Collaborative Control for Wearable Robots

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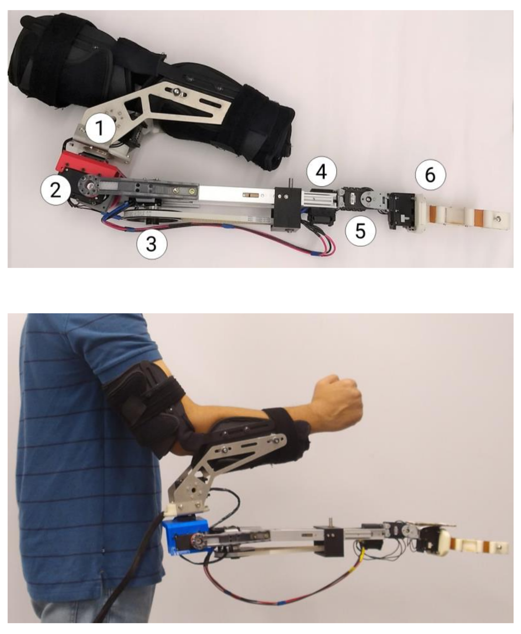
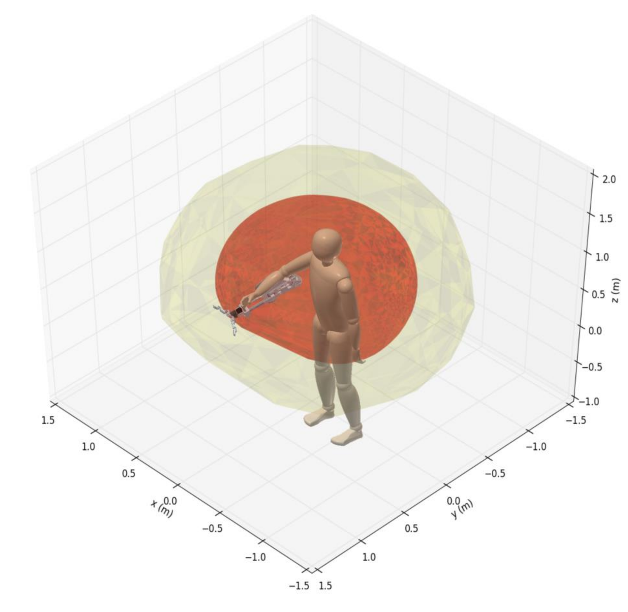
Overview

In this project, we are investigating the human interaction aspects of an autonomous supernumerary **wearable robotic forearm** (WRF). Following the design, kinematics, and biomechanics analyses of the device ([1-2]), ongoing work includes human-robot collaboration experiments, and methods for compensation of the robot's pose against disturbances from the wearer's motion.

Indicative usage scenario: collaborative assembly



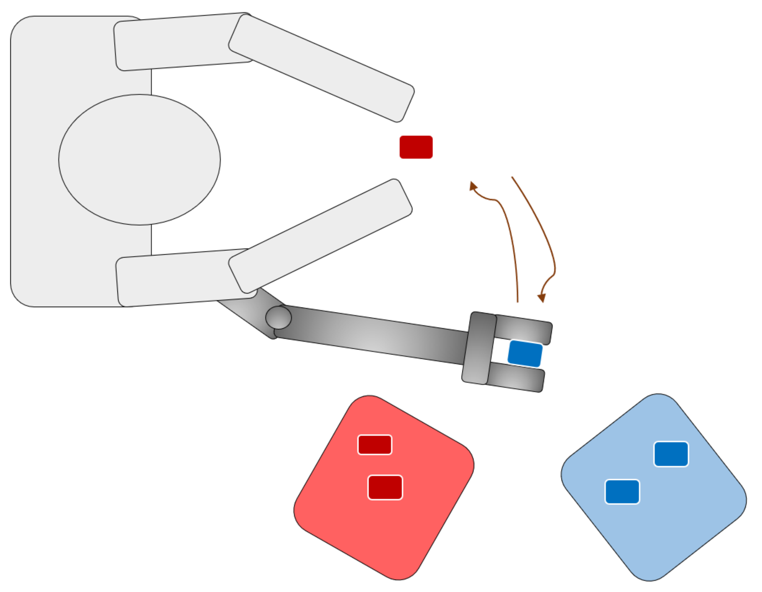
The WRF with five degrees-of-freedom, plus a gripper



