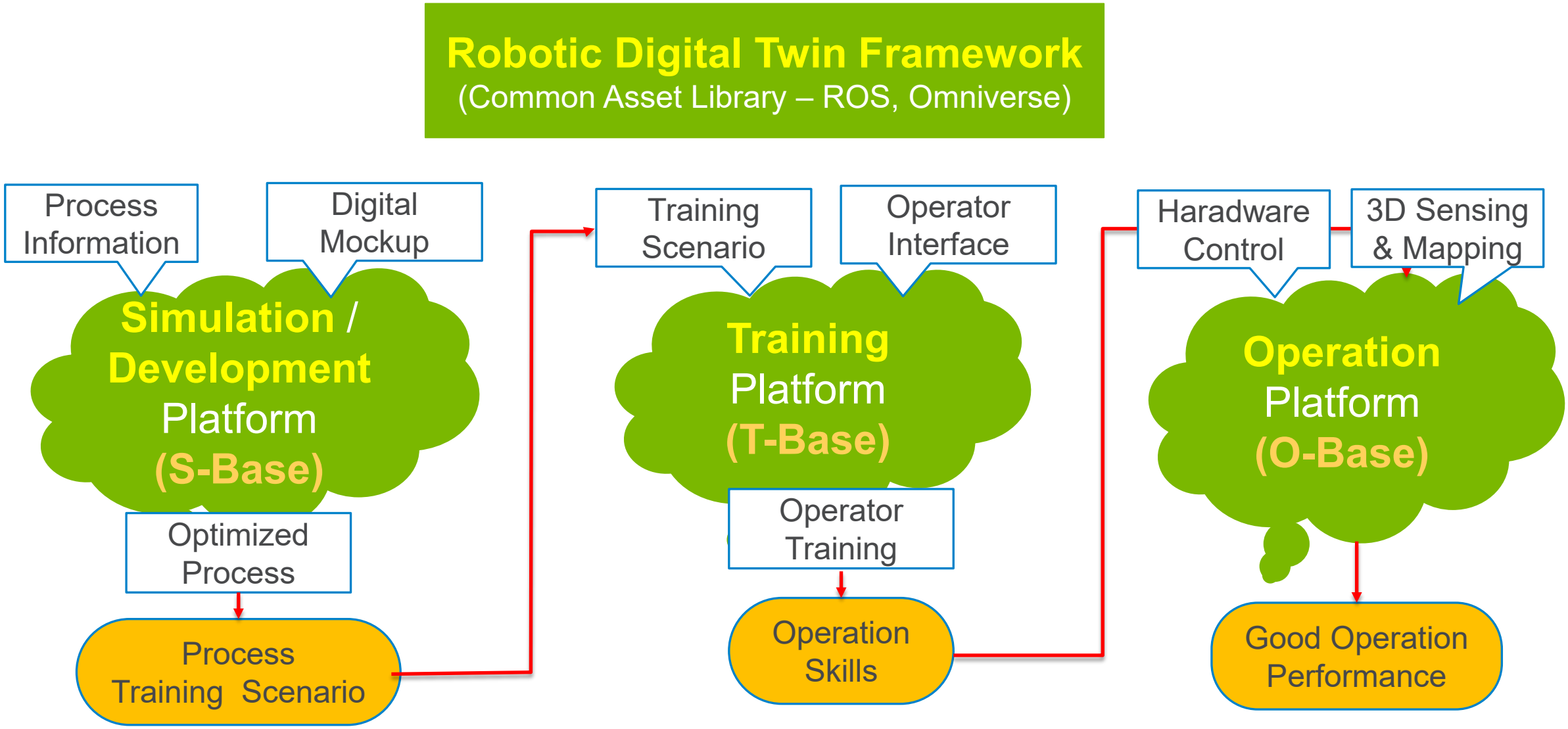
- Robotic deployment requires numerous test and verification.
  - However, it is difficulty to access the task environments.
- **Digital Twin**: Digital representation of a system in all its aspects of its life-cycle
  - Design / Prototyping
  - Training
  - Operations
  - Service and maintenance
  - Analysis
- **Robotic Digital Twin**
  - Integration of simulation, data exchange, and hardware control
  - AI



