Adaptive Hip Exoskeleton Control for Personalized Assistance Using Deep Learning

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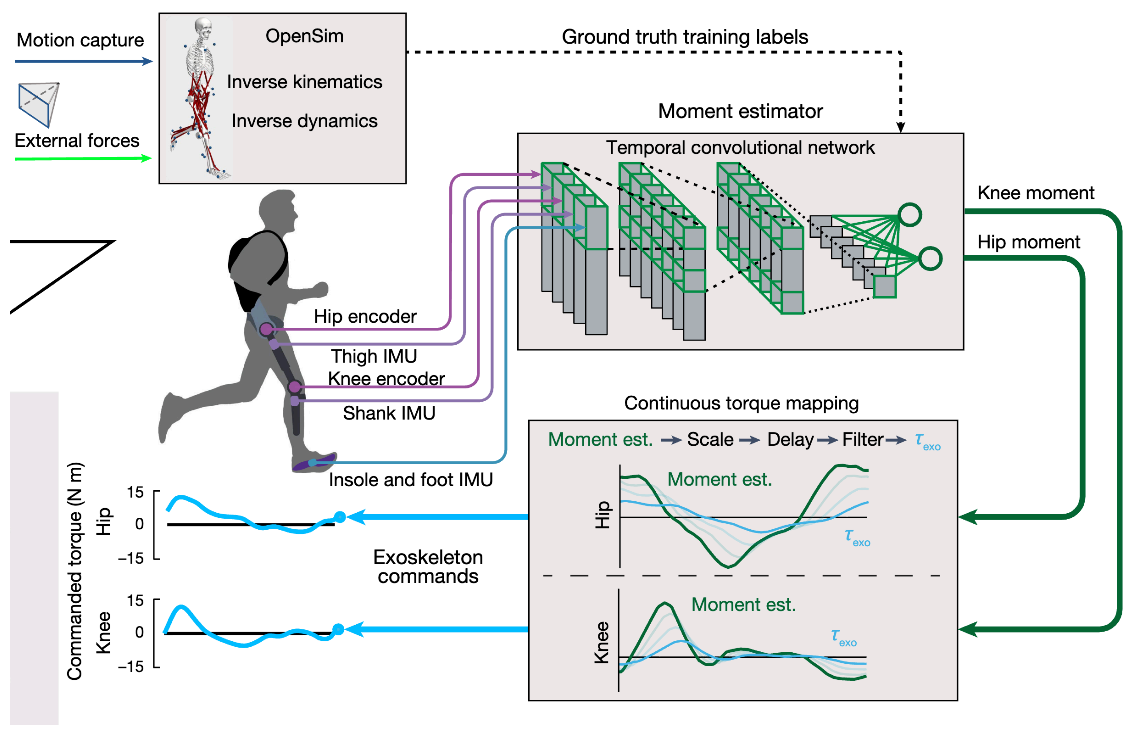
Georgia Tech

EPIC
Exoskeleton & Prosthetic Intelligent Controls
GEORGIA TECH

Research Vision

Enable wearable robots to provide personalized, tuning-free assistance by estimating human physiological states in real-time using deep learning

Key Contributions



AI-Driven Control

Temporal Convolutional Network (TCN) estimates biological joint moments from wearable IMUs in real-time

