Towards Functional Exoskeleton Control

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Discipline: Mechanical Engineering, Robotics
Sponsor: Army

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ART

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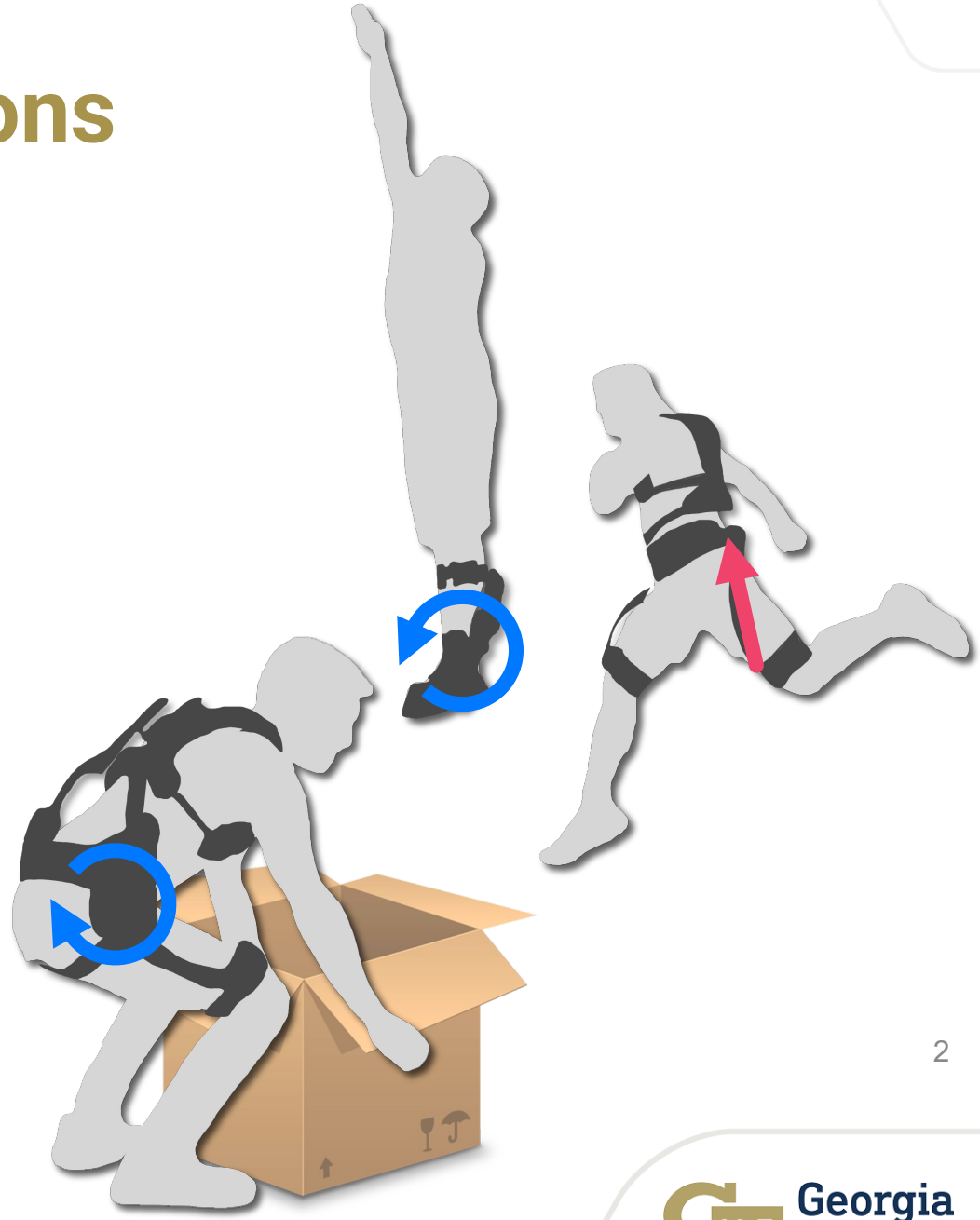
State of Lower Limb Exoskeletons

Active wearable exoskeletons assist by applying **torques** or **forces** in parallel with human **joints** or **muscles**

Benefits:

- Reduced energetic cost
- Increased performance
- Higher endurance



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Common Criticisms

Comfort

"It feels a little heavy."

"It's digging into my thigh."

Convenience

"It takes too long to put on."

"I have to charge it after 2 hours of use."

Utility

"But can it help me jump higher?"

"Is it going to help me get to work?"

Quality of Assistance

"It feels out of phase when I walk."

"It doesn't feel like it's helping me lift."

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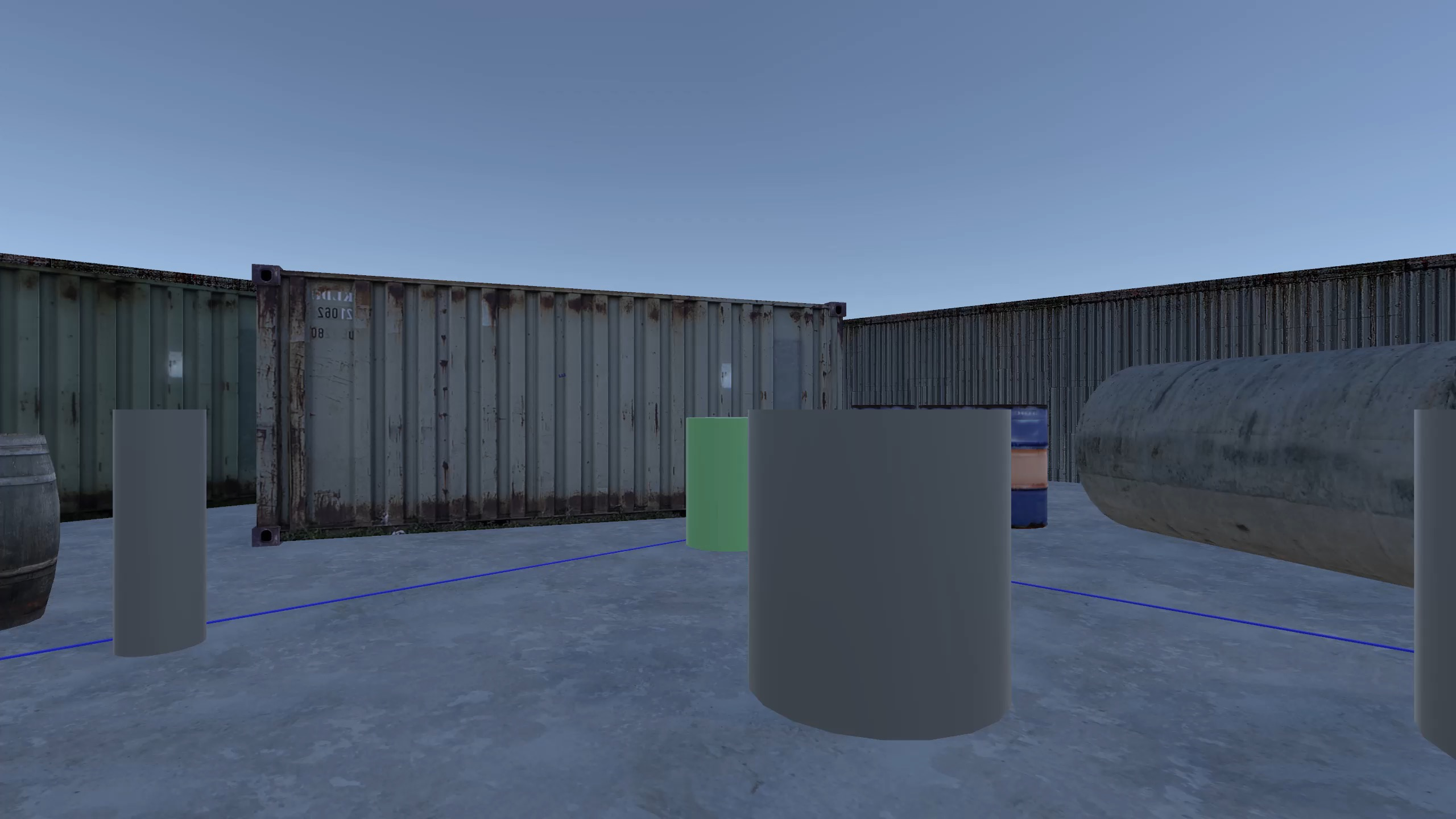
Agenda

Utility: Enhancing Blind Navigation using Feedback from a Lower-Limb Exoskeleton

Quality of Assistance: Towards Energetically Optimal Exoskeleton Assistance



Tear Gas

Nighttime Operations

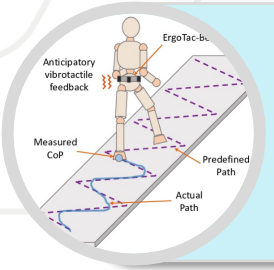
But what happens if you can’t see?

