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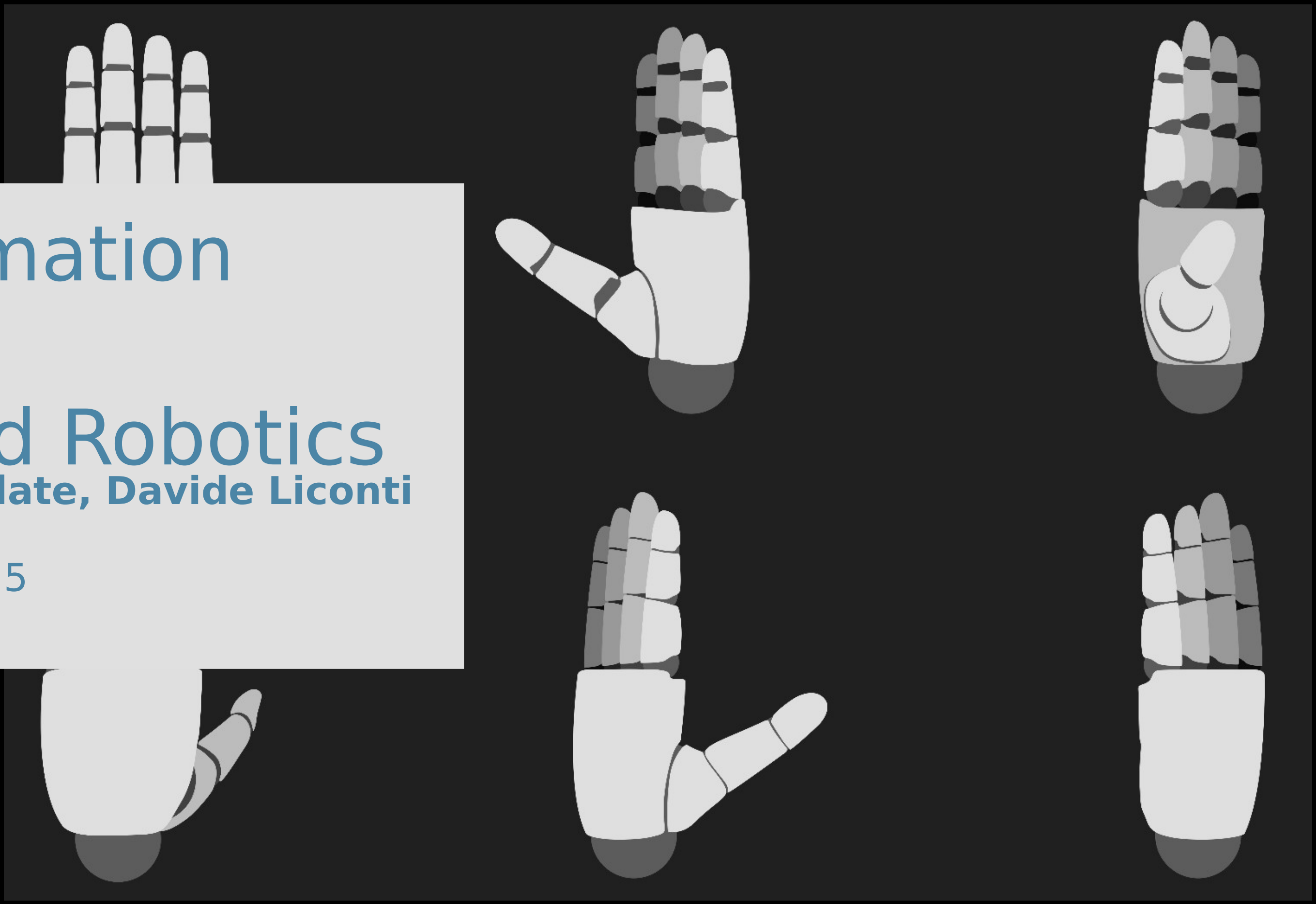