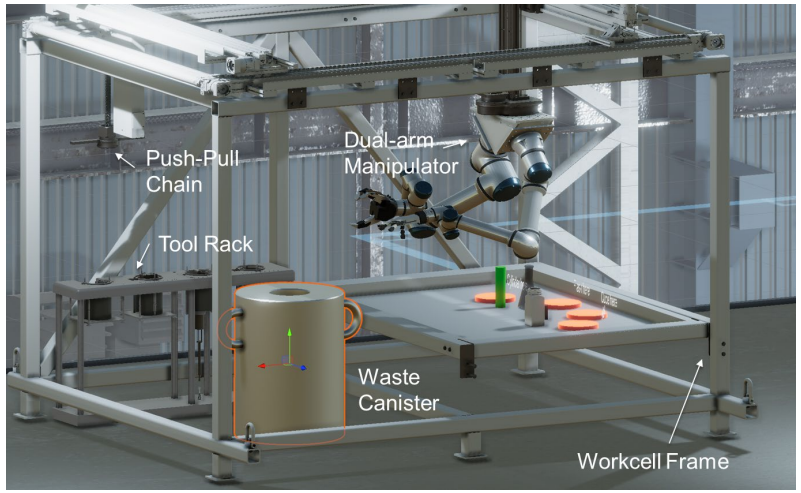
HIL

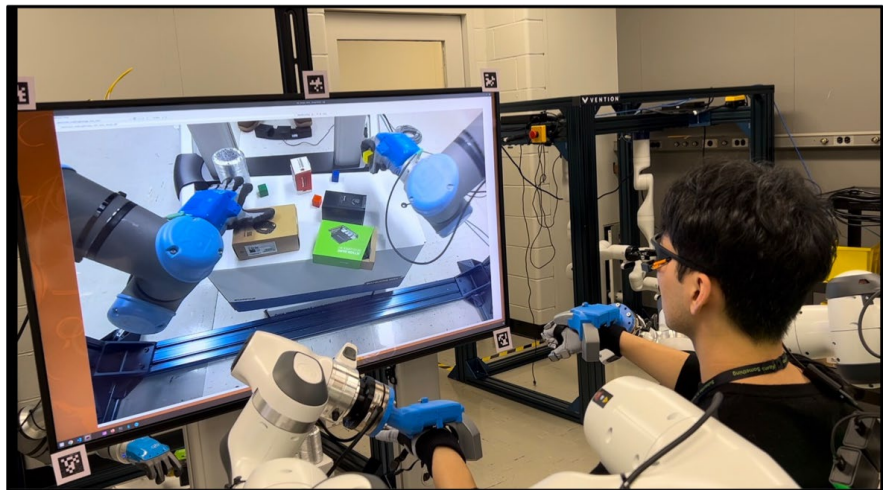
AI

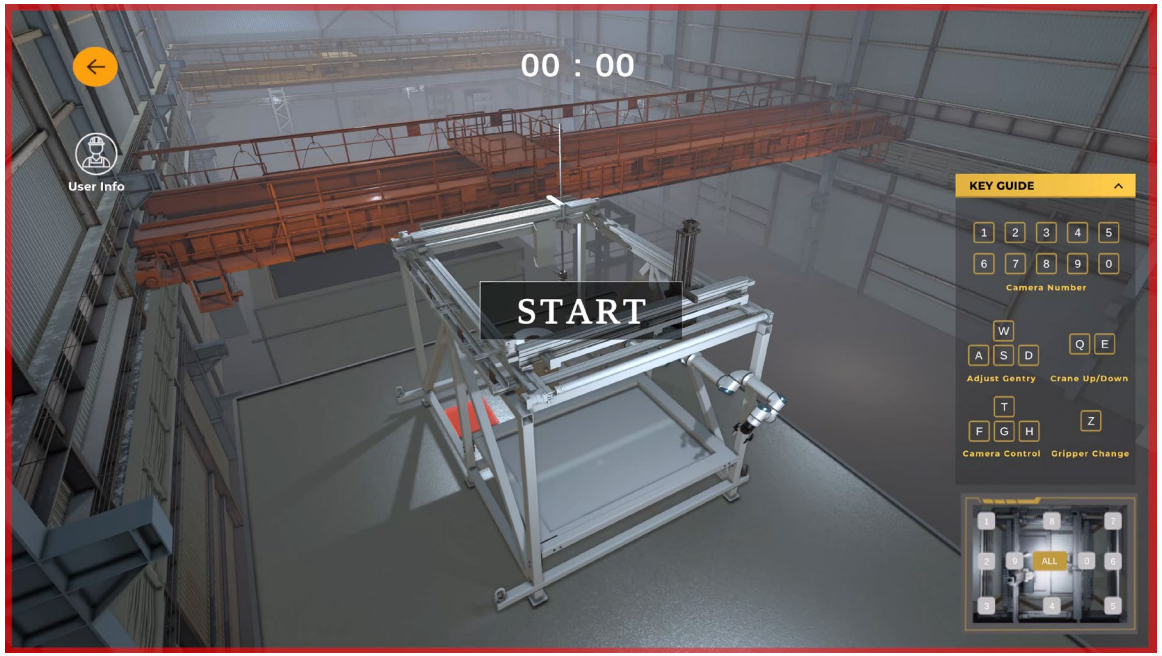
Robotic Digital Twin Platforms