Heavy Smoke

Blindness

Distractions

Previous Work



Vibrotactile Devices

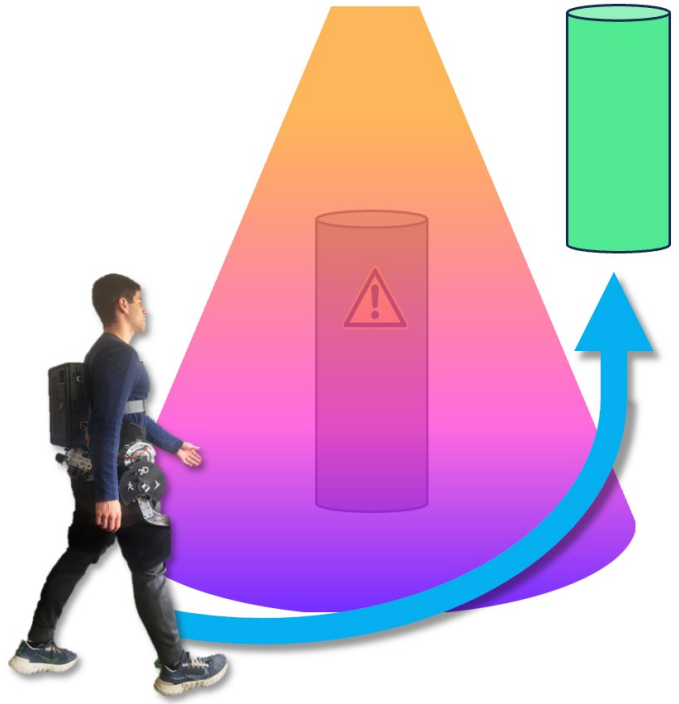
Handheld Tactile Devices

Series Force-Feedback

Co-Robots

Proposed Work

Parallel Force-Feedback using an active wearable exoskeleton.



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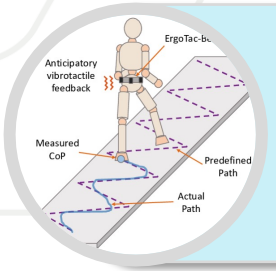
Previous Work



Vibrotactile Devices

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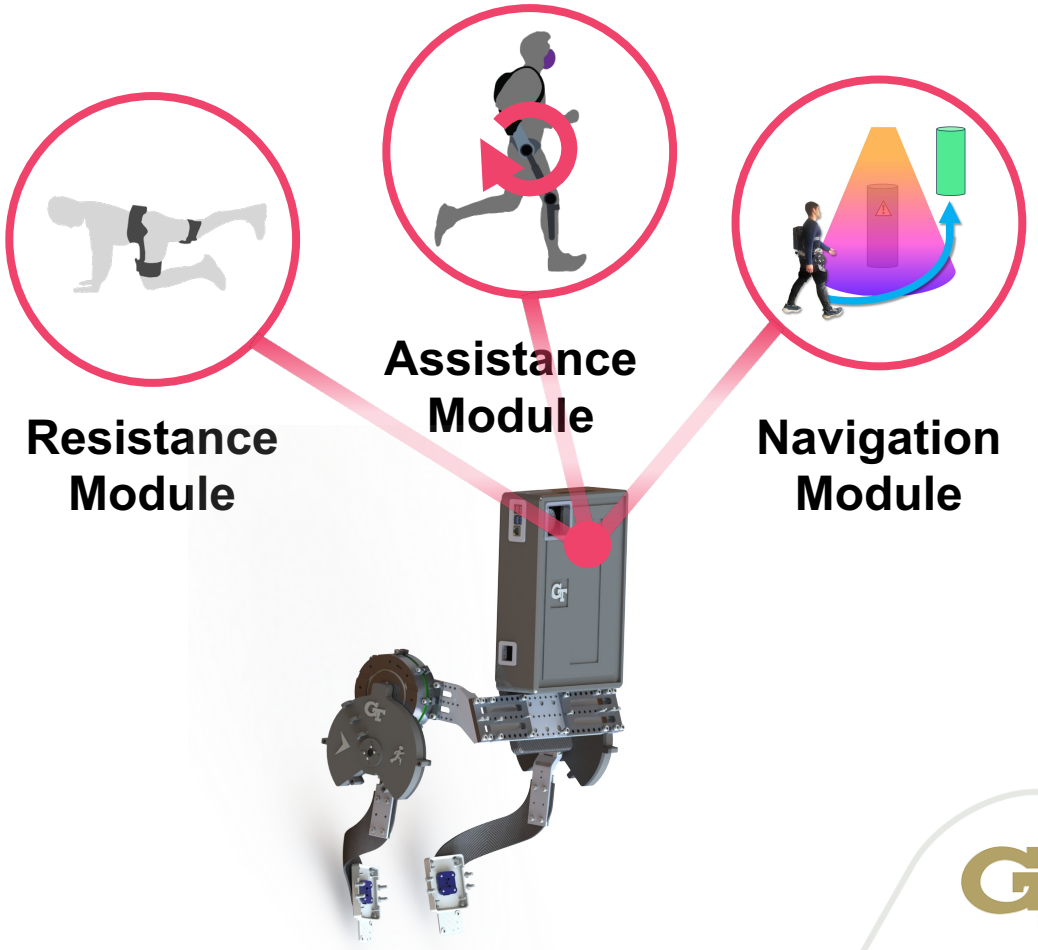
Parallel Force-Feedback using an active wearable exoskeleton.