Key Information about Real World Robotics

Robert Jomar Malate, Davide Liconti

Unit 00 - 22.09.2025

Soft Robotics Laboratory

Class Structure

- Video Tutorials
  - → teach you the theoretical basics
  - uploaded one week prior to class
- Focus & Q&A Talk
  - → deepens your knowledge through discussions
  - post your questions on Moodle prior to class
  - Mondays, 14:15 - 15:00 @ CLA E4
- Workshop
  - → teaches you a practical skill useful to complete the challenge
  - Mondays, 15:15 - 16:00 @ workshop room
- The class will be public at *https://rwr.ethz.ch*

Class Structure

Group Challenge		
	Start Date	Due Date
Task 1 (RL)	October 20th	November 10th
Task 2 (IL)	November 3rd	December 8th
Task X (differet for each team)		December 15th

Individual Assignments		
	Start Date	Due Date
Ass 1 (Design and Fabrication)	September 29th	October 13th
Ass 2 (Control)	October 13th	October 27th
Ass 3 (Learning)	October 27th	November 17th

Class Syllabus

Class Day	Focus and Q&A Talk	Workshop	Assignments
22/09/2025	Course Introduction *Robert Katzschmann*	Project Management *Robert Jomar Malate*	
29/09/2025	Design of Robotic Hands, Prototyping and Fabrication Techniques for Robots *Robert Katzschmann*	ORCA Assembly, 3D-Printing *Filippos Katsimalis*	Assignment 1 release: *Palm CAD Design*
6/10/2025	Kinematics, dynamics, and control *Robert Katzschmann*	ORCA software *Aristotelis Sympetheros*	
13/10/2025	State-of-the-art Sensors in Dexterous Manipulation *Jaehoon Kim*	Sensor Practice *Habib Ben Abda*	Assignment 1 Due Assignment 2 release: *Simulation & Control*
20/10/2025	Simulation for Dexterous Manipulation *Yasunori Toshimitsu*	Simulation for RL *Esteban Padilla*	
27/10/2025	Reinforcement Learning *Chenyu Yang*	*Bridging sim-to-real gap* *Chenyu Yang*	Assignment 2 Due Assignment 3 release: *Robotics Learning*
3/11	Teleoperation and Object Detection *Robert Katzschmann*	Teleoperation and Data Collection *Davide Liconti*	
10/11/2025	Task 1 Due & Demostration *Robert Katzschmann and Staff*		
17/11/2025	Imitation Learning Theory and Foundations *Robert Katzschmann*	Imitation Learning in Software stack *Chenyu Yang, Davide Liconti*	Assignment 3 Due
24/11/2025	VLA Models and General Intelligence *Robert Katzschmann*	Practical Tips for Robotics Project Chenyu Yang, Davide Liconti	
1/12/2025	Guest Lecture *To be decided*	Project Check-Up and Q&A *Robert Katzschmann & Staff*	
8/12/2025	Task 2 Due & Demostration *Robert Katzschmann and Staff*		
15/12/2025	Task 2 Due & Demostration *Robert Katzschmann and Staff*		

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Note: Topics and content subject to minor change, link to spreadsheet will be on Moodle

