Mechanical Engineering

Enhancing Human Navigation Ability Using Force-Feedback from an Active Wearable Exoskeleton

CARLOS CARRASQUILLO
Georgia Institute of Technology, Institute for Robotics and Intelligent Machines

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Advisor/Mentor: Anirban Mazumdar, Aaron Young

INTRODUCTION

How can we promote **safe navigation** in low-visibility environments?

- Visibility may be impaired by dust, smoke, dense fog, or poor eyesight.
- Existing tactile devices require single-purpose hardware.
  - Perceptibility of vibrotactile stimulus affected by clothing, environmental confounds, attention of the wearer, and temporal effects[1]

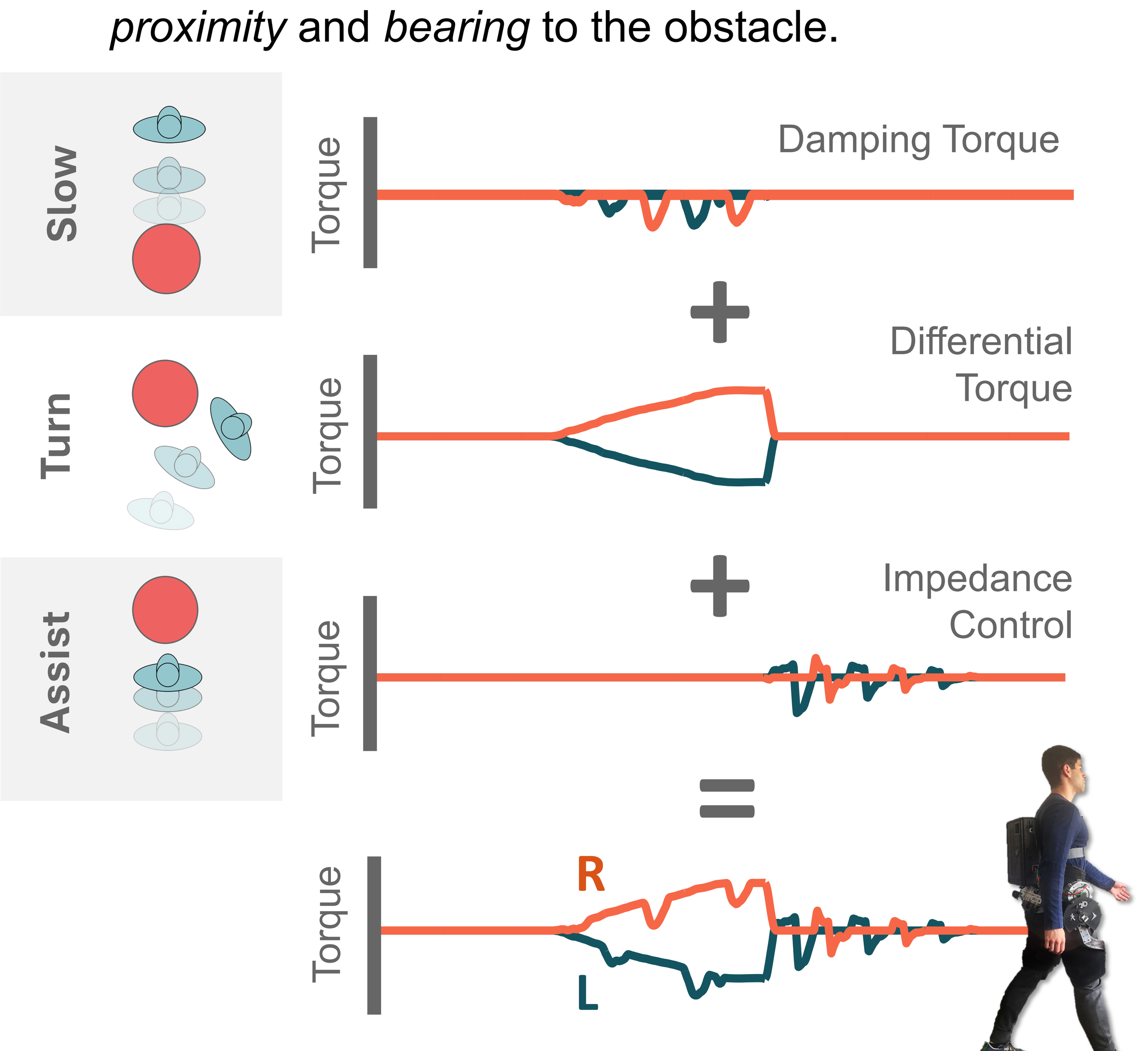
Hypothesis: Tactile feedback from an **active wearable exoskeleton** can improve navigation ability compared to vision alone.