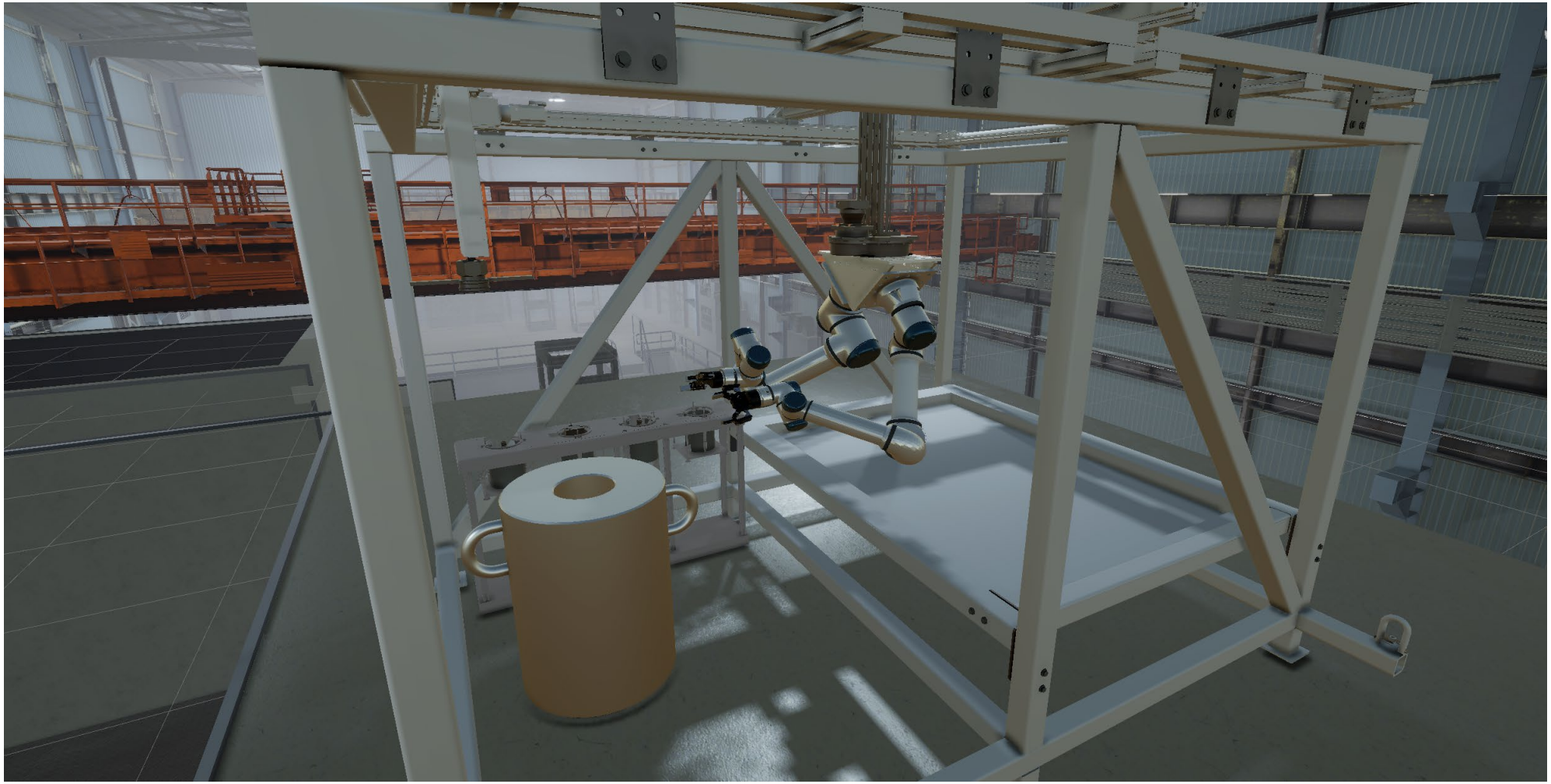


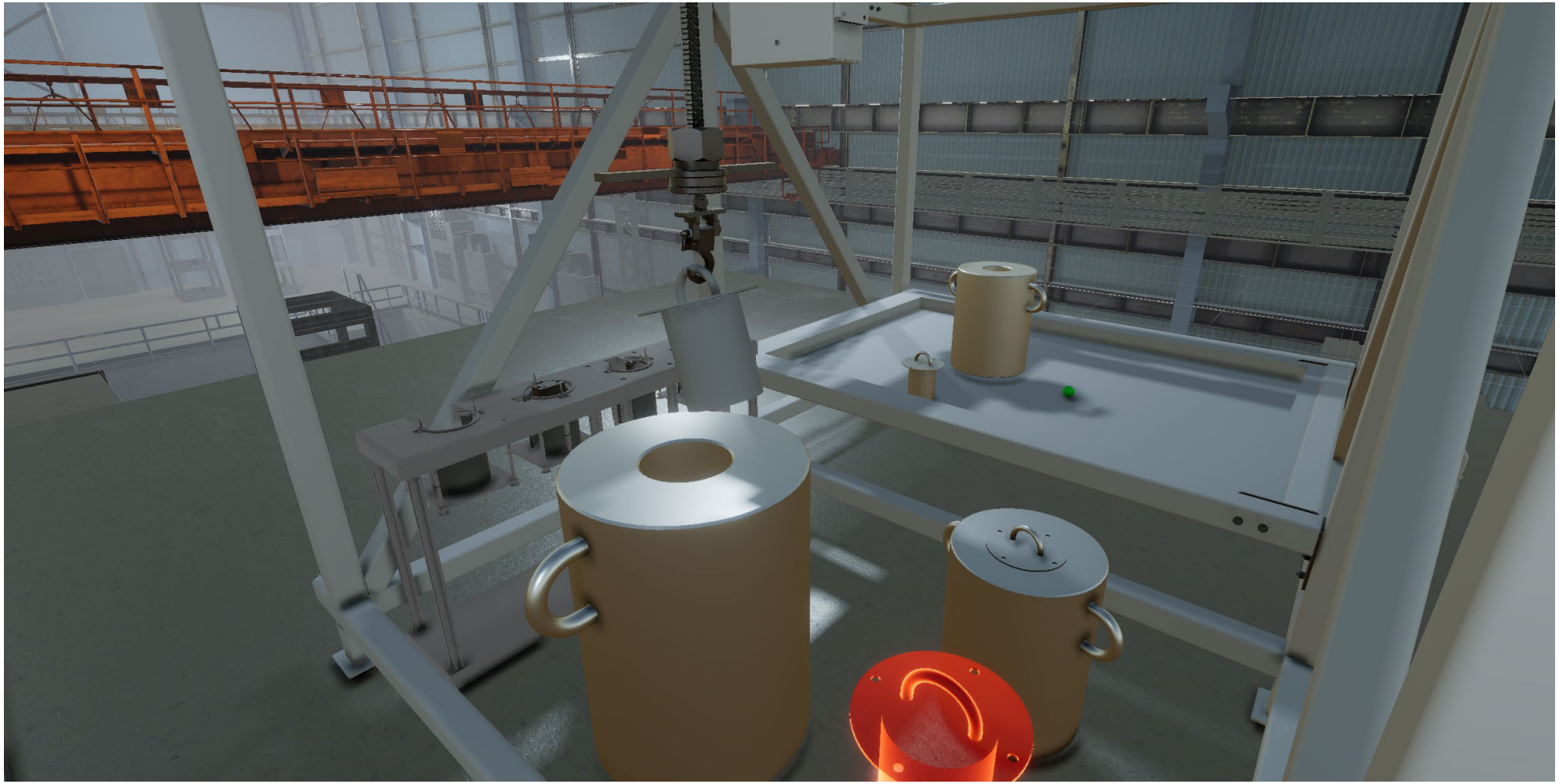
Example: Training Simulator Platform

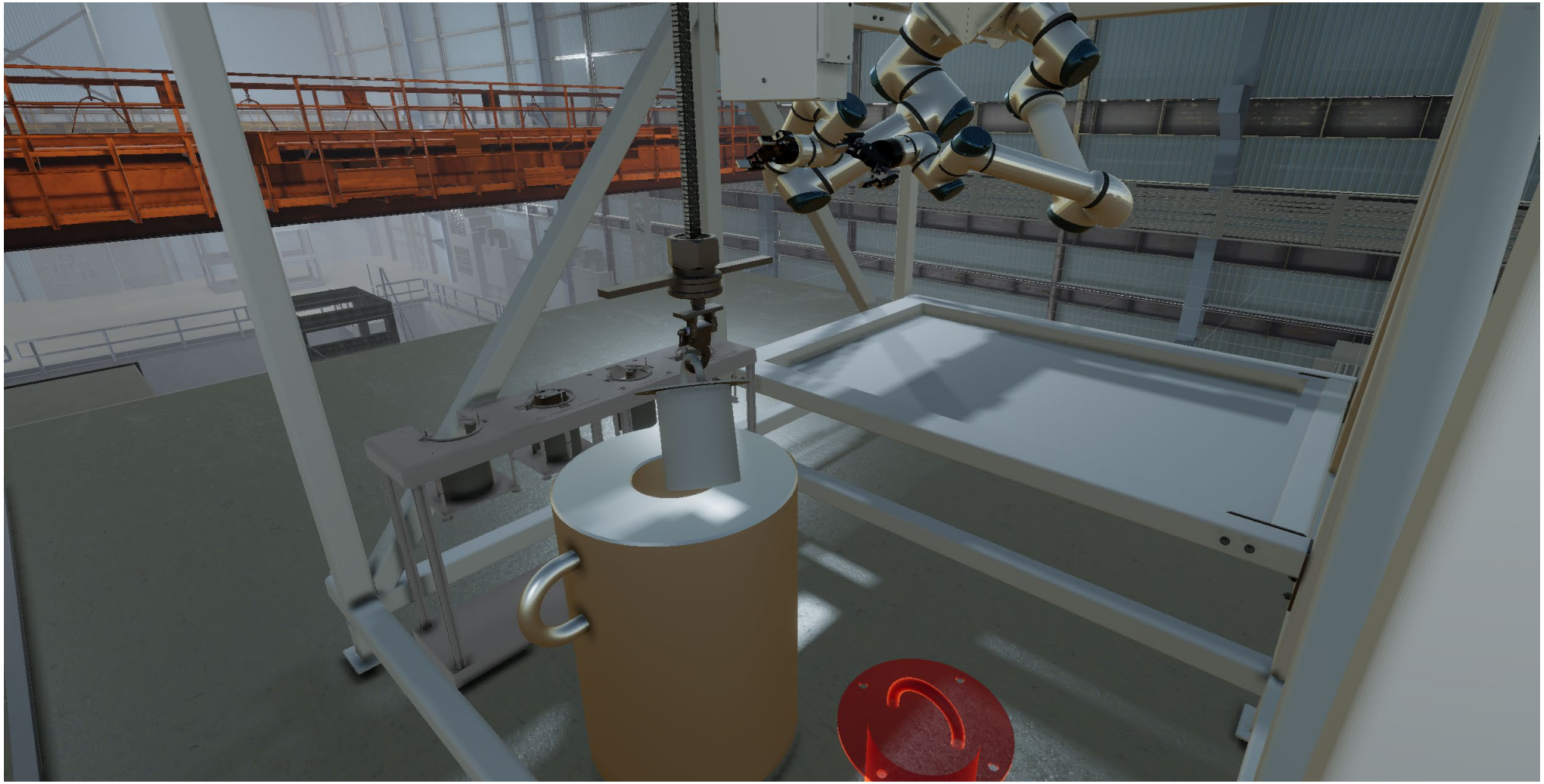