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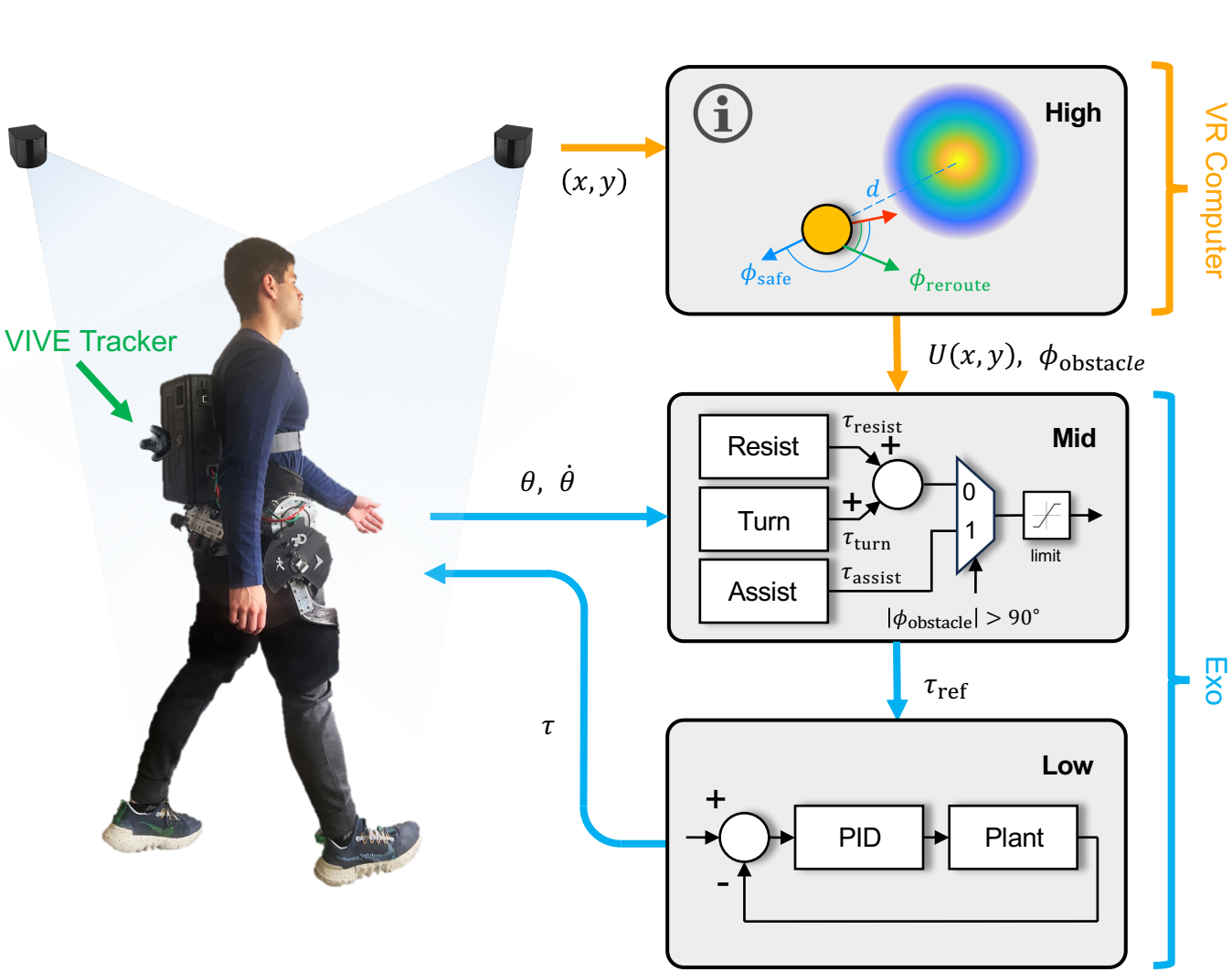
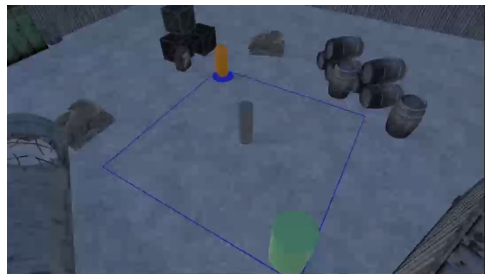
Turning
Resistive
Assistive

Control Hierarchy





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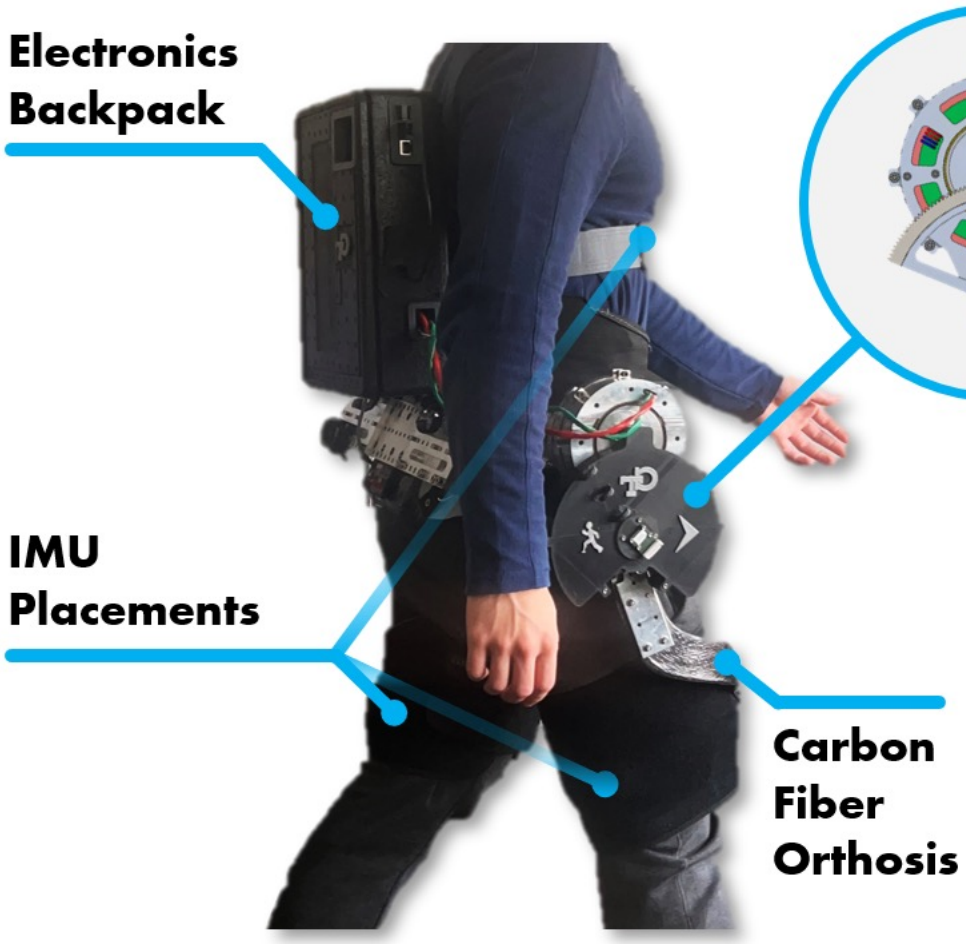
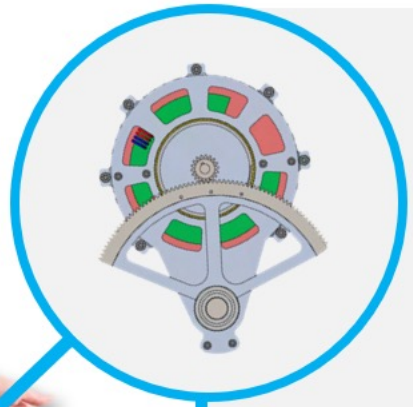
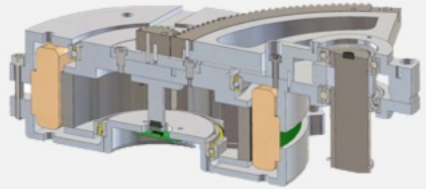
Exoskeleton Platform