Group Challenge

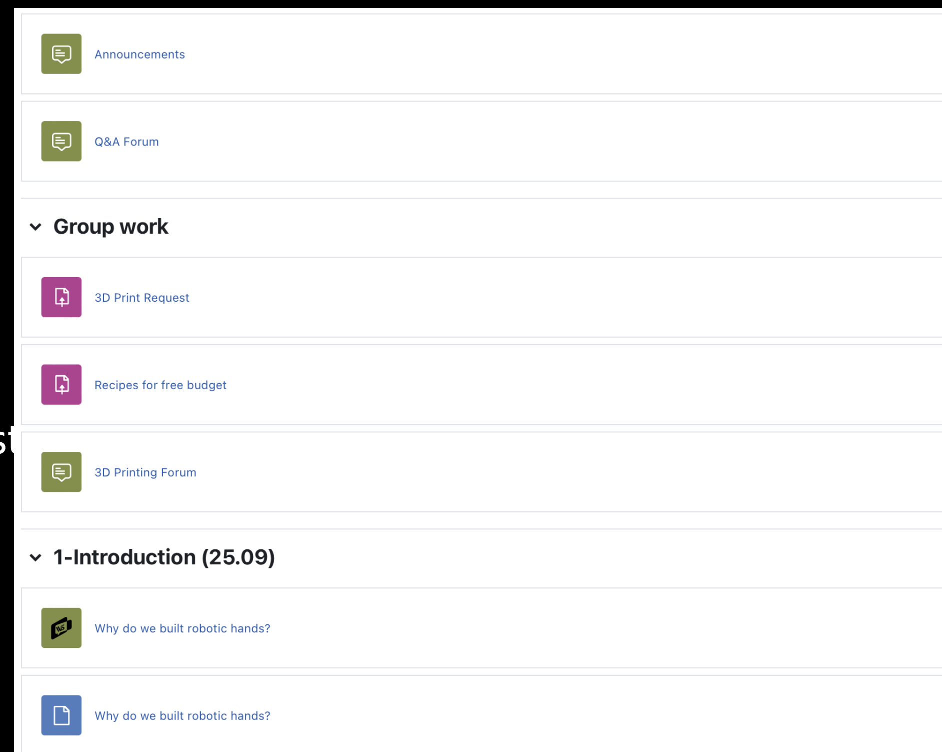
- **Assemble your own ORCA hand!**
- All hand materials are provided (3D printed parts, tendons, bearings, etc..)
  - A set of basic tools + 2 3D printers are provided

- Group size: 5 Students
  - Submit your preference on Google Forms

- Work in our classroom whenever you want!
  - One key per team → more information soon
  - Coffee Machine

Communication

- Moodle
  - Video tutorials, quizzes, …
  - Q&A forums for discussion
  - Announcements
  - Reimbursement request for free budget
  - Group forming
  - 3D printing submission
- Slack: https://rwr2025.slack.com
  - Preferred communication with TAs and st
- Website: rwr.ethz.ch
- Email the class team: rwr@srl.ethz.ch



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Team Formation

- **Today, September 22nd the acceptance decision will be out**. If you realize that you don't want to take the class let us know by the next few hours!!
- For the selected students, tomorrow September 23rd 5-7 PM there will be an Apero to meet your colleagues and form the teams. Then submit a google form with team and task preference by Wednesday September 24th
- Teams are formed based on student preference, task X preference and individual skills
- Final teams will be communicated on Friday, September 26th , along with the assigned Task X

Grading

Task	Type	Relative Weight	Absolute Weight
Challenge	**Group**		**70%**
Task 1 (RL)		33.3%	23.3%
Task 2 (IL)		33.3%	23.3%
Task X		33.3%	23.3%
Report	**Group**		**10%**
Assignments	**Individual**		**20%**
Ass 1		33.3%	6.7%
Ass 2		33.3%	6.7%
Ass 3		33.3%	6.7%
Attendance			**10%**
Total			**110%**

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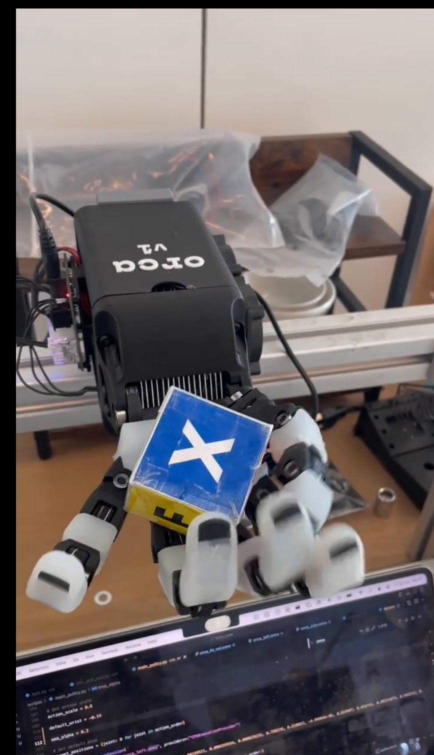
Task 1: Reinforcement Learning for in-hand reorientation

