Collaborative Control for Wearable Robots

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Overview

In this project we are developing collaborative control algorithms for a supernumerary wearable robotic arm. We aim to extend the state of the art in two domains: **wearable robotics**, which has thus far been dominated by directly controlled agents, or agents programmed by demonstration; and **human-robot collaboration**, which has generally assumed the robot to be physically separated from the human, either on a fixed base or a mobile platform. We aim to bridge these literatures and investigate the collaboration and human interaction aspects of an autonomous wearable robotic device.

User-Centered Design

Close-range collaboration with a wearable robot is a relatively unexplored design domain. We started by identifying usage contexts for such a device, and found through an online survey that it is seen as a functional tool in professional settings, such as construction [1].

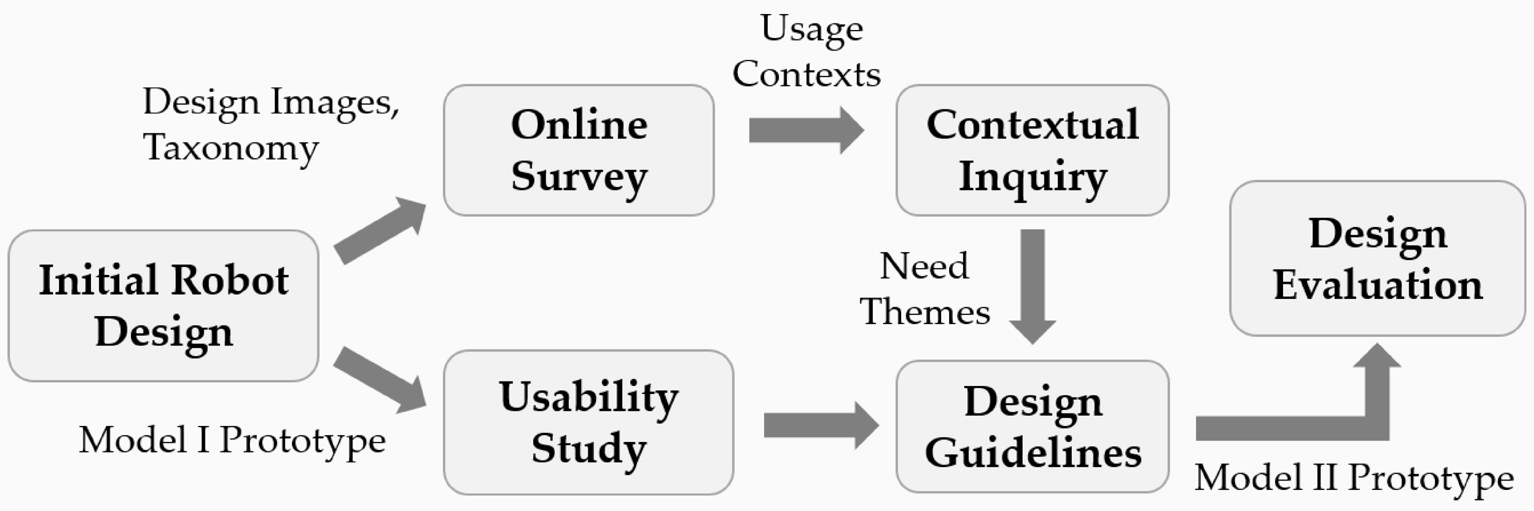
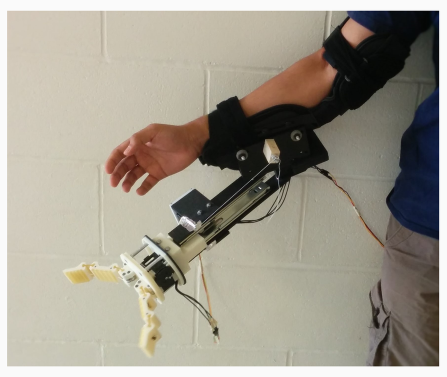


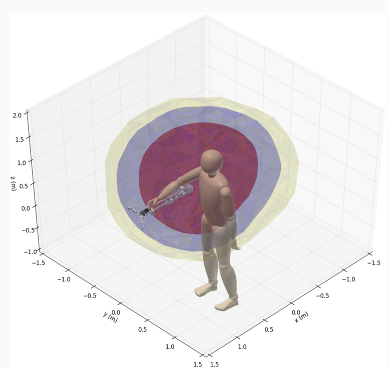
Figure: Iterative user-centered design procedure.

