Personalized H-R Interaction through Adaptive Motion Mapping

Shahar Golan*
sgolan38@haifa.ac.il
Department of Computer Science
University of Haifa
Haifa, Israel

Daniel Bobritski†
dbobritsk@staff.haifa.ac.il
Department of Computer Science
University of Haifa
Haifa, Israel

Roi Poranne‡
roi.poranne@ds.haifa.ac.il
Department of Computer Science
University of Haifa
Haifa, Israel

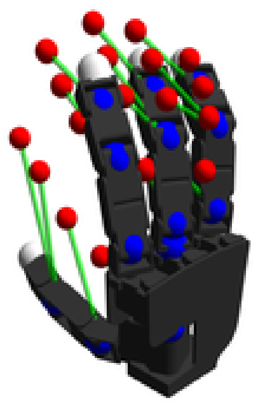

Figure 1: Mapping human hand joints (red) to robotic hand links (blue).

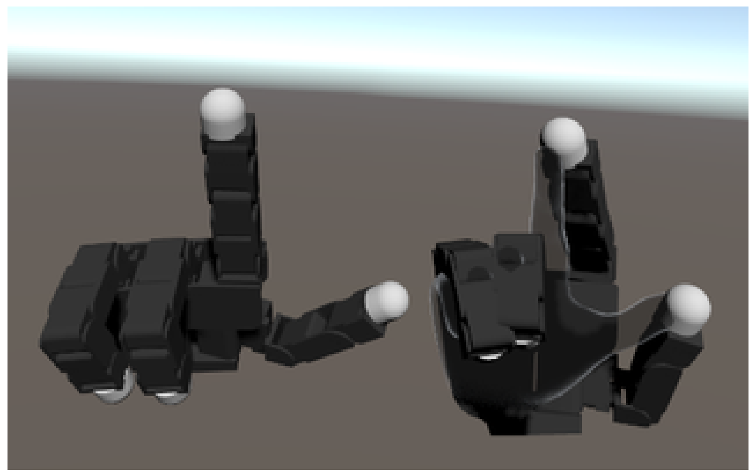

Figure 2: User mimics the static hand to match the target pose.

Abstract

Robotic teleoperation is advancing rapidly with virtual reality (VR) and real-time motion tracking, creating more natural and immersive human–robot interactions. However, many systems still assume all users behave the same, overlooking differences in skills, preferences, and interaction styles. Our goal is to develop a VR system that adapts to each user, rather than forcing them to adapt to the robot. Using a VR interface and motion mapping, the system connects human hand movements to a robotic hand for both real-time mirroring and guided pose replication. Through controlled experiments, we observed how participants naturally perform gestures and imitate specific target poses. By identifying patterns in these behaviors, we seek to group users by interaction style and ultimately enable adaptive control that adjusts in real time to improve comfort, accuracy, and overall task performance.

1 Introduction

Motivation. In recent years, human-robotic interaction has evolved from the realm of science fiction into reality. From LLM's, AI agents, and even a walking Tesla robot, autonomous systems are increasingly integrated into households and workplaces. Despite these advances, a fundamental question remains: *How can we design robotic systems that adapt to individual users rather than forcing users to adapt to the robot?*

Current robotic systems typically assume uniform user behavior and capabilities. However, humans exhibit significant variability in their motor skills, cognitive processes, and preferences for interaction. This variability comes from various factors including physical differences, cultural background, previous technology experience, and individual learning styles. Traditional robotic interfaces often require extensive user training and adaptation periods, leading to frustration and reduced task performance.

Use case example. Imagine being asked to use a robotic hand that mirrors your gestures to pick up an apple and place it on a shelf. Many users may fail on the first attempt but succeed on following tries. This improvement reflects the human brain's ability to adapt to the robot's behavior. Our project explores the opposite approach—*adapting the robot to the user's behavior.*

Challenge. The challenge lies in accounting for not only physical differences (e.g., palm size, finger length, hand width) but also genetic and cultural factors that may cause two people with identical hand dimensions to use the robot differently. Furthermore, weighing mapping accuracy for each joint introduces run-time latency and creates *competition* between robot links, where optimizing one joint may negatively impact neighboring joints.

Goals. Find the lowest possible number of clusters that can effectively group users based on their behavioral patterns with the robotic hand. In the long term, our aim is to develop an algorithm that adjusts the robot's motion mapping in real time to maximize task accuracy for each user.

2 The Demo

System Architecture. Our teleoperation system bridges human hand motion with robotic control through a VR-based interface coupled with real-time inverse kinematics. The architecture consists of two primary components: a Unity-based client that captures hand-tracking data and a C++ server that processes this data for robotic control. The client utilizes hand-tracking APIs to capture absolute positions and orientations of 20 hand joints at 60 FPS, transmitting this data in real time to the server where an inverse kinematics algorithm maps human joint coordinates to the corresponding links of an Allegro robotic hand.

Experimental Design. The experimental setup incorporates two robotic hands that serve complementary purposes in evaluating human-robot interaction patterns:

(1) **Active Robot Hand** – Mirrors the user's hand movements in real time through the mapping algorithm, enabling natural interaction where participants can observe immediate visual feedback of their gestures translated into robotic motion.
(2) **Static Robot Hand** – Displays a sequence of 15 predefined target poses that participants are instructed to replicate, providing a controlled baseline for evaluating gesture accuracy.

The static robot hand displays a sequence of 15 predefined target poses (see Figure 3) that participants are instructed to replicate, providing a controlled baseline for evaluating gesture accuracy.

This dual-robot configuration allows us to observe two distinct behavioral patterns: natural interaction through direct motion mirroring and task-driven imitation, where users adapt their movements to match specific target configurations. Examples of target poses include basic hand positions (Figure 1) and specific gestures such as pointing upward (Figure 2).

Data Collection. When a static pose is displayed, the user attempts to replicate it with their own hand. Each attempt is recorded for 120 frames ($\approx$ 2 seconds) at 60 FPS, capturing both:

- **Position:** 3D Cartesian coordinates (x, y, z) for each joint.
- **Orientation:** unit quaternions (x, y, z, w) representing the local rotation of each joint.

Figure 3: Poses present to the participants

The continuous recording of joint positions and orientations enables the construction of comprehensive user profiles that capture individual characteristics across multiple dimensions. These profiles contain personal data such as age/sex/gender/occupation and a self-assessment of VR experience.

Analysis. After collecting samples from several users, we compared their hand rotations to assess pose stability and consistency. For each joint, we calculated the mean and standard deviation across a 120-frame recording window. Rotation differences were measured using a quaternion-based angular distance metric, yielding values between 0° and 180°. This allowed us to identify individual movement strategies and user-specific patterns that could guide adaptive control algorithms.

References.