Goal: Train RL policy to rotate a cube in the hand

Tasks:
- Setup RL environment with Isaac lab
- Define reward function and train the policy
- Track the cube rotation angle in the real world (Will be provided)
- Apply sim2real techniques to have a robust policy

Metric: number of success (reach next target angle) in a given time

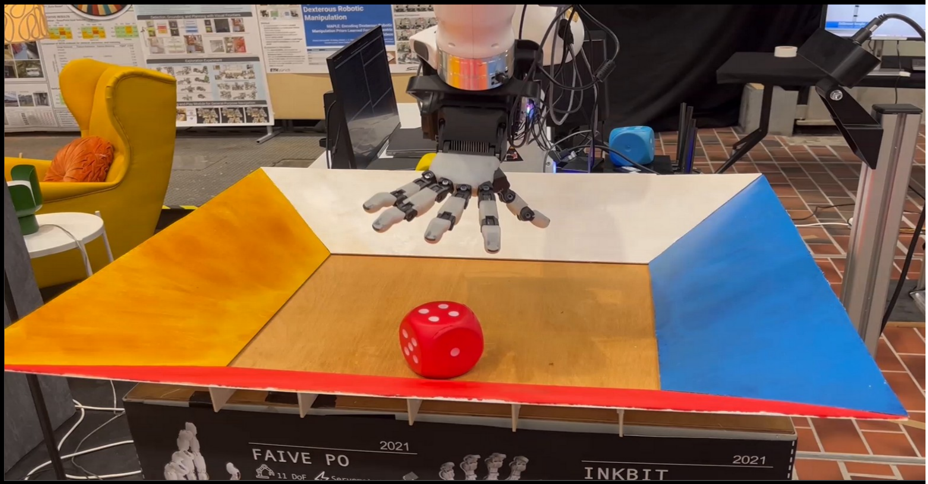


Task 2: Color-based sorting with imitation learning

Goal: Train IL policy to pick-and-place objects based on colors

Tasks:
- Collect an extensive dataset of demonstrations
- Setup the IL training and train policy
- Deploy policy in the real world

Metric: number of successful relocations in a given time



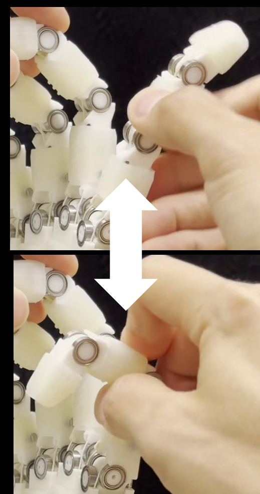
Task X.1: Upgrade the Motors and the Actuation Tower of the ORCA Hand

Task Description:
Dynamixel motors are well-suited for rapid prototyping due to their ease of use and straightforward control interface. However, for production scenarios, higher-performance motors are required. This task focuses on integrating Faulhaber motors and designing a new actuation tower to support them. In parallel, a dedicated software API will be developed to enable reliable and flexible motor control.

Expected Results:
Show effective motor integration, calibration and usage. Teleoperation of the hand can be used to effectively showcase the hardware integration and control.

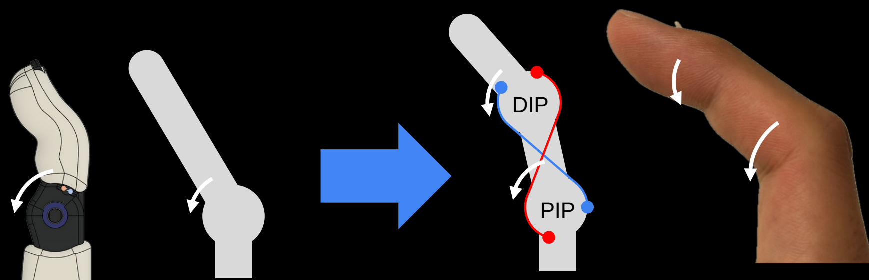
Task X.2: PIP-DIP coupling to improve manipulation capability

Example: PIP-DIP coupling on the mimic hand



Task Description:
The proximal interphalangeal (PIP) and distal interphalangeal (DIP) joint of human fingers are coupled at approximately [1]. The two joints move together, working as one DoF. Modify the ORCA hand hardware to implement a mechanism to achieve this coupling and show that it improves the manipulation capability.