With a basic prototype (Model I), we conducted a contextual inquiry at a construction site, and an in-lab usability study. We identified design guidelines and need themes, and developed Model II, which enhances a user's reach by 246%.



(a) Model I

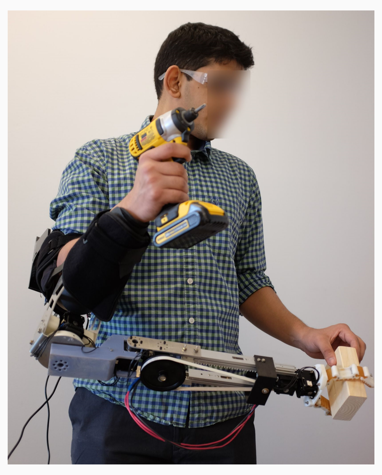
(b) Model II



(c) Workspace volume enhancement

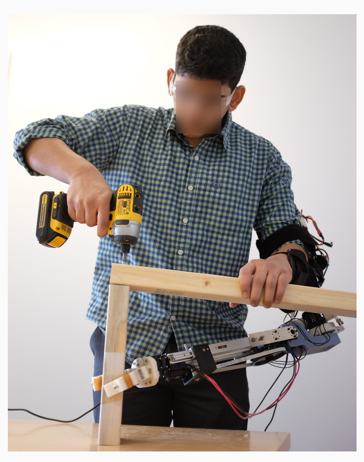
Figure: Successive prototypes and the increase in human reach afforded by them.

We also evaluated the biomechanical loads that Model II places on the human body in indicative usage scenarios, and found that the loads are within 60% of ergonomic limits [2].



(a) Self-handover

(b) Two-person handover



(c) Bracing a workpiece

Figure: Indicative usage scenarios with the wearable robotic arm.

Control Systems and Kinematics

The wearable robot needs to react in real-time to disturbances introduced in its plan by the wearer's body movements. It requires fast and robust controllers for this purpose. We conducted linear system identification tests and tuned the PID controllers of Model II to perform well in the indicative usage scenarios.

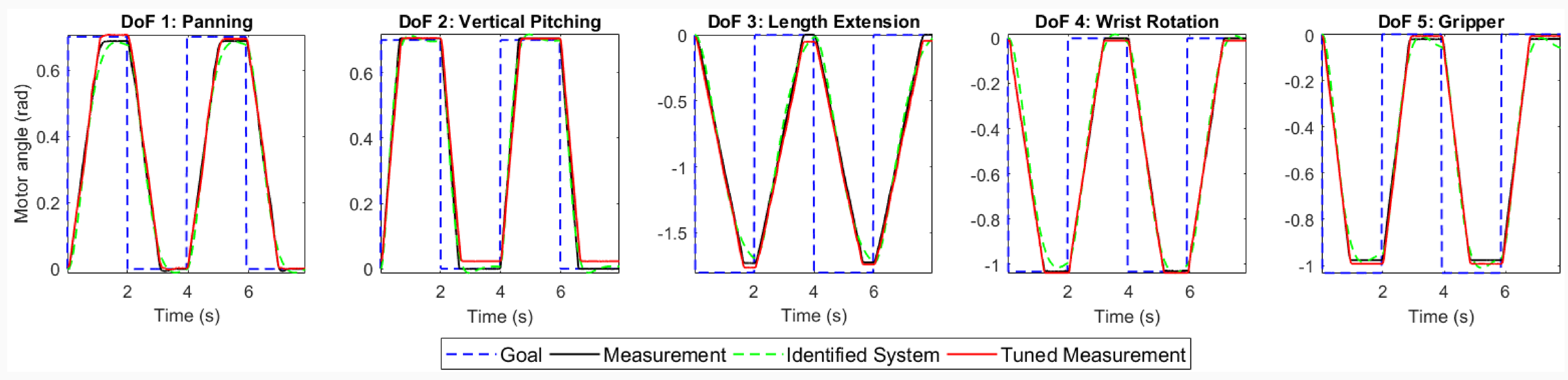
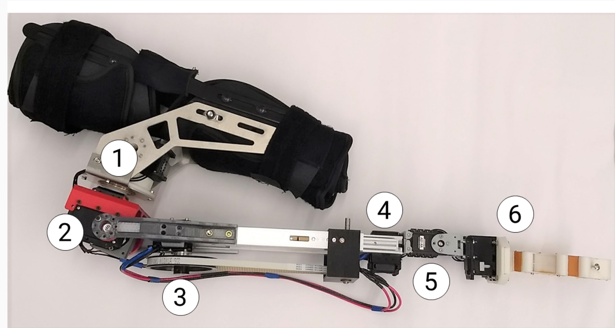
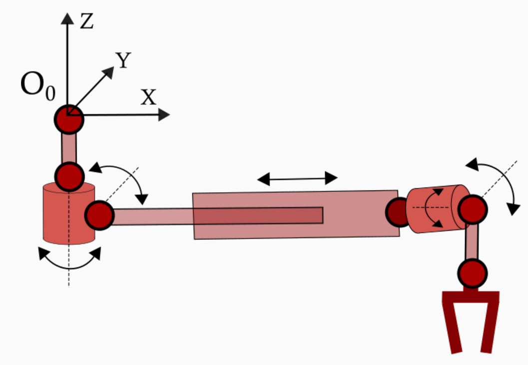