Without Assistance

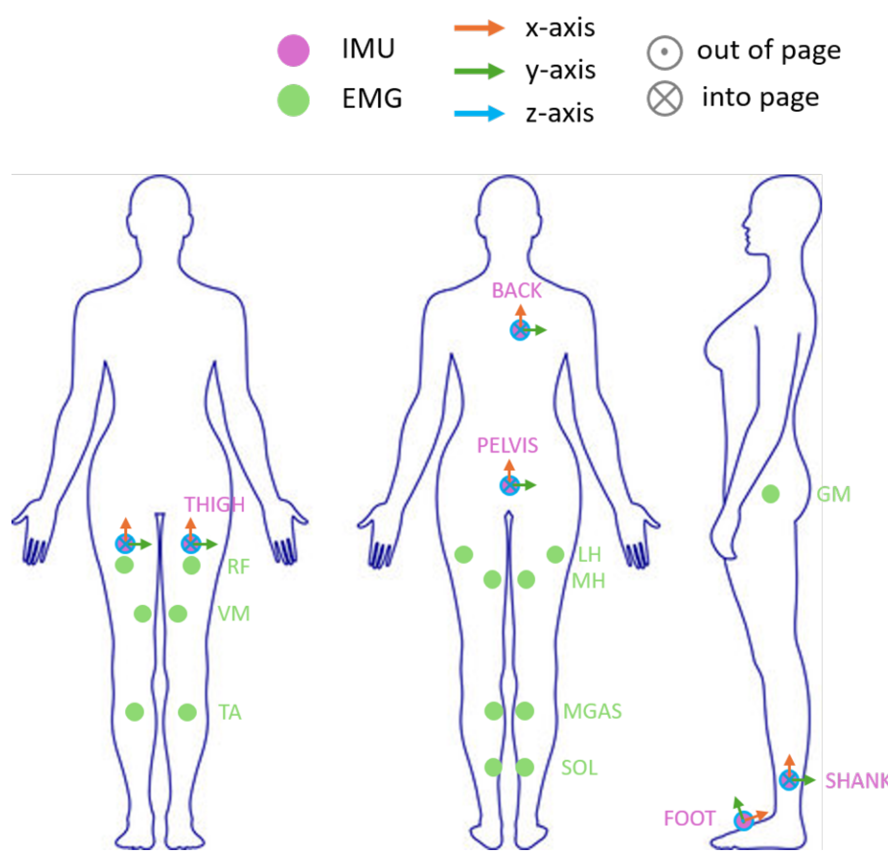
With Assistance

Clinical Validation

First tuning-free hip exoskeleton tested across diverse daily activities in stroke survivors (N=13)

Hardware Design

Designed and fabricated hip exoskeleton optimized for clinical populations



Open-Source Dataset

Comprehensive stroke biomechanics dataset (N=20, 30 activities, multi-modal sensors) to be released publicly

The Problem: Stroke & Mobility

Global Burden

- 1 in 4 people will experience stroke
- 94M survivors
- #2 cause of death and disability

Impact on mobility

- 50-70% reduction in walking speed
- 80% gait asymmetry
- 1.5-2x energy cost
- 2x fall risk

The Gap

7M chronic stroke survivors in US have
limited rehab access after insurance ends.
Assitive robots could restore independence

“Assistive wearables could help—but
require extensive manual tuning”

Technical Challenge: Why Personalization is Hard

Current Exoskeleton Limitations

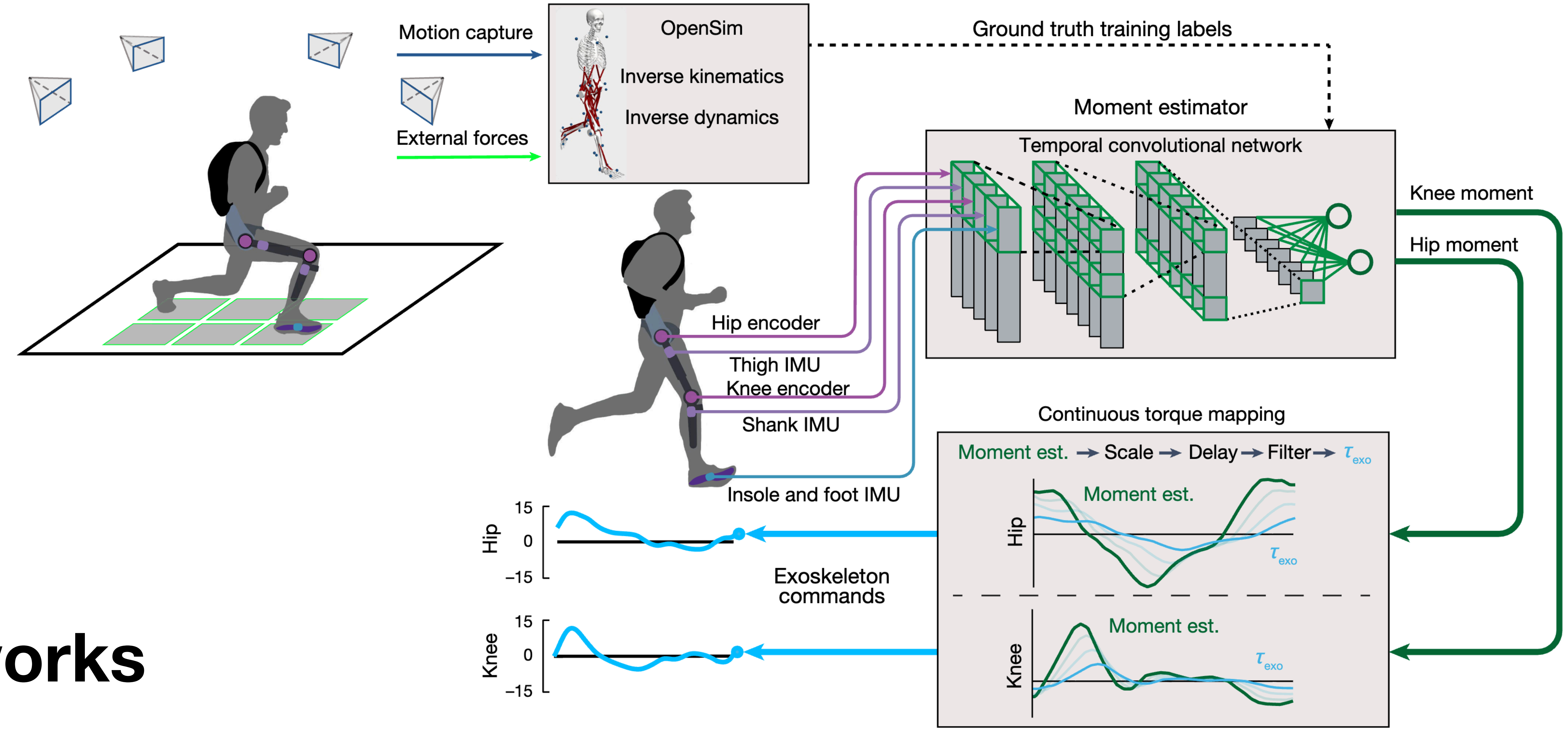
Challenge	Current Approach	Problem
Tuning	Manual parameter adjustment	Required expert; time-consuming
Adaptation	Fixed assistance profiles	Can't adapt to user variability
Activities	Limited tasks	Limited real-world utility
Outcomes	Highly variable	Some users don't benefit

