Robust Learning of Sequential Motion from Human Demonstrations to Enable Robot-guided Exercise Training

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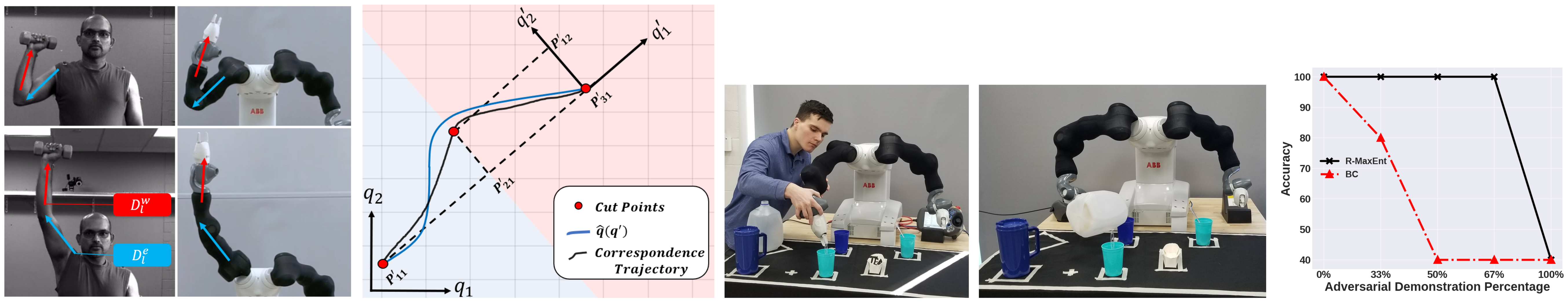
Introduction

The project has three goals: 1) designing a low-level LfD framework to learn robust trajectory only from kinematic variables of motion, 2) designing a high-level LfD framework to learn task structure while accommodating inter-demonstration variability, and 3) leveraging these two Lfd frameworks to learn therapeutic exercises from therapist's demonstrations, and evaluating the feasibility of LfD-enabled robots in the wild.

Progress Summary

Goal 1. Low-level LfD framework: We developed a dynamic system based approach for trajectory learning – namely, Phase Space Model (PSM) – that is robust to temporal and spatial perturbation, minimizes energy and torque-change, and inherently offers a way to quantitatively evaluate the reproduced motion. The iterative development of PSM has produced full papers in ICRA 2019, IROS 2020, IROS 2021, and ICRA 2023.



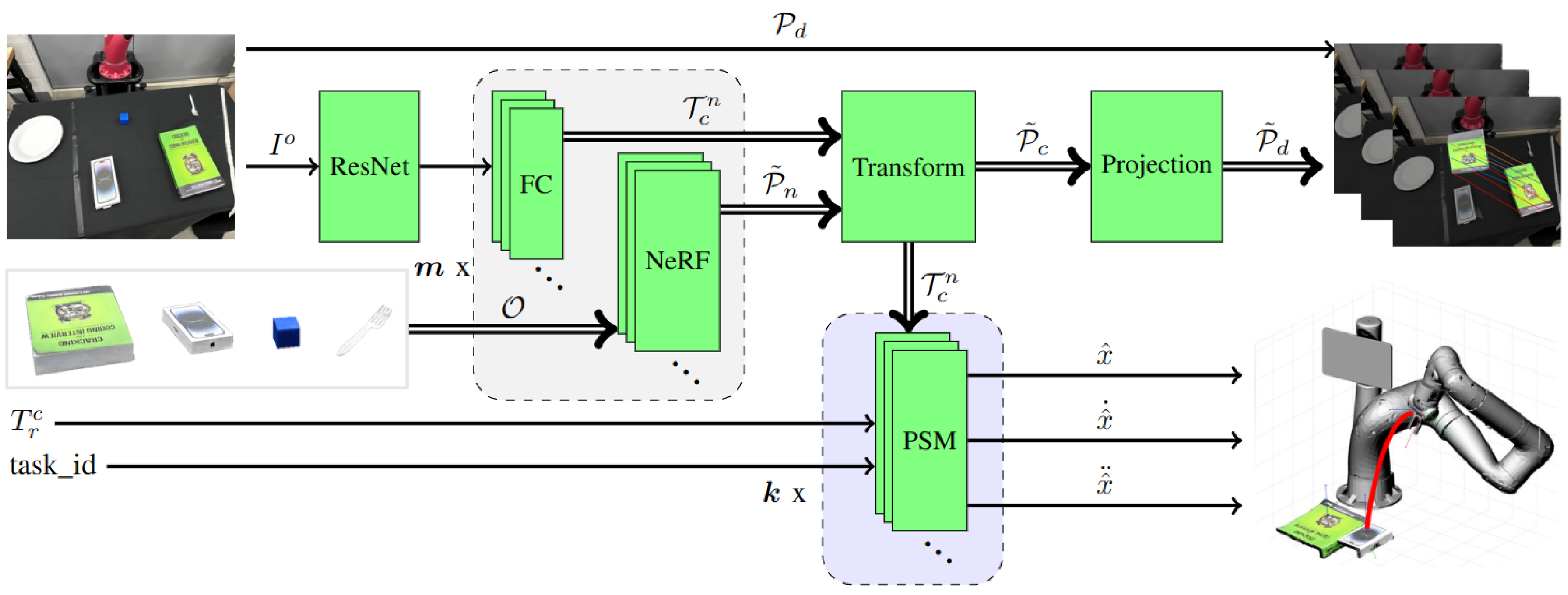
Evaluation of Low- and High-level LfD framework with a YuMi robot for learning therapeutic exercises and a tea-making task