Figure: Identified and tuned control systems for the robot's DoFs.

The inverse kinematics (IK) of the robot needs to have a fast solution in order achieve real-time control. A general IK solution does not exist for the latest 5-DoF configuration, and numerical solvers are error-prone. We applied geometric projections to develop an analytical IK solution for our design, which quickly generates trajectories for the controller.



(a) 5-DoF prototype



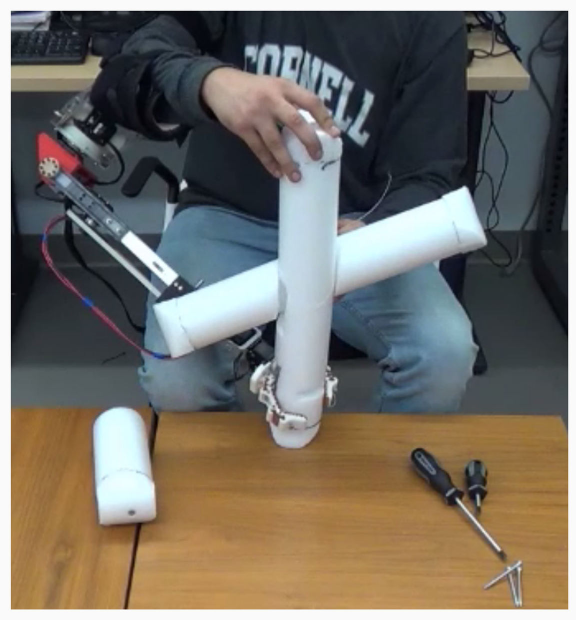
(b) Kinematic Structure

Figure: Latest prototype and schematic diagram used to develop IK for the wearable robot.

Intentionality and Collaboration

In order for the wearable robot to be an autonomous collaborative agent in a particular well-defined task, it needs to detect the user's intention and act while adapting to their body movements. We are developing a sparse IMU-based human arm tracking system, to be used along with stereo cameras for predicting the user's intent through body movements and workspace configuration. We are also conducting Wizard-of-Oz (WoZ) trials to build data-driven collaboration algorithms in an assembly task.

(a) IMU-based arm tracking



(b) Collaborative assembly task

Figure: Present work in human tracking for intent recognition, and WoZ trials for collaborative assembly

[1] V. Vatsal and G. Hoffman, *Wearing your arm on your sleeve: Studying usage contexts for a wearable robotic forearm*, RO-MAN 2017.
[2] V. Vatsal and G. Hoffman, *Design and Analysis of a Wearable Robotic Forearm*, ICRA 2018.

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