Research Question: "How can we provide personalized assistance that adapts to each user's unique needs without manual tuning?"

My Solution: Use deep learning to continuously estimate the user's biological joint moments from wearable sensors, then provide proportional assistance in real-time

My Approach: Biological Moment-Based Control

Concept: Instead of pre-programmed assistance patterns, estimate what the user's muscles are trying to do, then assist accordingly



Why this works

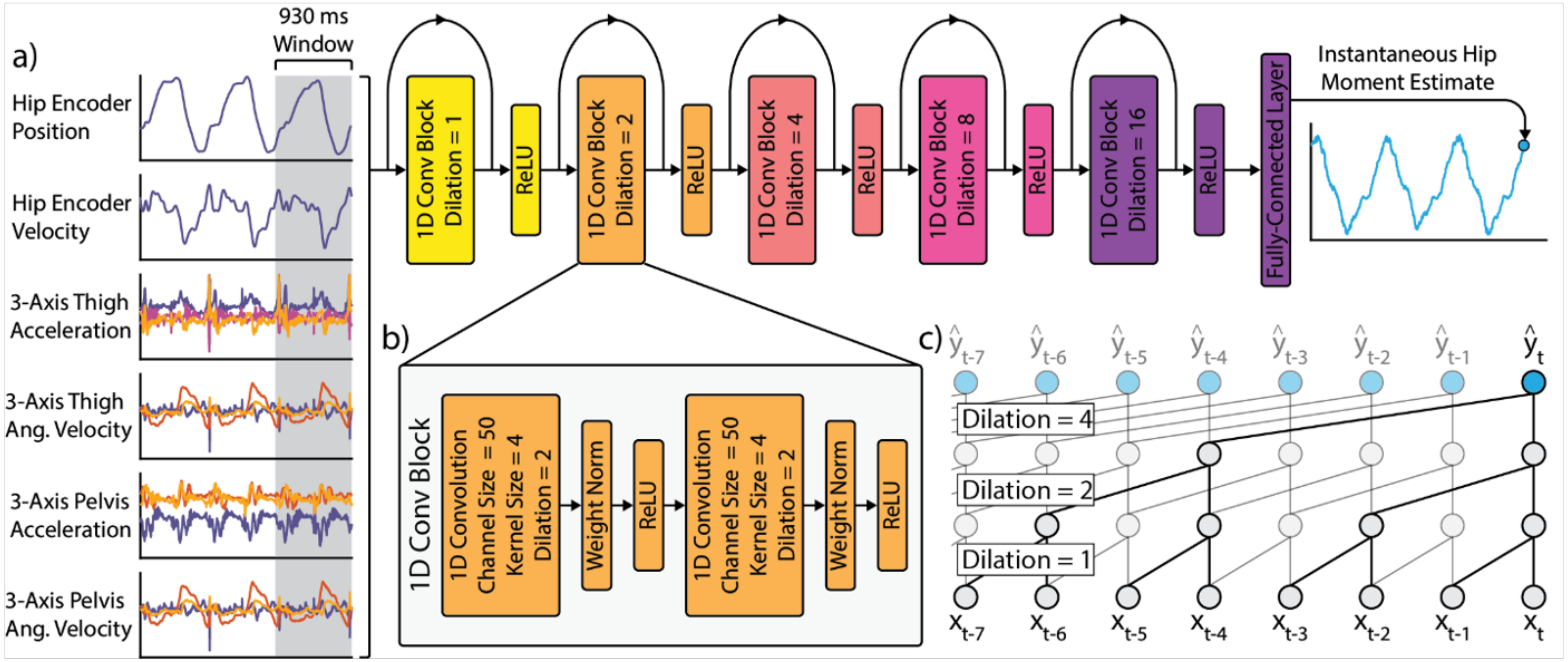
User-independent	Task-agnostic	Volitional
Single model works across different users without retraining	Seamlessly adapts to walk, stairs, sit-to-stand, and other activities	Assistance follows user intent continuously

Method: TCN for Joint Moment Estimation

Input
- 7 IMUs (pelvis,
  thighs, shanks, foot)
- 2 insoles
- 44 features

Architecture
- Temporal Convolutional Network (TCN)
- Causal convolutions
- ~5ms inference

Output
- Bilateral hip moments
  (Nm/kg)