Goal 2. High-level LfD framework: We developed a BC framework – namely, Robust Maximum Entropy (R-MaxEnt) – that analyzes entropy to identify erroneous demonstrations in order to learn robust policy. The work has produced a full paper in IROS 2021.
Goal 3. Feasibility Study: The goal of the feasibility study is to investigate if a PSM-enabled robot can serve as a 'digital-twin' of a therapist for helping patients with motor impairments. We completed the first phase of the study to determine how faithfully – with respect to smoothness, velocity, and accuracy – the robot can reproduce therapists demonstrated upper-extremity exercises. A video-based evaluation completed by more than 100 practicing therapists across the US reports the percent agreement for joint motion between demonstrator and robot to be 84%-88%. In the next phase, the PSM-enabled robot will guide patients to perform the same set of exercises. A high motion agreement between these patients and the original demonstrators will indicate effective motion transfer from therapist to patient via LfD-enabled robots – a first of its kind

A New Direction: Learning Motion Trajectory and Task-structure from Visual Demonstrations

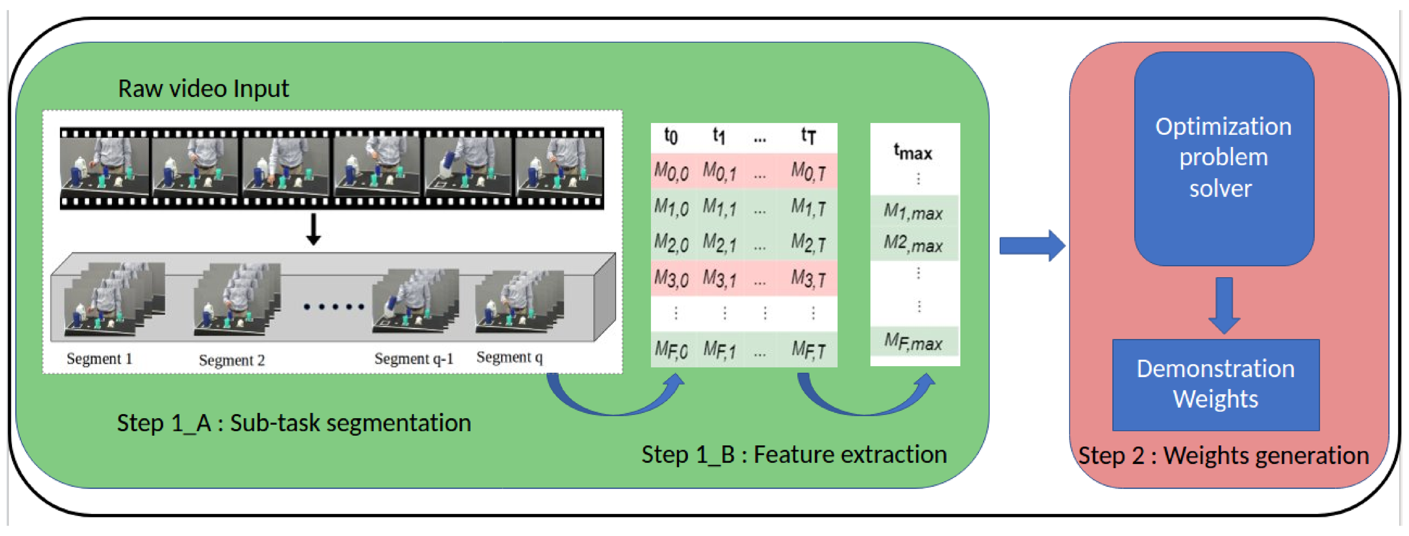
Self-Supervised Visual Motor Skill Learning via NERF

- Novel network architecture for visual imitation learning that exploits neural radiance fields (NeRFs) and key-point correspondence for self-supervised visual motor policy learning
- Incorporates a dynamic system output layer for stable policy learning
- Combining NERF perception with DS stability yields a policy that is invariant to significant clutter, occlusions, lighting conditions changes, and spatial variations in goal configurations.



Detecting Incorrect Visual Demonstrations

- In Lfd research, a typical assumption is that the expert always provide correct demonstrations. Despite theoretical convenience, it has limited practical value.
- Only a handful of LfD frameworks consider sub-optimal demonstrations. However, all of them assume prior knowledge about which demonstrations are sub-optima.
- We are interested in directly learning a sample-efficient policy after autonomously identifying and discarding adversarial demonstrations from the training set.



#Seq_1	#Seq_2	Accuracy	Recall	Precision
10	1	90	100	67
10	2	92	100	80
10	4	85	100	80
10	6	81	100	80
10	8	83	100	84
Average		**86%**	**100**	**78**

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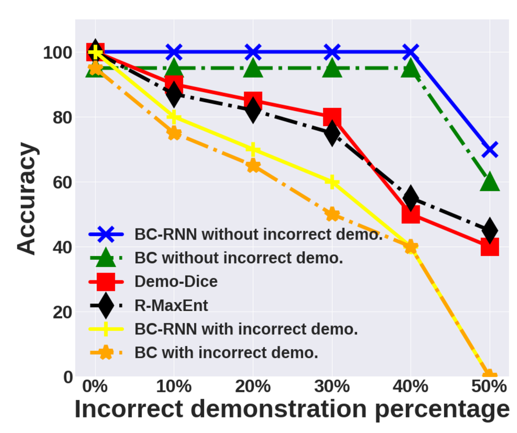
#Seq_1	#Seq_3	Accuracy	Recall	Precision
10	1	90	100	67
10	2	92	100	80
10	4	93	100	89
10	6	88	100	86
10	8	89	100	89
Average		**90%**	**100**	**83**



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