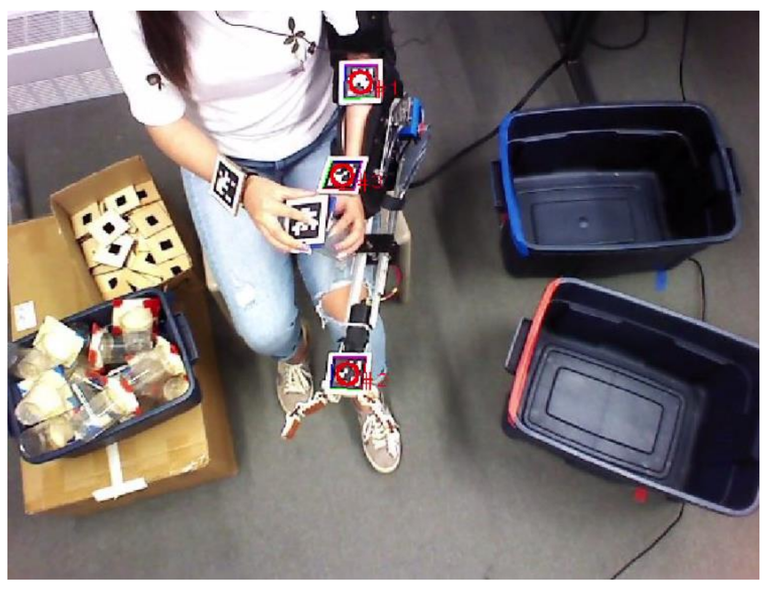
Enhancement in workspace volume afforded by the WRF

Human-Robot Collaboration

To study the close-range collaboration and mutual adaptation with the WRF, we conducted trials involving a pick-and-place activity. Participants would assemble lids onto color-coded cups, and pass them off to the WRF which would drop them into appropriate bins.

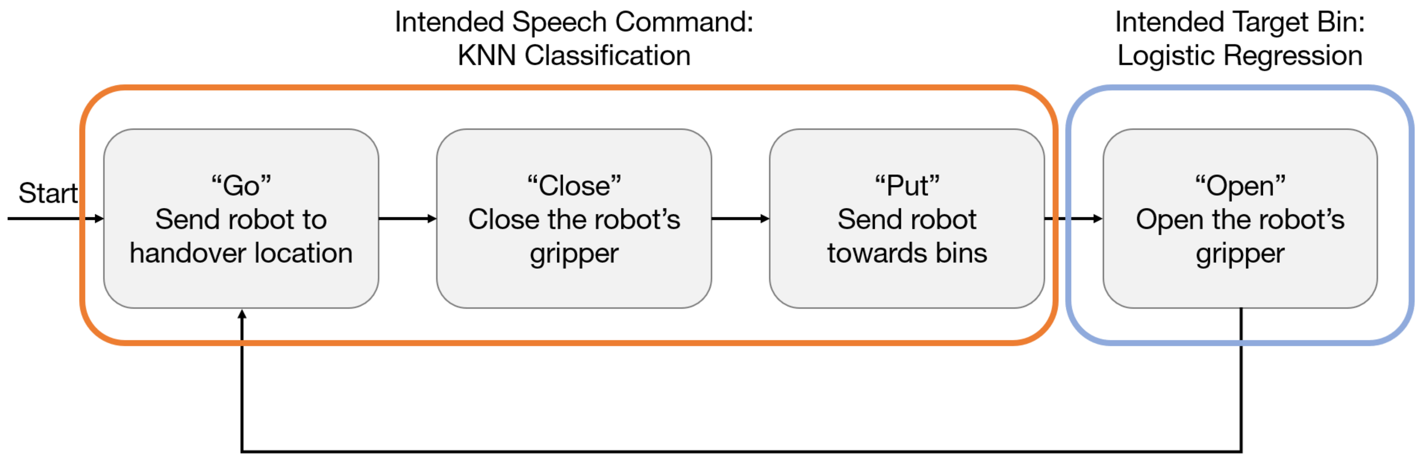


Schematic: User assembles red or blue cups, WRF places them in bins



View from stereo camera used for tracking the cups, human poses and robot poses,

Users initially gave **speech commands** to directly control the WRF. These commands, along with human and robot trajectories, were used to train a **K-Nearest Neighbors classifier** to predict the intended command, and **a Logistic Regression** model to predict the intended target bin.