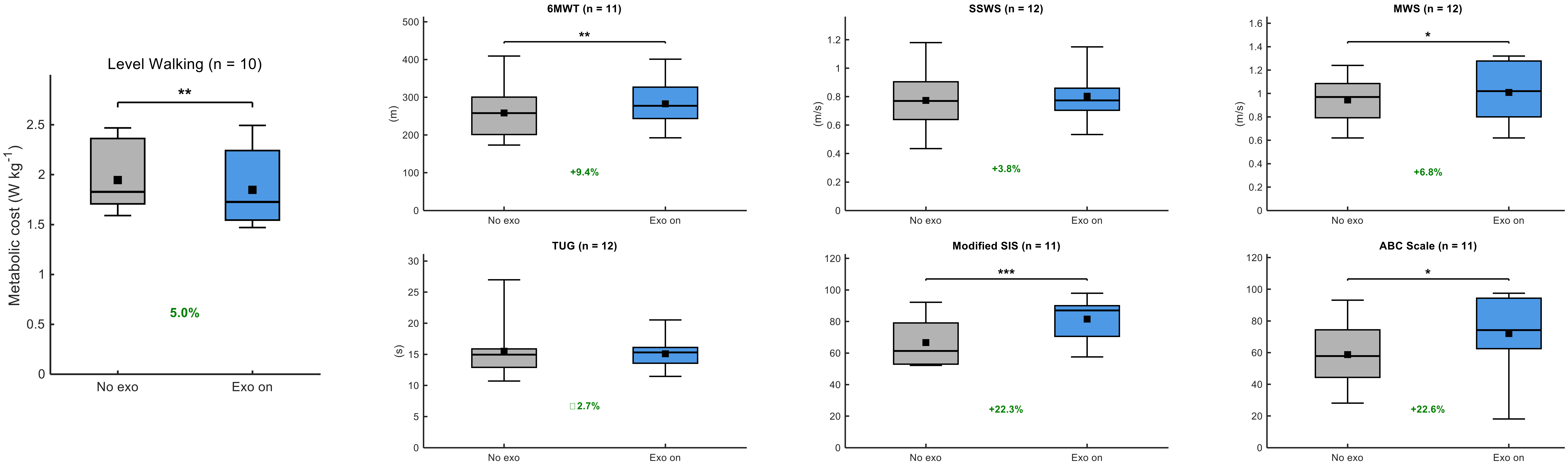


Training Data: N=20 stoke, 39 activities, motion capture + force plates + IMUs

Targeting *Nature Medicine* (Feb 2026)

Results: Clinical Trial (N=13 Chronic Stroke)

Study Design: 2-day protocol, No Exo vs. Exo with TCN-base control



Improved metabolic costs, gait quality, and quality of life

Key Insight: The same controller, without any tuning, automatically adapted to individual deficits without any tuning