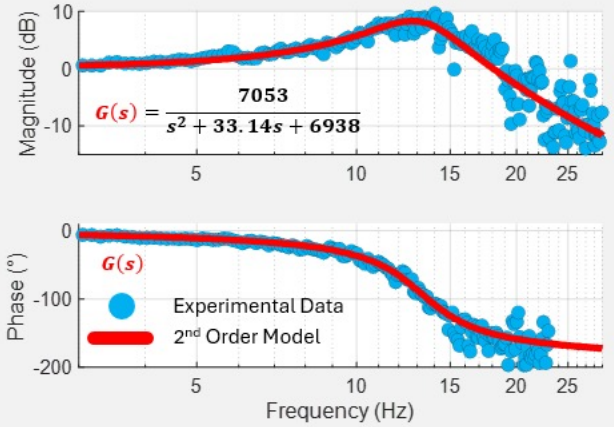




Quasi-Direct Drive Actuator



Cross Sectional View



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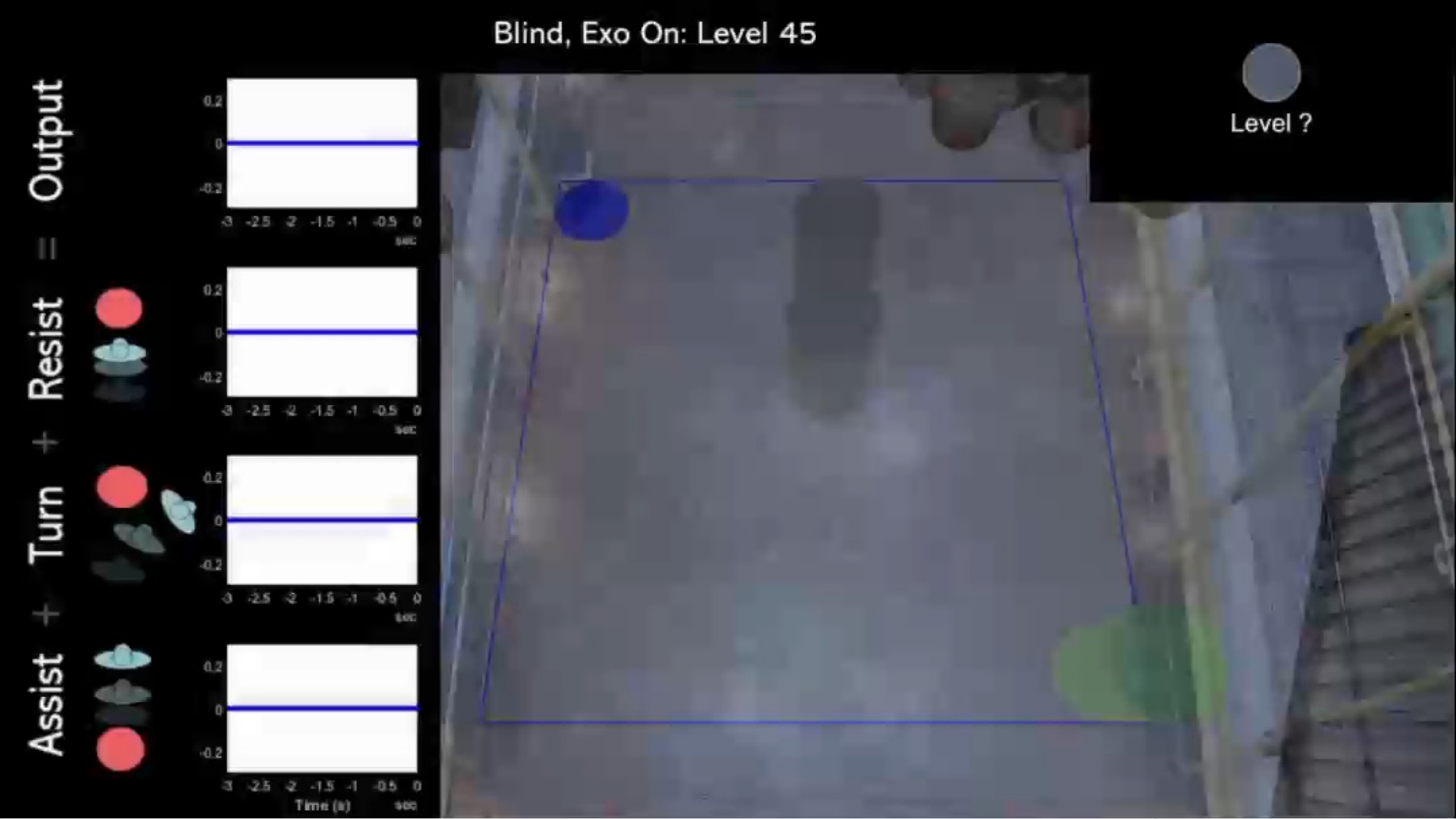
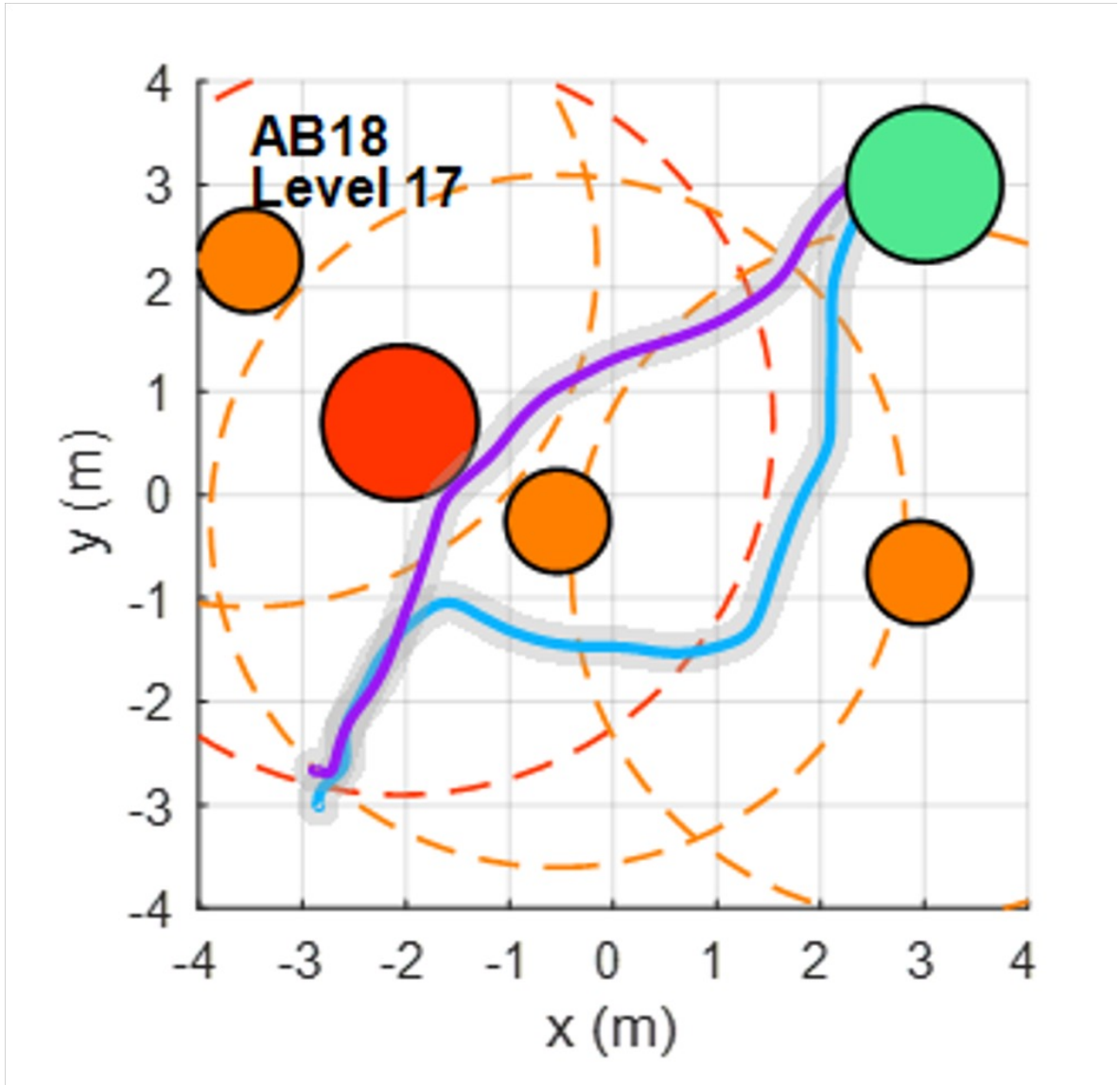
100


Blind, Exo On: Level 45
Level ?
Assist + Turn + Resist = Output
0.2
0
-0.2
-3 -2.5 -2 -1.5 -1 -0.5 0
sec
Time (s)