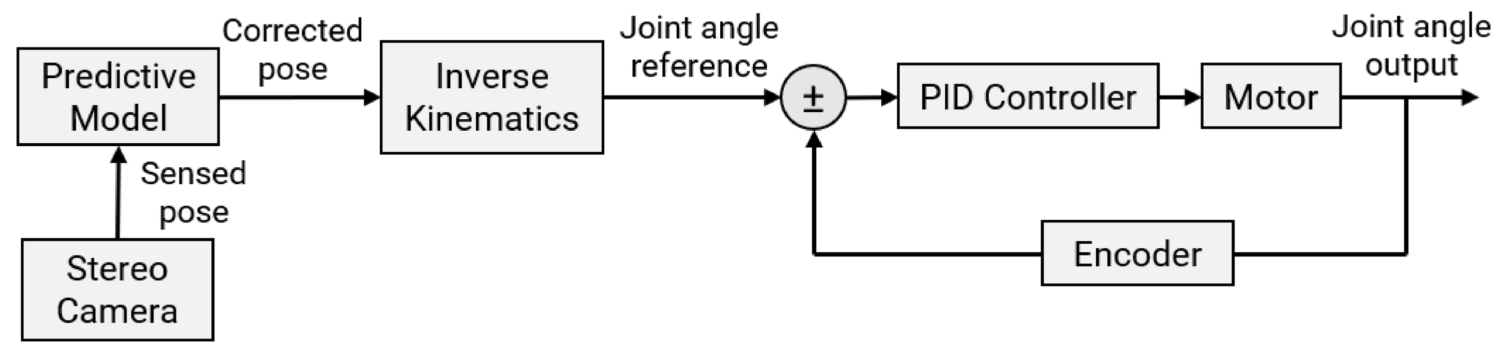
Speech commands and related prediction models for collaborative pick-and-place experiments

Following this training routine, users performed 20 trials each in direct speech control mode and predictive mode. Results from a **pilot study** with 24 participants indicate improved performance in the predictive mode:

Metric	Speech Mode		Predictive Mode	
	Mean	Std Dev	Mean	Std Dev
Average Trial Time (s)	12.46	3.48	11.51	2.88
Total Time per Condition (s)	347.84	94.41	325.64	72.72

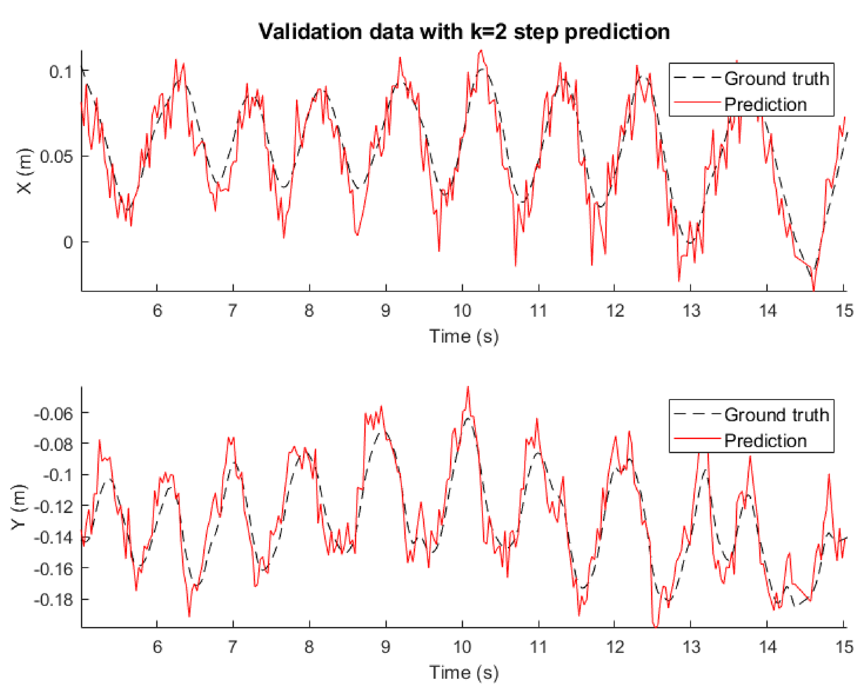
Human Motion Compensation

As the WRF is attached to the user's elbow, it is subjected to **disturbances** in its base position due to **human arm movements**. To compensate for these disturbances, as well as delays in sensing and actuation, we predict the human elbow motion and generate set-points for the WRF.