Hardware: Hip Exoskeleton Design

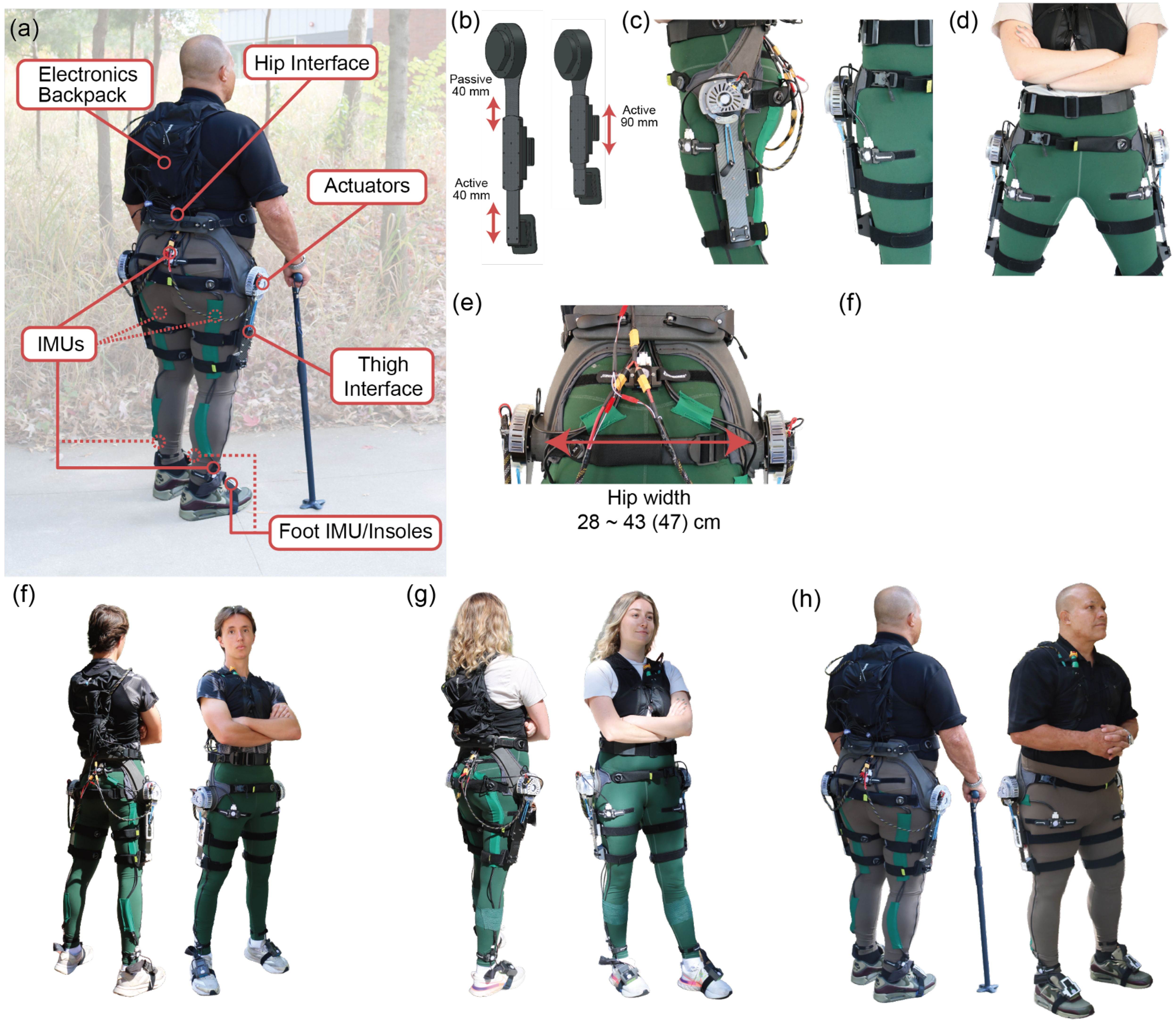
Specifications

- Bilateral hip flex/extension assistance
- Peak torque: 15 Nm
- Weight: 2.68 kg

Clinical Features

- Adjustable hip width for diverse body types
- Quick-adjust thigh cuffs for easy donning
- Passive ab/adduction to not restrict natural movement
- “Second Skin” sensor integration for comfortable IMU placement

I designed and fabricated this system, iterating based on feedback from stroke survivors and clinicians