METHODS

To communicate directional cues to a human, the following control paradigm was used:

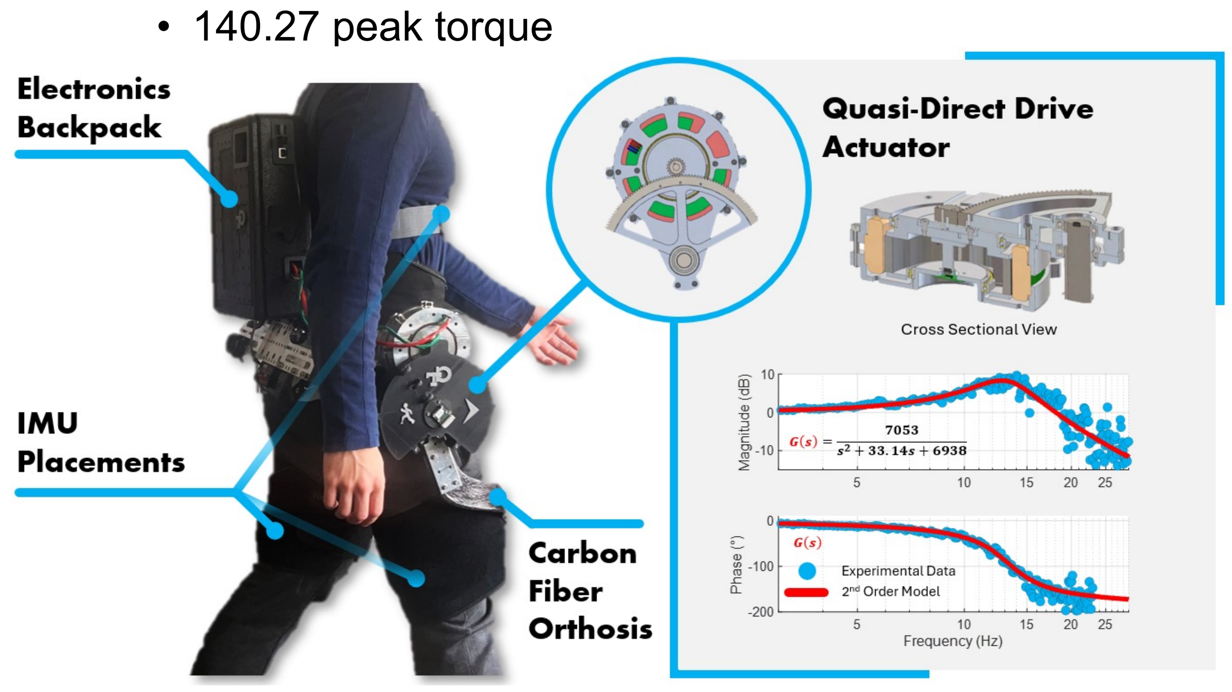
1. **Slow** the human if they are approaching an obstacle. Damping torque makes the user feel like they are walking through a viscous fluid.
2. **Turn** the human away from the obstacle and towards a safe area. Uses differential torque.
3. **Assist** the human as they walk away from the obstacle. Four-state FSM with impedance control.

The magnitude of each controller depends on the *proximity* and *bearing* to the obstacle.



The exoskeleton platform is a 1-DoF sagittal plane hip exoskeleton.