Expected Results:
- A full ORCA hand hardware implementing the PIP-DIP coupling
    - the method for coupling can be the same or different from what is shown here).
    - the coupling ratio should be based on biomechanical measurements
- A task demonstrating how the additional joint with coupling improves manipulation capability of the hand
    - e.g. it can grasp smaller cylinders more robustly
    - control method can be anything- teleop, RL, IL, hardcoded etc.



One possible method using passive tendons to implement this coupling
(note: this is not how it works in humans: we do not have criss-crossing tendons. For an alternative, highly biomimetic approach, see [2].)

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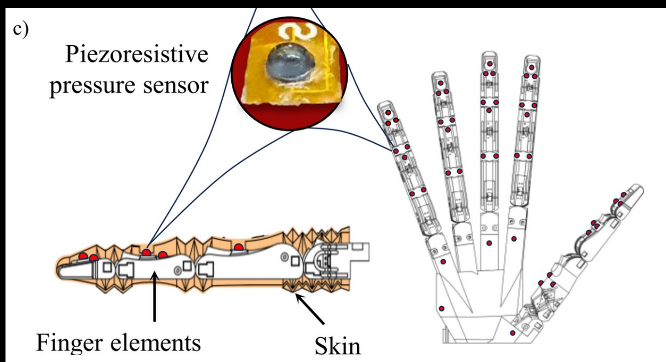
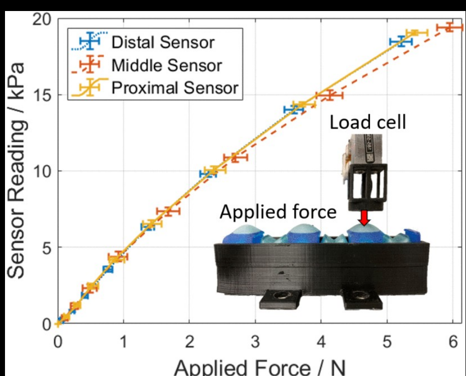
1. Nimbarte AD, Kaz R, Li ZM. Finger joint motion generated by individual extrinsic muscles: a cadaveric study. J Orthop Surg Res. 2008 Jul 11;3:27. doi: 10.1186/1749-799X-3-27. PMID: 18620584; PMCID: PMC2483967.
2. Shirafuji S, Ikemoto S, Hosoda K. Development of a tendon-driven robotic finger for an anthropomorphic robotic hand. The International Journal of Robotics Research. 2014;33(5):677-693. doi:10.1177/0278364913518357