Sample Obstacle Map Trajectory



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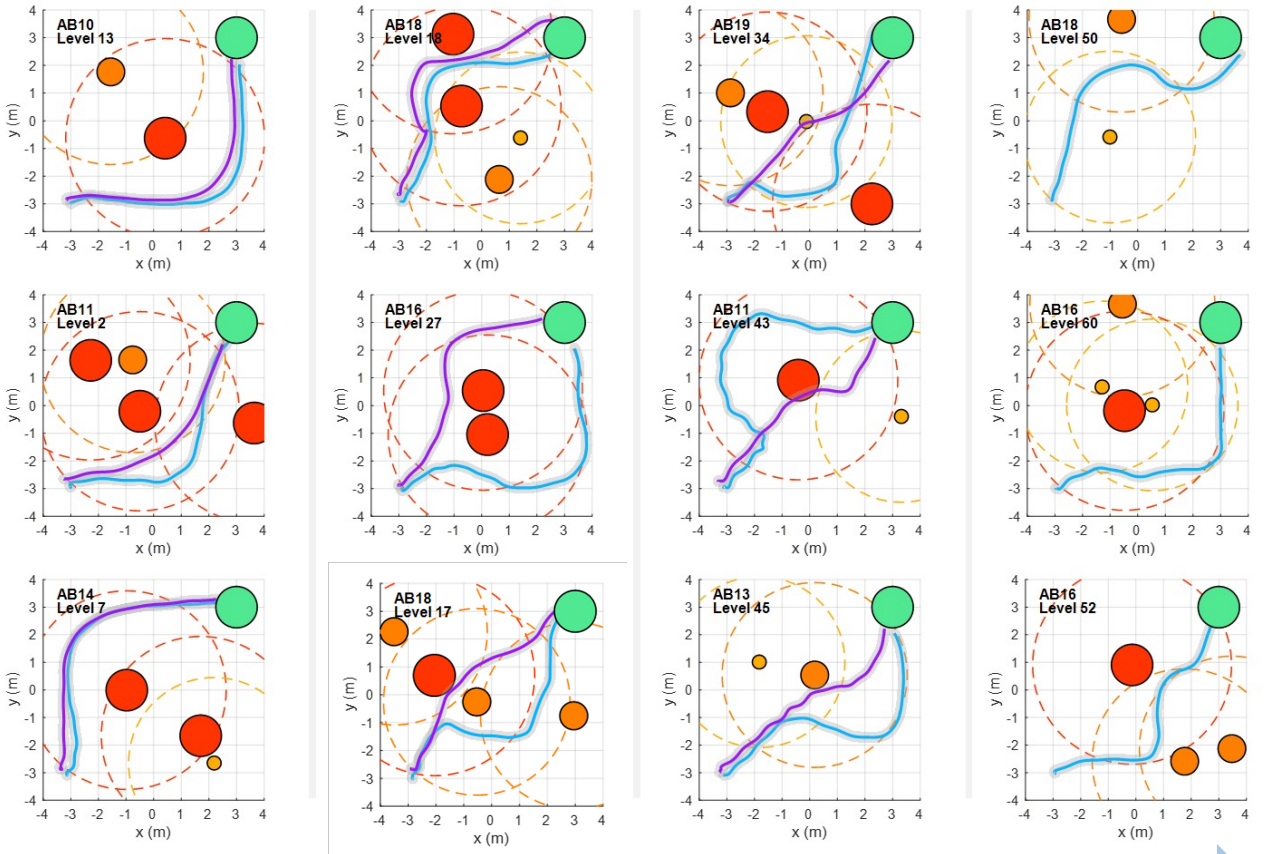
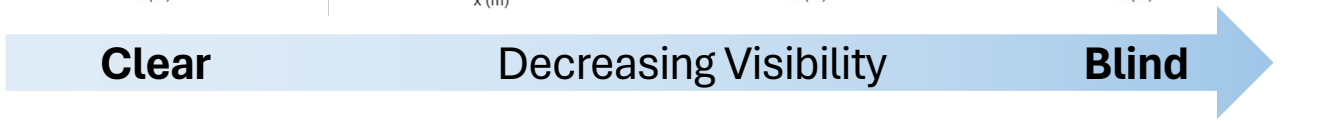
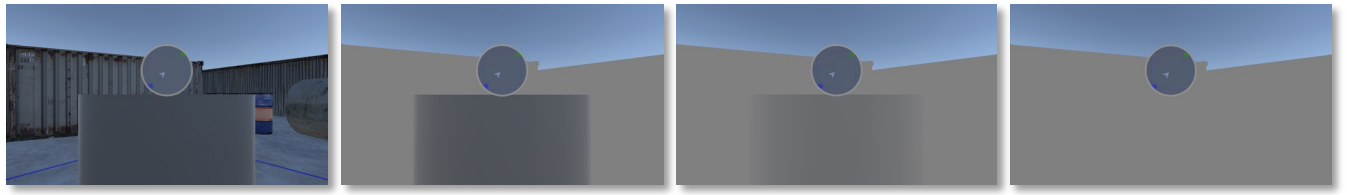
Sample Obstacle Map Trajectories







Exo On

Exo Off

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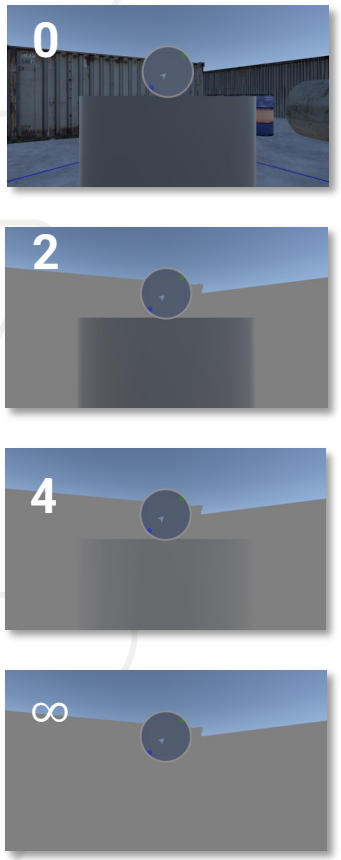
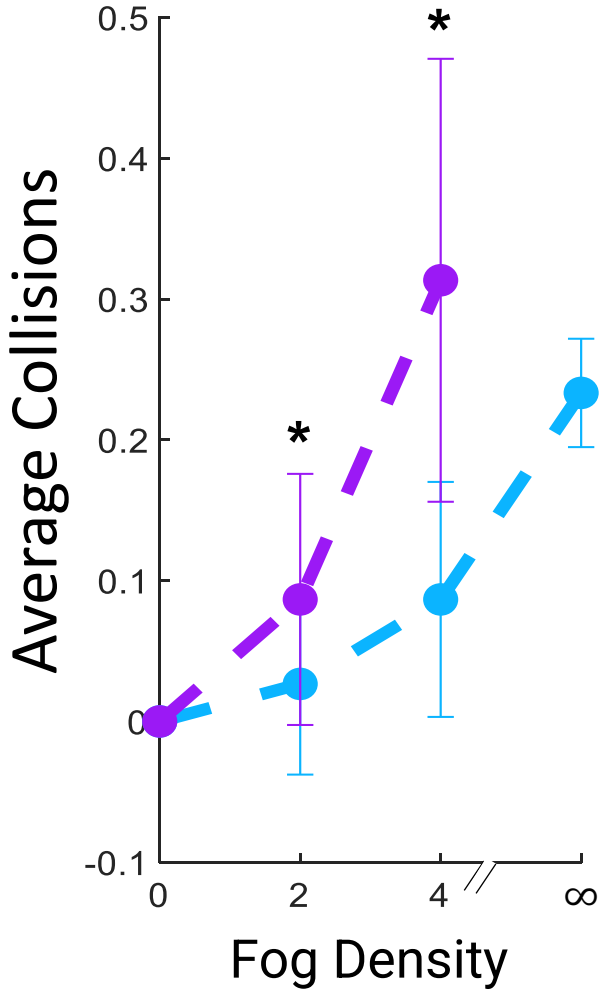
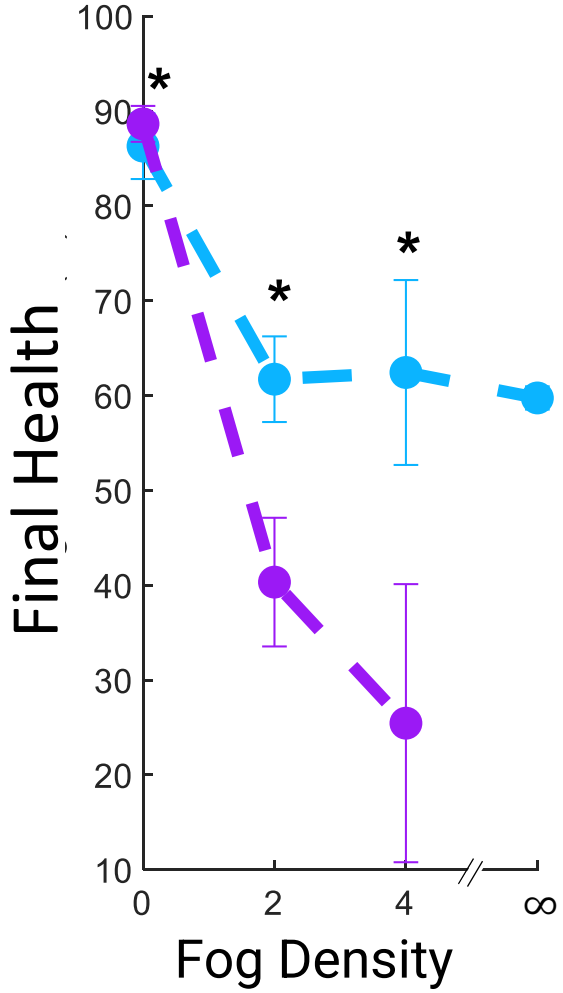
Results