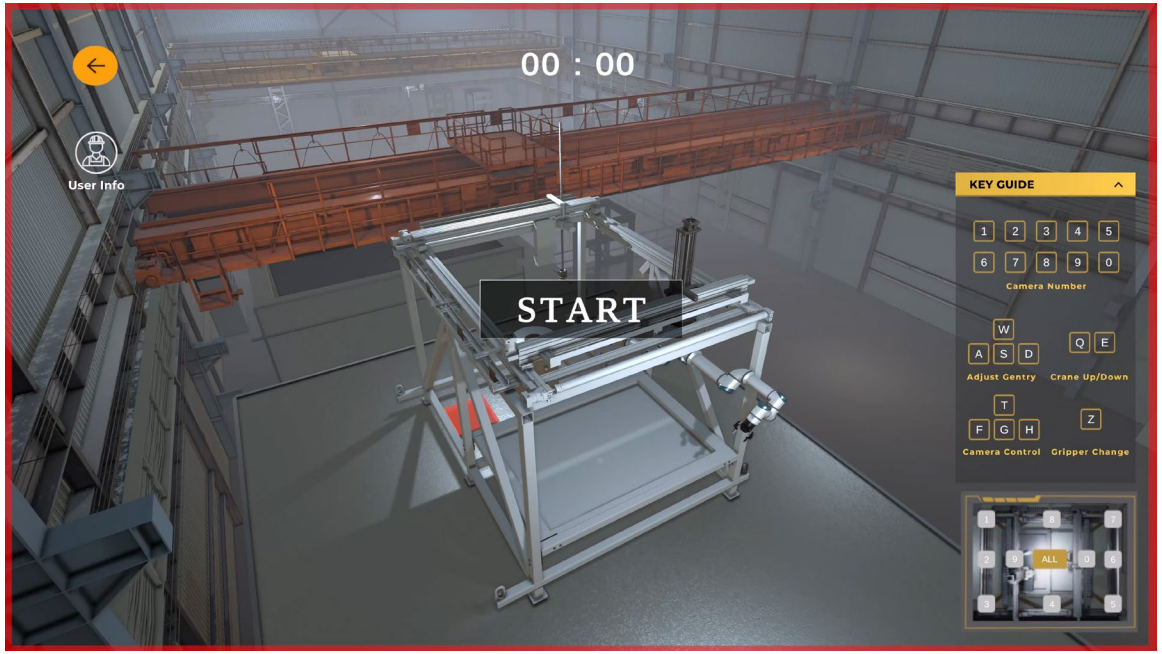


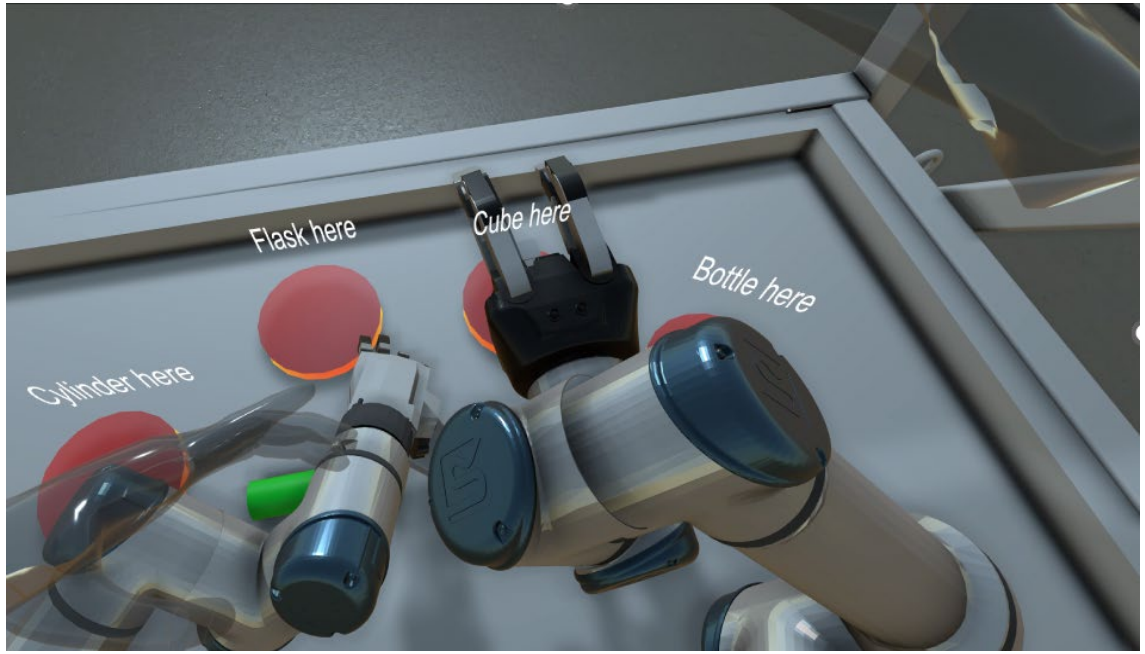




Training Simulator

- Training simulator is needed to help operators acquire operational skills, become familiar with the operational procedures, practice execution of task operation
- Allows practice both with real hardware and in mixed-reality environment
- **Status:** Enhancement of dual-arm simulation to allow effective contact gripping





Dexterous Manipulation

Grasp motion mapping

Haptic Feedback

- Hand Control