- 42.1 Nm Rated torque
- 140.27 peak torque



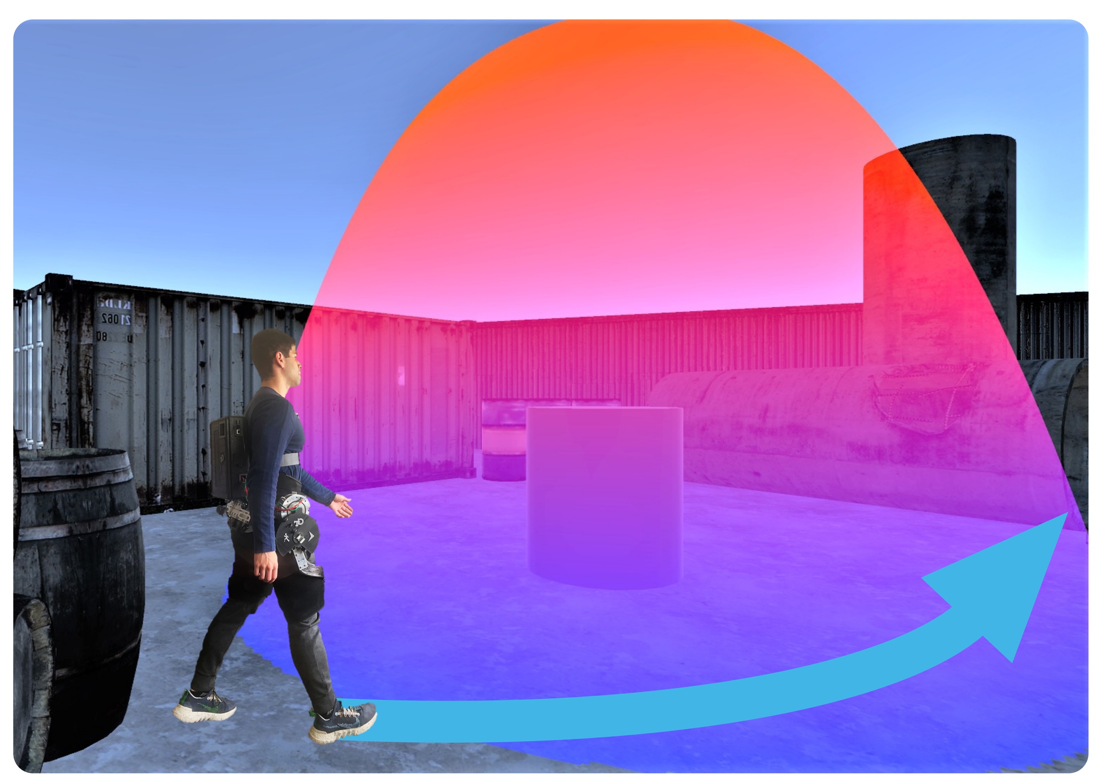
DATA ANALYSIS

Two separate experiments were conducted: **Simulated Environment**, and **Outdoors**

Simulated Environment

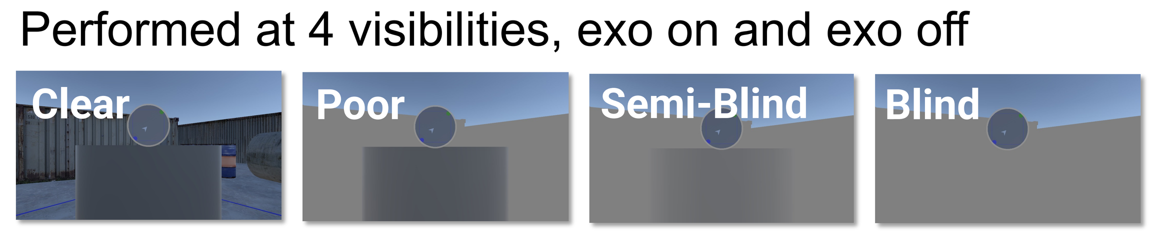
Goal: Evaluate the feasibility of the proposed control scheme in virtual reality to decrease risk of injury.