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Adding Onboard Sensing

We can use **INS+GPS** to help a user **navigate to a waypoint** while using **LiDAR** to **avoid obstacles**

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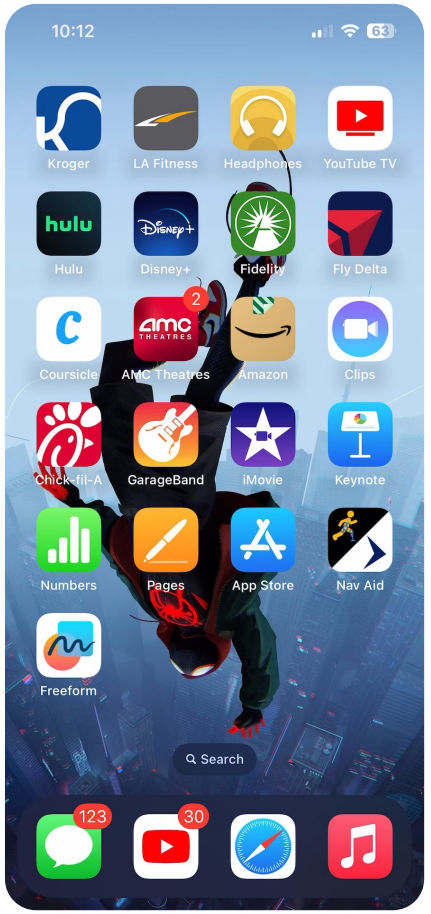
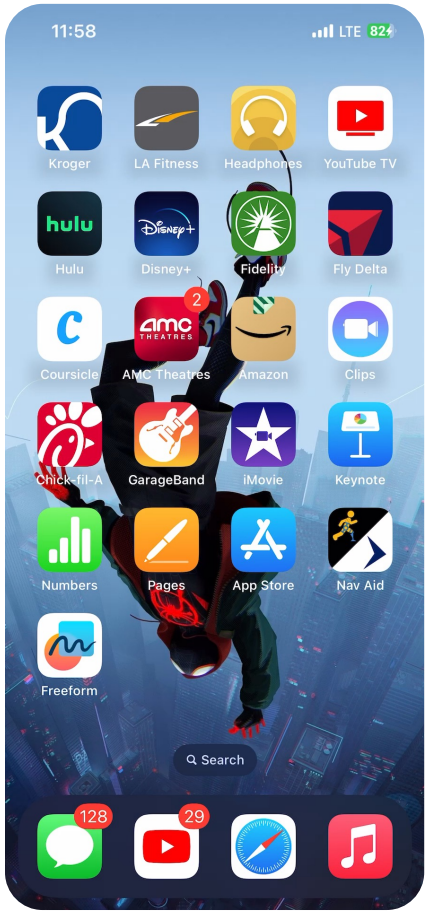
Local and Global Planners

We can use **INS+GPS** to help a user **navigate to a waypoint** while using **LiDAR** to **avoid obstacles**



Local Planner



Global Planner

Note: Left and right footage are from separate collections.

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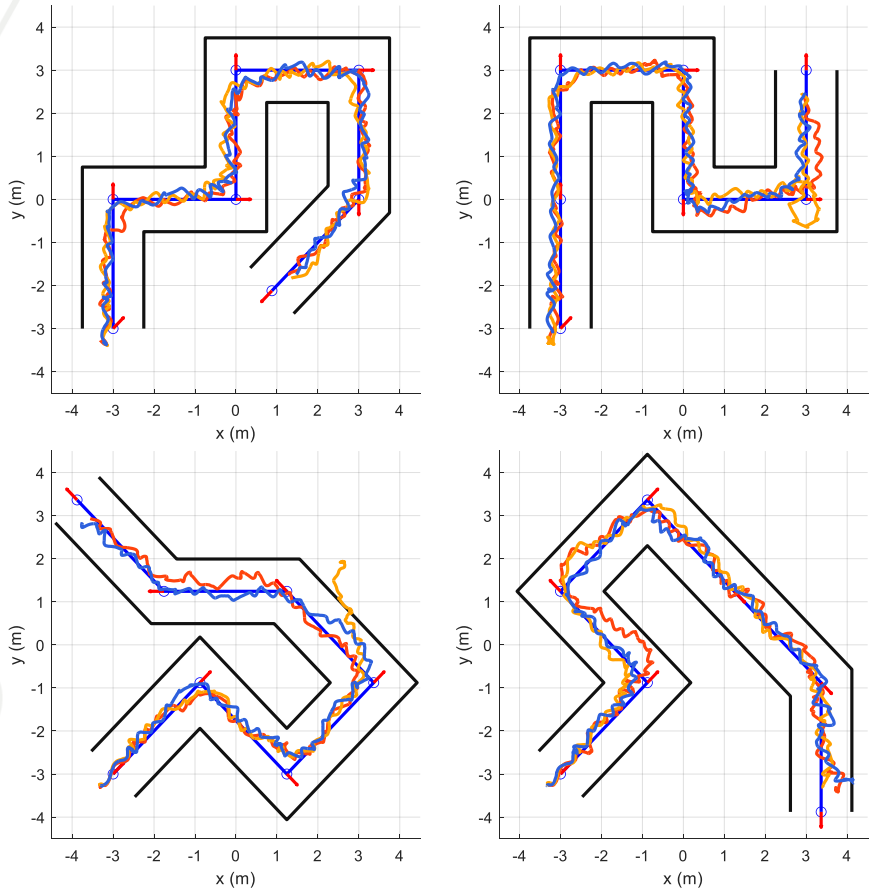
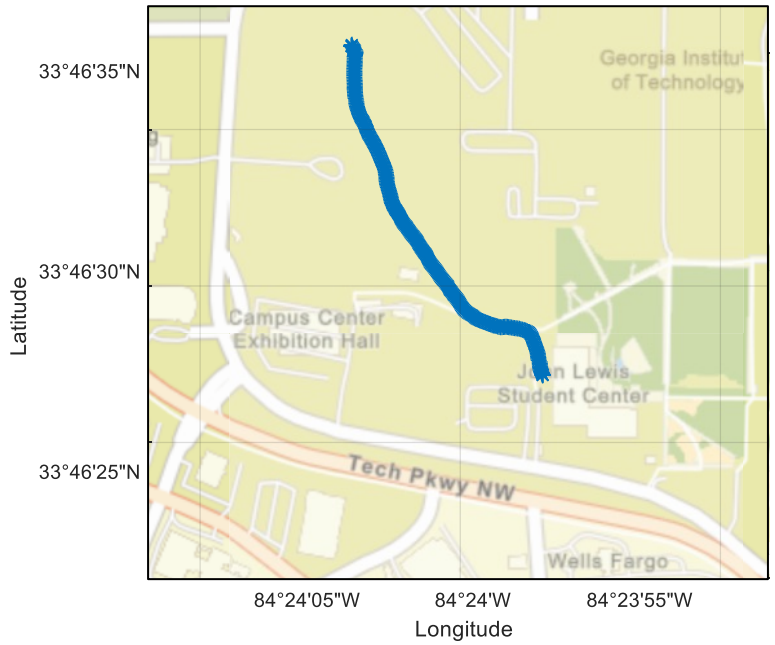
Local and Global Planner Tests