Dataset Contribution: Open-Source Resource

Dataset Overview

Participants

- N=20 stroke + N=5 able-bodied controls

Activities

- 39 daily living tasks

Modalities

- Motion capture
- Force plates
- IMUs
- EMG

Curb Up

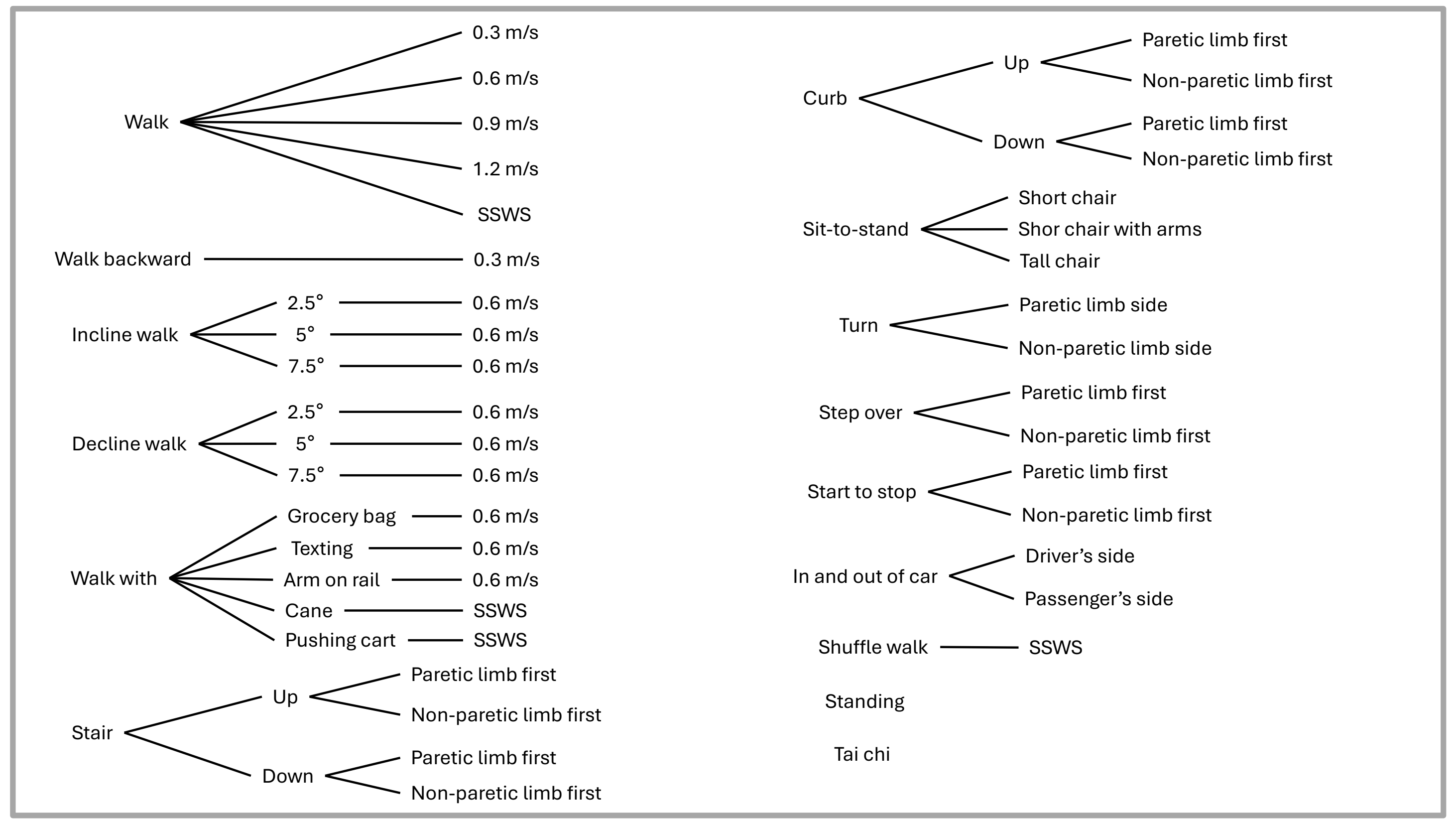
Sit to Stand

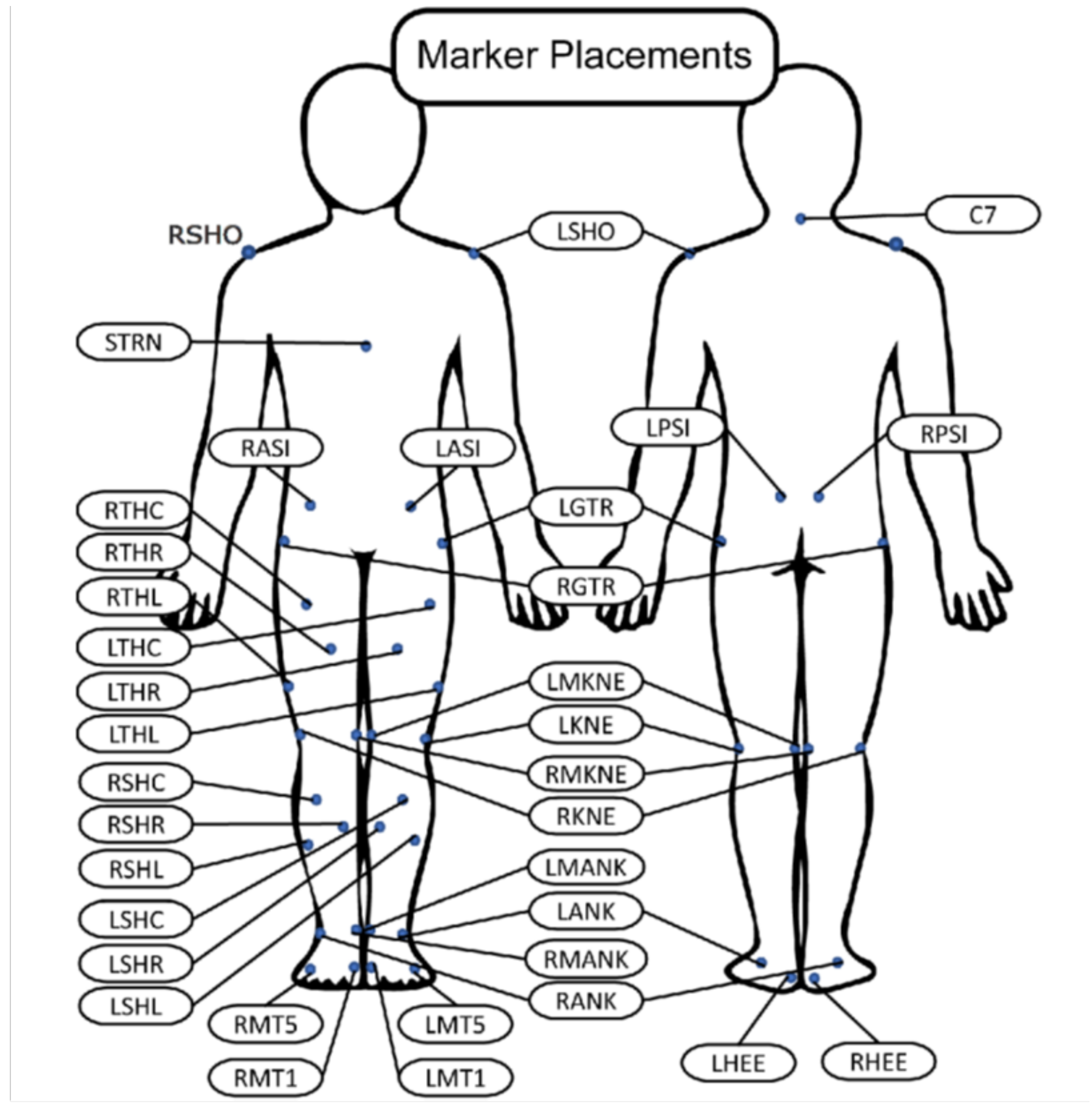
Step Over

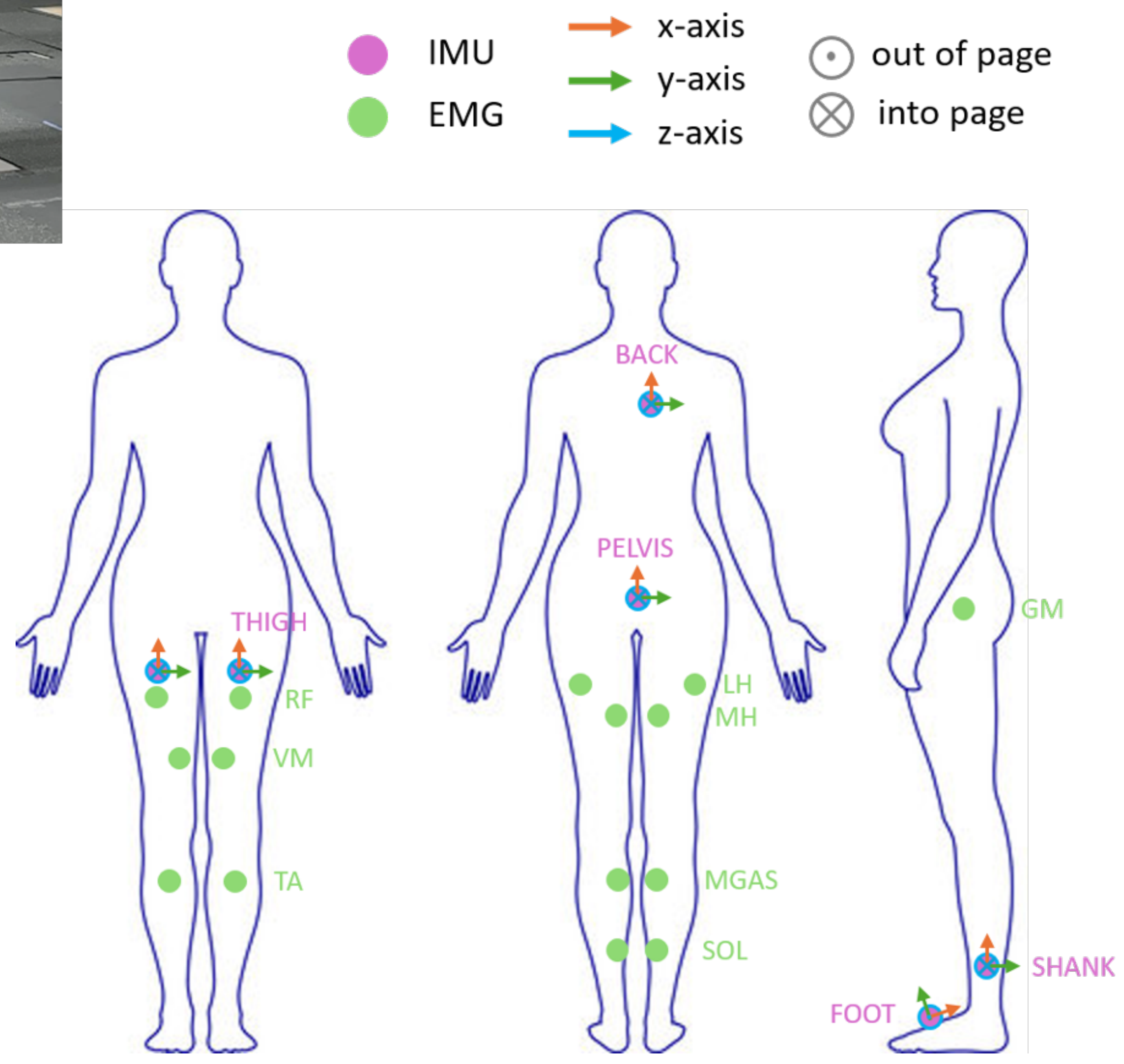
Start to Stop

Turn

Tai Chi







Future Vision: From Rigid Sensors to Soft Biointerfaces

<table>
<tr><th colspan="2">Current (My Work)</th><th colspan="2">Future (Bao Lab Synergy)</th></tr>
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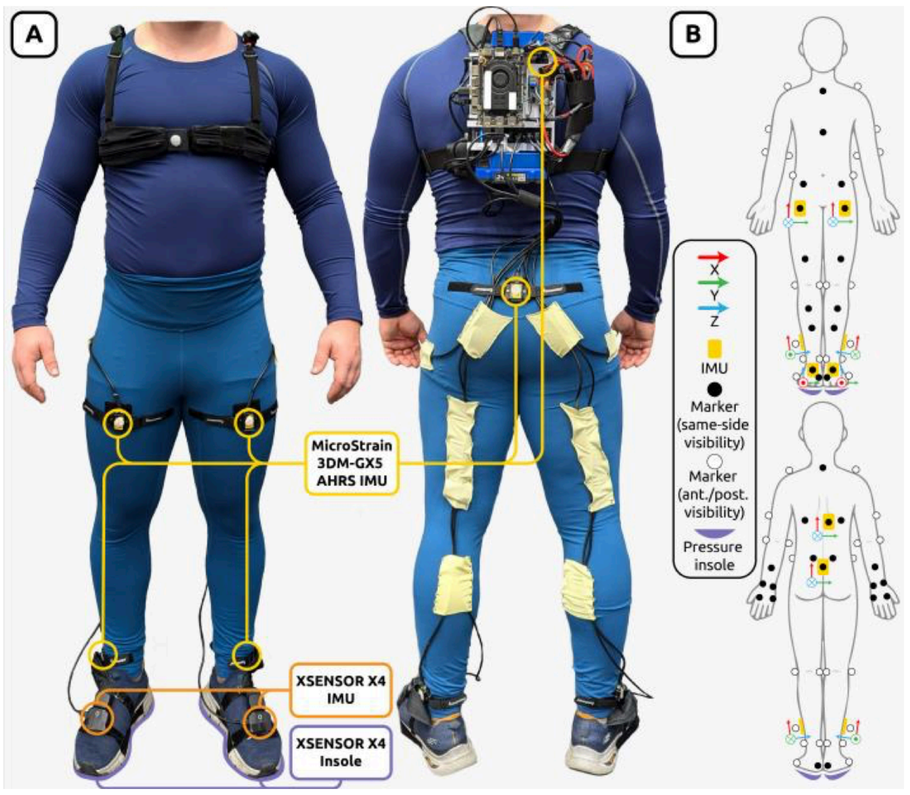
<td>
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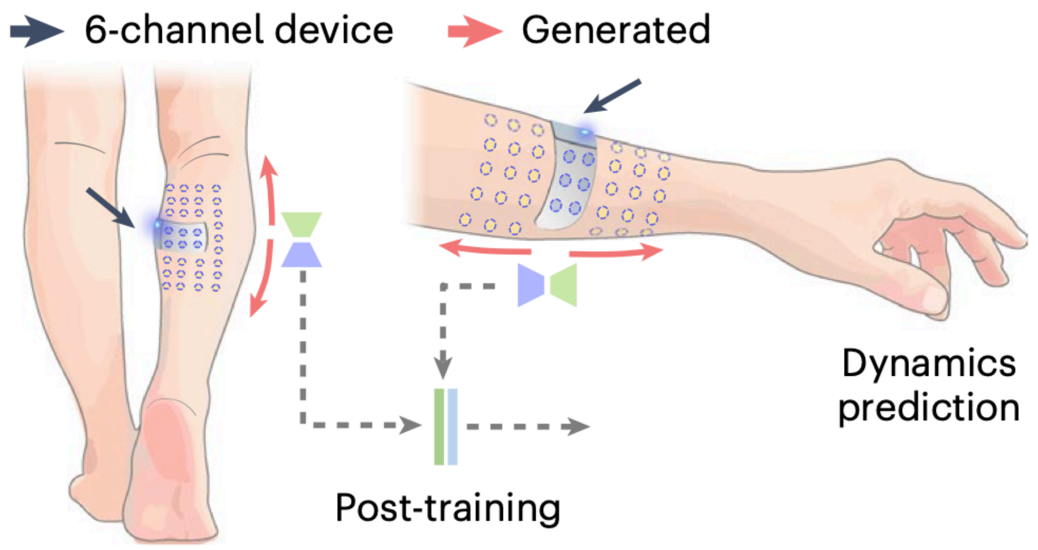