Task X.3 : Fingertip Tactile Sensors for Desired Force Output





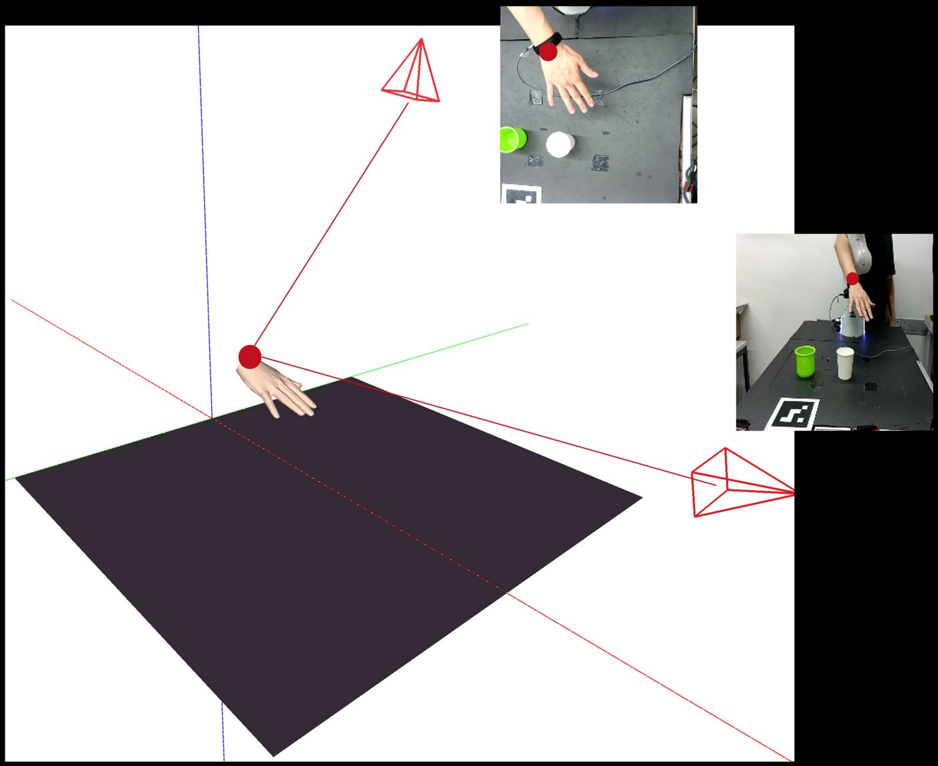
[1] J. Egli, B. Forrai, T. Buchner, J. Su, X. Chen and R. K. Katzschmann, "Sensorized Soft Skin for Dexterous Robotic Hands," 2024 IEEE International Conference on Robotics and Automation (ICRA), Yokohama, Japan, 2024, pp. 18127-18133.
[2] O. Shorthose, A. Albini, L. He and P. Maiolino, "Design of a 3D-Printed Soft Robotic Hand With Integrated Distributed Tactile Sensing," in IEEE Robotics and Automation Letters, vol. 7, no. 2, pp. 3945-3952, April 2022.

Task Description:
Robotic hands require tactile sensors to achieve precise and reliable manipulation. This project follows the research process of developing and integrating tactile sensors, including sensor design, calibration, data processing, and application. The goal is to enable the robotic hand to achieve higher dexterity and robust performance in real-world manipulation tasks.

Expected Results:
Potential outcomes include, but are not limited to:
1. Development of a Fingertip Tactile Sensor for the Orca Hand:
- Design and fabrication of the tactile sensor
- Firmware and code for reading tactile data on a microcontroller (e.g., STM32, Arduino) or a single-board computer (e.g., Raspberry Pi)
- A software package for sensor data processing
- Setup for dataset collection to support sensor calibration
- Development of a force estimation algorithm

2. Additional Demonstrations Leveraging the Tactile Sensor:
- A fingertip controller capable of tracking the desired force trajectory
- Manipulation of fragile objects

Task X.4: Real Time RGB-only Teleoperation



Task Description
Current teleoperation methods for dexterous robotic hands typically rely on motion capture gloves or specialized hand-tracking devices (e.g., AVP). This task proposes an alternative approach that leverages state-of-the-art hand pose estimation algorithms, combined with traditional vision techniques, to enable teleoperation of a dexterous hand mounted on a Franka arm using only two RGB cameras (e.g., two iPhones).

Expected Results
Demonstrate the reliability and robustness of the system through a live teleoperation demo, showcasing accurate hand pose tracking and seamless control of the robotic hand.