Local Planner



Global Planner

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Agenda

Utility: Enhancing Blind Navigation using Feedback from a Lower-Limb Exoskeleton

Quality of Assistance: Towards Energetically Optimal Exoskeleton Assistance

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What is Exoskeleton Control?

Specifically regarding **active wearable exoskeletons**, we aim to answer the following question:

How do we command actuators in a way that is most beneficial to a human?

How do we command actuators in a way that reduces the metabolic cost of a human?

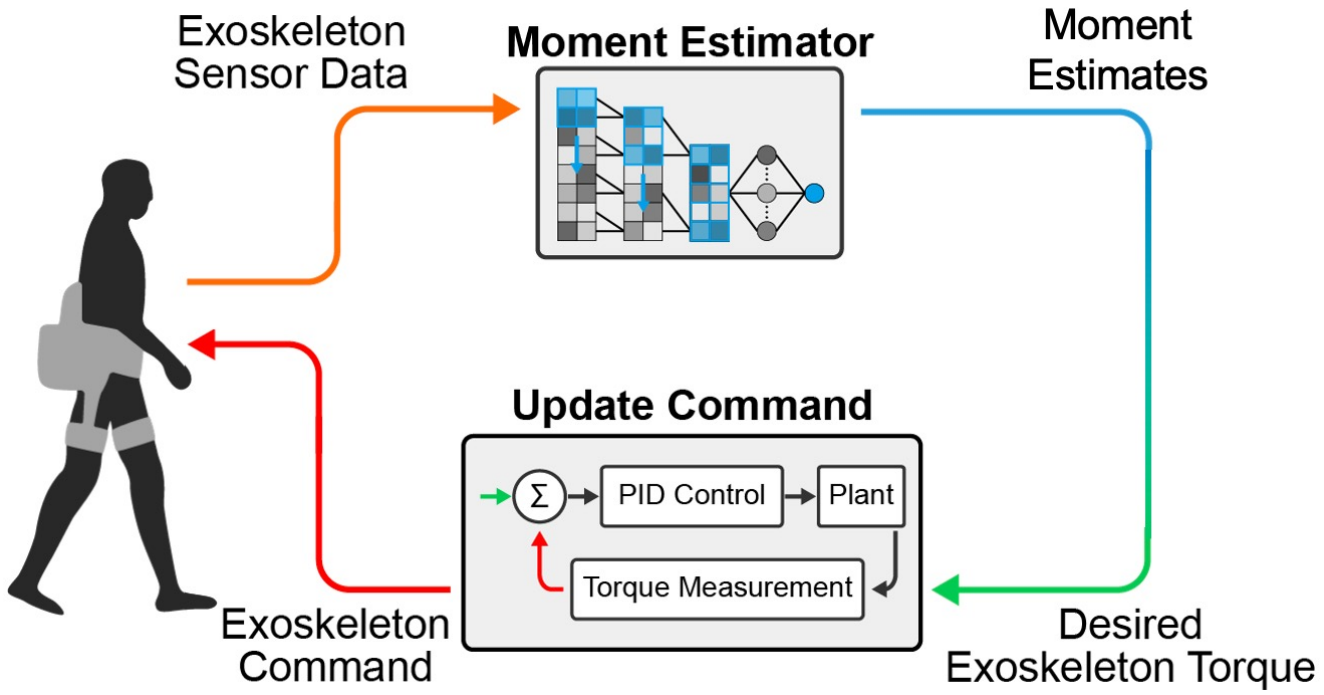
Naïve Approach

Just do what the joints are doing!

Biological Torque Controller

Steps:

1. Estimate joint torque
2. Apply it



Inspired by
Molinaro *et al.*, 2024

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Naïve Approach

Just do what the joints are doing!

Steps:

1. Estimate joint torque
2. Apply it

it… doesn't feel that great

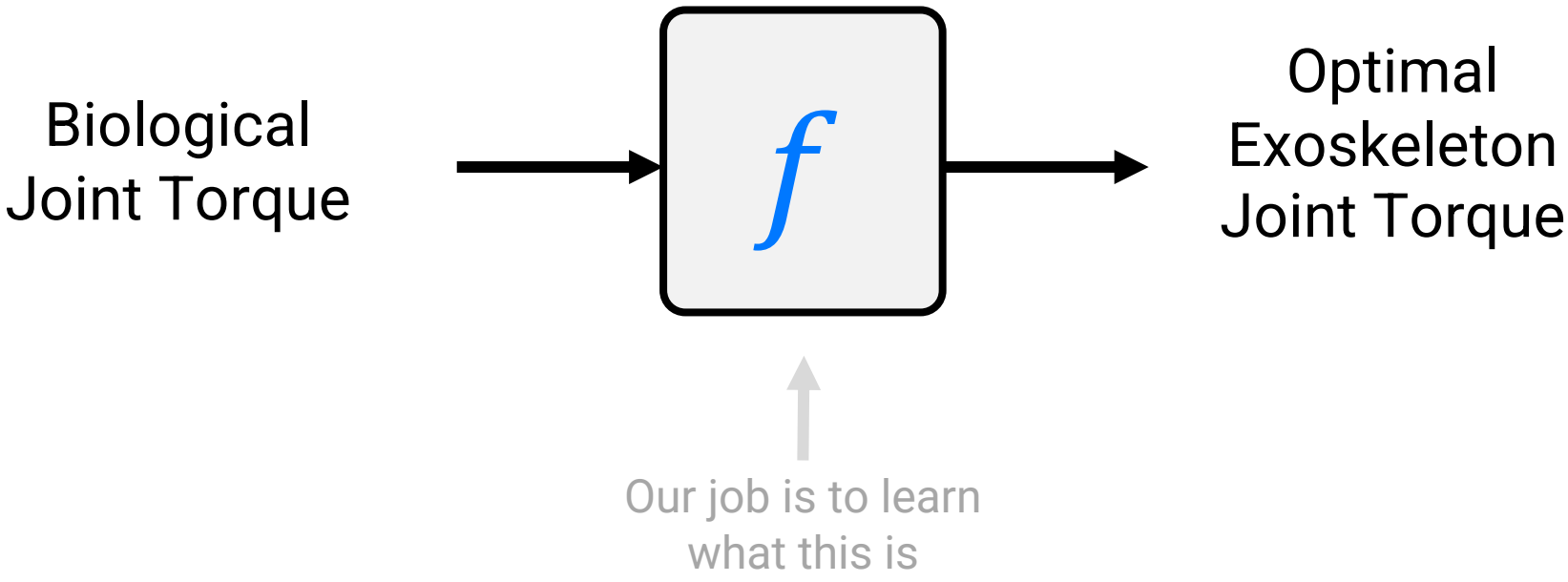
and the metabolic cost reflects it

Realization: biological torque is <u>not</u> optimal

Inspired by Molinaro *et al.*, 2024

Research Question

- **Field's Hypothesis:** The optimal exoskeleton torque is some **transformation** of biological joint torque.