- **High Level Control:** fractional potential fields
- **Mid Level Control:** slow + turn + assist
- **Low Level Control:** proportional-integral

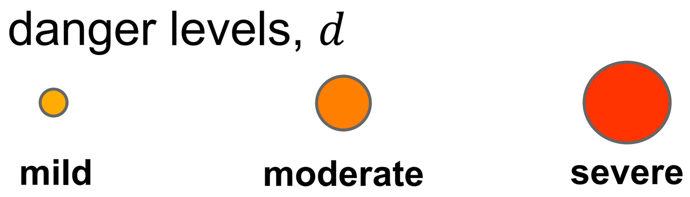


Conditions

- N=10
- Performed at 4 visibilities, exo on and exo off



- 16 levels/condition
- 3 obstacle danger levels, d



Protocol

- Navigate to the goal while maximizing a draining health score. 0 100
- Damage is taken based on proximity to obstacles. The more dangerous the obstacle, the more damage. Larger obstacles have a repulsive potential with a larger fractional order.
- Participants train with health score, only shown after level during experiment.

Outdoors — Piloting

Goal: Previous experiment assumed perfect information about obstacle positions. This experiment uses on-board sensors for navigation.

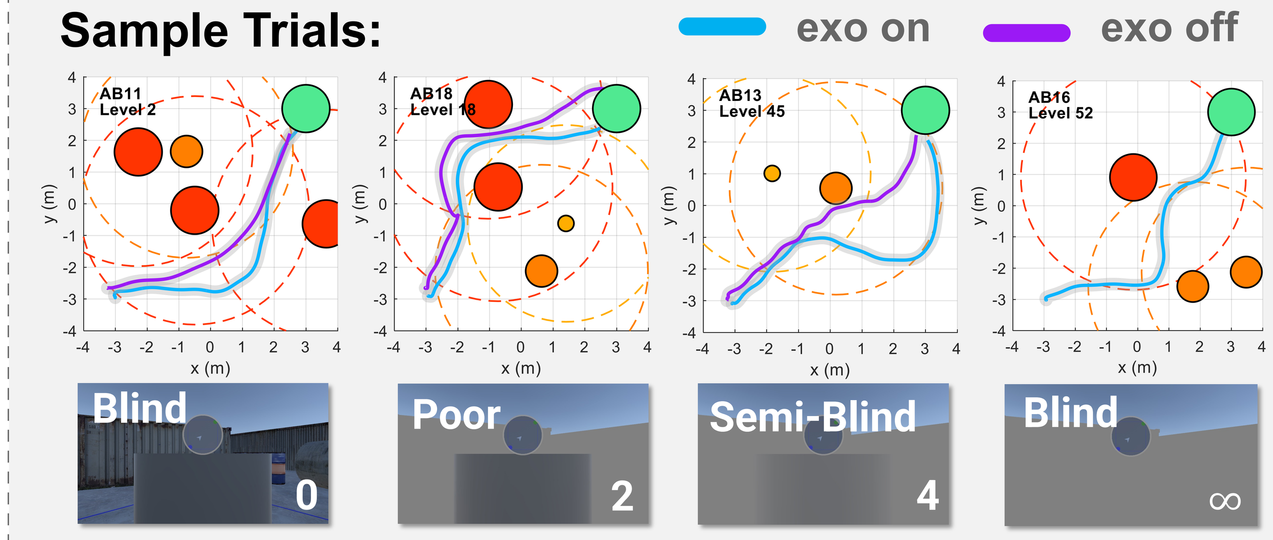
- **High Level Control:** vector field histograms
  - **Local Planner:** LiDAR (depth camera)
  - **Global Planner:** GPS + INS fusion (extended Kalman filter)
- **Mid Level Control:** slow + turn
- **Low Level Control:** proportional-integral