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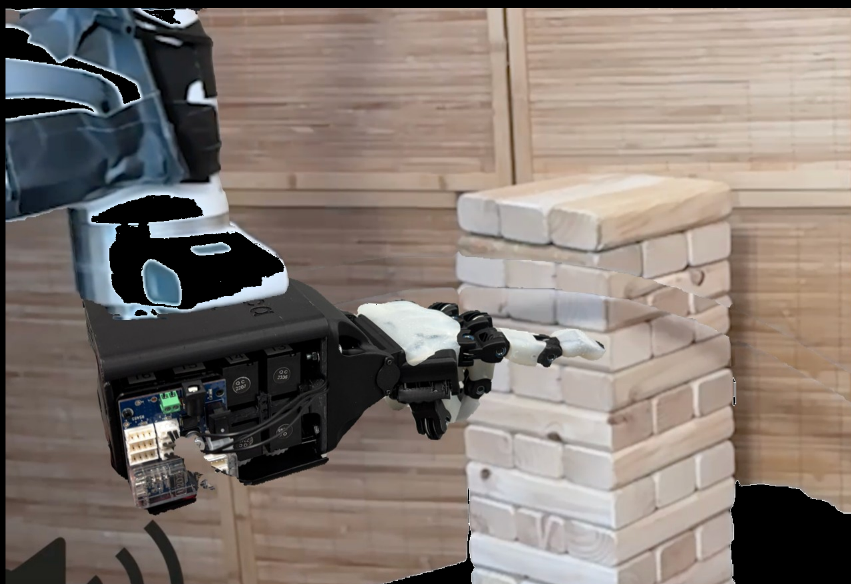
Task X.5 : Robot Playing Jenga in the Real World with RL



Reference: HIL-SERL: Precise and Dexterous Robotic Manipulation via Human-in-the-Loop Reinforcement Learning

Task Description:

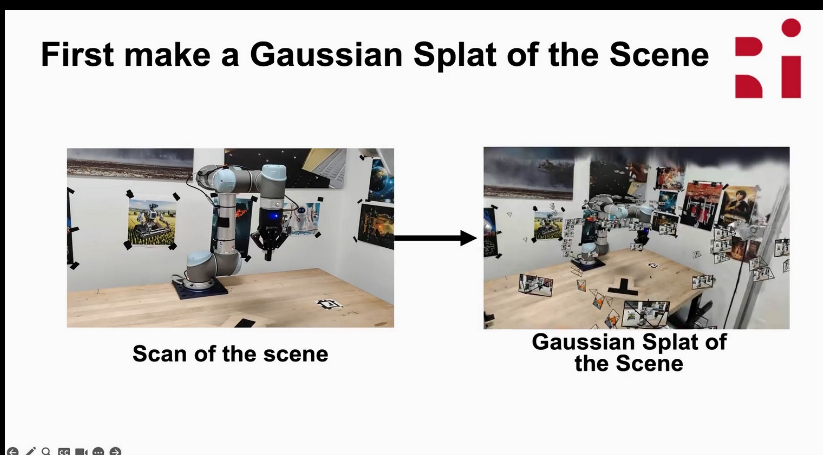
Train a reinforcement learning (RL) manipulation policy to play Jenga in the real world. This task represents a challenging benchmark in robotic manipulation, as it requires extremely high precision, fine motor control, and coordinated decision-making.

Expected Results:

The trained policy will be able to autonomously remove Jenga blocks with image input (no April tag or similar).

- The Jenga tower will be placed at a randomized position.
- Use orca hand, any hand posture is ok.
- The success rate of pushing one block off a full Jenga tower should be greater than 50%.

Task X.6: Digital Twin with Gaussian Splatting



Task Description:
Most current simulation frameworks fall short in providing the level of photorealism required for training visuomotor policies. This project proposes leveraging **3D Gaussian Splatting (3DGS)** to reconstruct a highly realistic digital replica of a real-world scene, and then using this simulated environment to train an autonomous manipulation policy.

Expected Results:
Potential outcomes include, but are not limited to:
- **Zero-shot sim2real transfer**: using the photorealistic digital twin to train policies in simulation and directly deploy them on real robots, reducing the sim-to-real gap
- **Evaluation of real-world policies in simulation**: providing a safe, controlled environment for testing and benchmarking learned policies before deployment.

Teaching Team

Prof. Robert Katzschmann
Lead Organizer

Dr. Ronan Hinchet
Sr. Scientist @ SRL

Yasunori Toshimitsu
PhD @ SRL

Chenyu Yang
PhD @ SRL

Davide Liconti
PhD @ SRL

Jaehoon Kim
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Robert Jomar Malate
Lead Teaching Assistant

Aristotelis Sympetheros

Filippos Katsimalis
Teaching Assistant

Habib Ben Abda
Teaching Assistant

Esteban Padilla Cerdio