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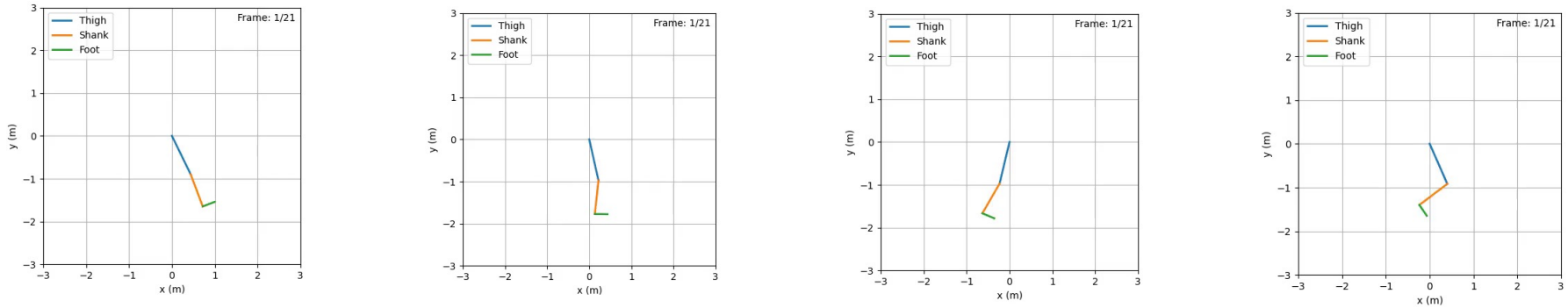
Hypothesis

The transformation depends on the **kinematics** and **dynamics** of a movement.



Idea: If we can optimize **motion primitives** individually, we can combine them to get an approximately optimal controller.

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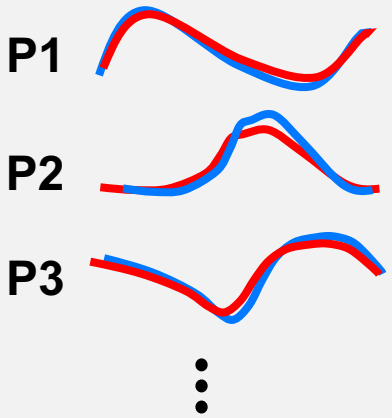
Proposed Plan to Obtain Optimal Torque Profiles

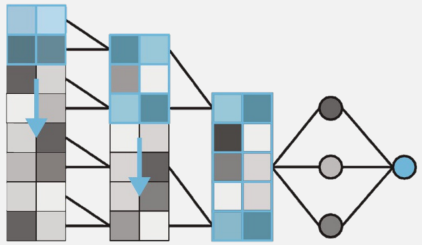
1

Learn
motion primitives



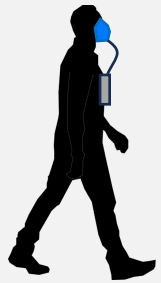
2

Classify
primitives in real time



3

Optimize
each primitive independently using human-in-the-loop optimization



Compare against baseline Biological Torque Controller

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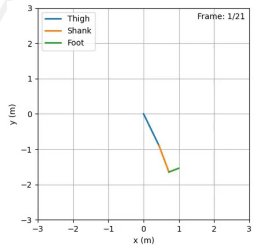
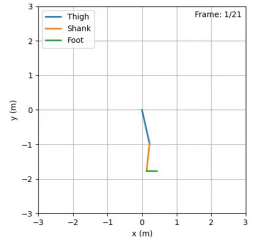
Primitive Library: Level Ground Walking Analysis

C0



C1



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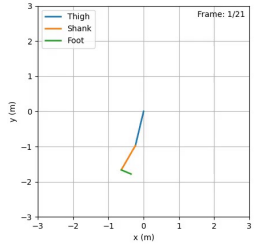
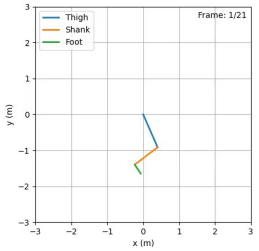
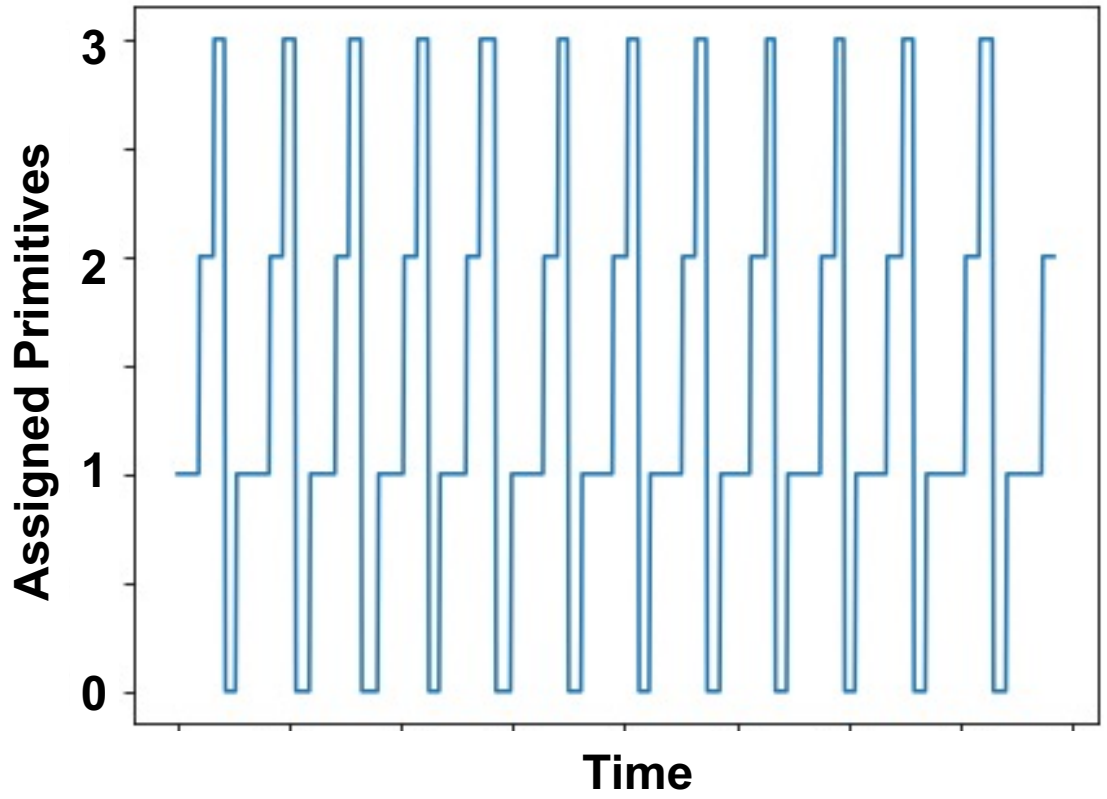


C3





Joint Variational Auto-Encoder used to create primitive library. Each discrete dimension is a primitive.

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Collaborators

Scan for More

or use the link:
carloscarras.tech/ndseg2024

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- Fardeen Khimani
- Jason Lei
- Christopher Semali
- Grace Shao
- Ryan Vo
- Eddy Wang

Other

- Marilyn Braojos

And thank you for listening!

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Appendix