RESULTS

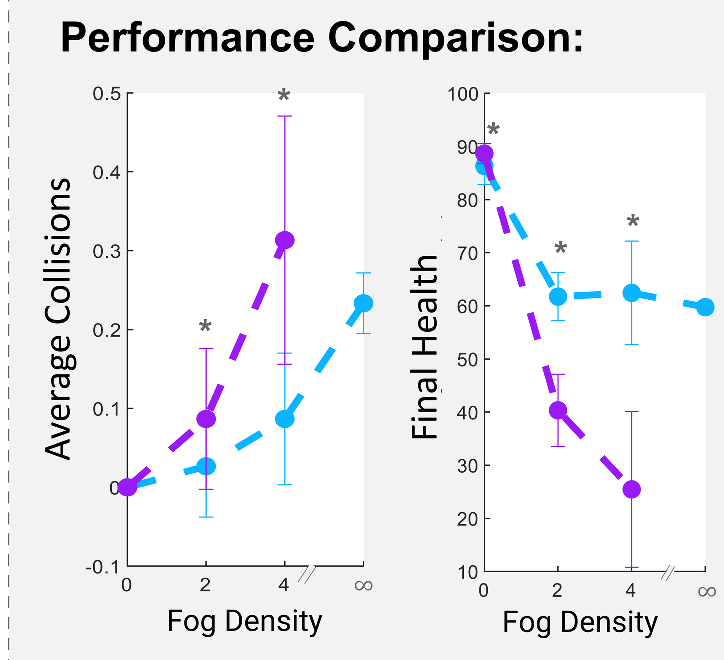
Simulated Environment

Takeaway: Number of collisions decreased with exo assistance. Separation from obstacles increased (evident from health score).

Sample Trials:



Performance Comparison:

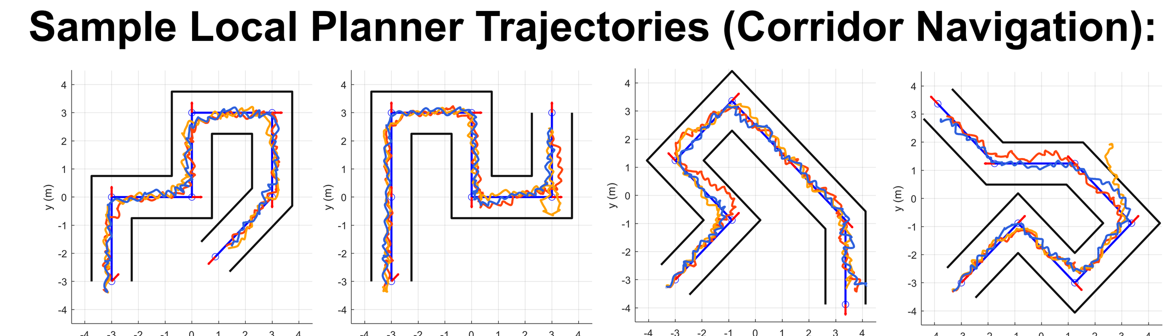


Except for clear condition, the **number of conditions significantly decreased** with exo assistance.

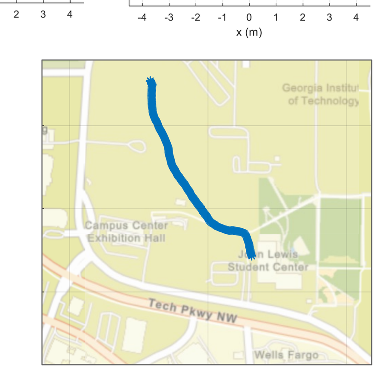
Except for clear condition, the **separation to obstacles was significantly increased** with exo assistance.

Outdoors — Piloting

Sample Local Planner Trajectories (Corridor Navigation):



Sample Global Planner Trajectories:



Planned Experiment: Evaluate **completely blind navigation** performance compared to walking cane and vibrotactile belt.

BENEFITS TO DOD

With improvements in actuator power and torque density, we can use a combination of assistance and force-feedback to **help warfighters accelerate away from threats** and quickly navigate to safe areas.

Note: Our second project (not proposed here) aims to improve the quality of exoskeleton assistance via human-in-the-loop optimization.

CONCLUSION

We can use **force-feedback in parallel with the human body** to illicit movement away from dangerous areas and towards safer ones. This can be achieved using sensors onboard an active wearable exoskeleton and intelligent controls.

REFERENCES

- J. R. Blum *et al.*, "Getting Your Hands Dirty Outside the Lab: A Practical Primer for Conducting Wearable Vibrotactile Haptics Research," *IEEE Transactions on Haptics*

Anticipated Graduation Date: May 2026

Website: carloscarras.tech
Email: ccarrasquillo3@gatech.edu