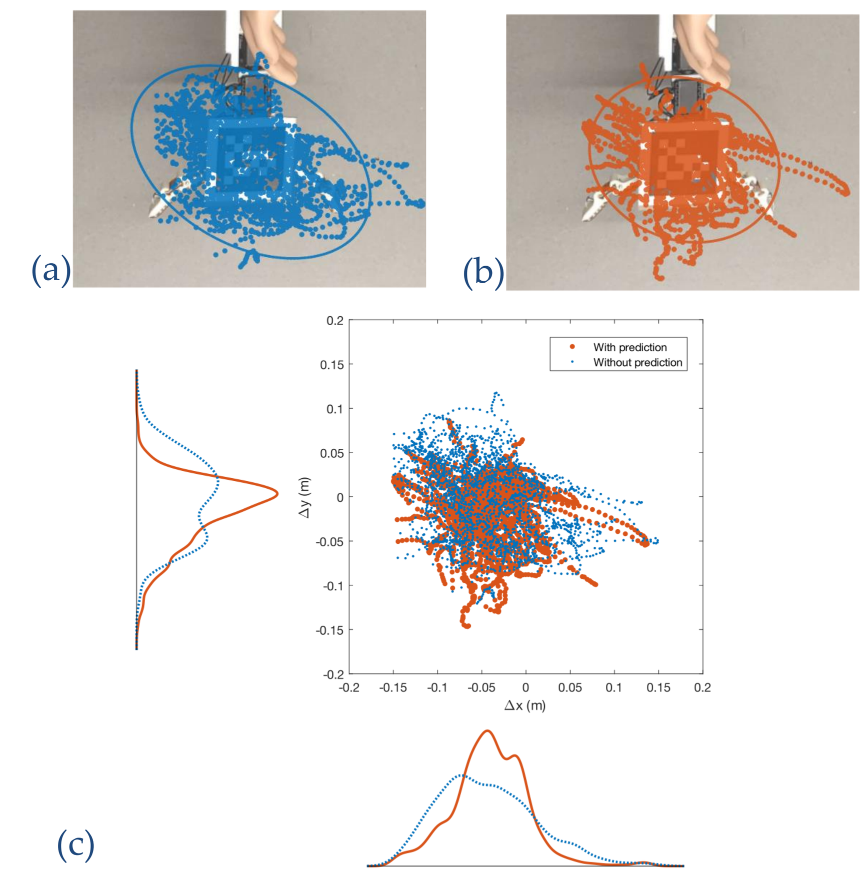


Schematic of closed-loop control of the WRF with a predictive model of human arm motion

In an initial study, we trained an 11th order autoregressive (AR) model on a 2D human elbow motion dataset. Predictions from this model were used to stabilize the WRF's end-effector about an initial pose. We achieved **~20% reduction** in deviation from the initial pose [3].



Validation of the AR(11) model on a 2D human elbow motion dataset



End-effector traces: (a) without prediction, (b) with prediction, (c) kernel density estimates

Future Work

- Conducting further human-robot collaboration experiments, including a **cognitively challenging task**.
- Applying **recurrent neural network** models for human motion prediction, and stabilizing the WRF in 3D.

[1] V. Vatsal and G. Hoffman, *"Wearing your arm on your sleeve: Studying usage contexts for a wearable robotic forearm,"* IEEE RO-MAN 2017.
[2] V. Vatsal and G. Hoffman, *"Design and Analysis of a Wearable Robotic Forearm,"* IEEE ICRA 2018.
[3] V. Vatsal and G. Hoffman, *"End-Effector Stabilization of a Wearable Robotic Arm Using Time Series Modeling of Human Disturbances,"* ASME DSCC 2019.

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