<td>- Rigid IMU sensors
- Strap-based attachment
- Fixed sensor locations
- Rehabbilitation-focused</td>
<td>
</td>
<td>- Soft, skin-integrated sensors
- Conformal, comfortable adhesion
- Flexible placement with generative learning
- Broader health monitoring applications</td>
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Inspired by GenENet (Kim & Bao, *Nature Sensors* 2025)

- Generative representation learning achieves 32-channel EMG performance from 6 channels
- Similar approach could enable rich physiological estimation from minimal soft sensors

Vision: Combine my experience in real-time physiological estimation and closed-loop control with Bao Lab's soft sensor expertise to create next-generation wearables that are:

- **Comfortable** enough for all-day wear
- **Intelligent** enough to interpret complex physiology
- **Adaptive** enough to provide personalized interventions

Applications: Stroke rehabilitation, Parkinson's monitoring, fall prediction, cardiac health

Summary & Publications

Summary

- Developed deep learning methods for real-time joint moment estimation from wearable sensors
- Validated tuning-free hip exoskeleton control in stroke clinical trials
- Designed exoskeleton hardware optimized for clinical populations
- Building open-source multimodal stroke biomechanics dataset

Selected Publications

In Preparation

- Park et al. “A versatile, tuning-free hip exoskeleton improves real-world mobility in a clinical trial with stroke survivors” Targeting *Nature Medicine (Feb 2026)*
- Park et al. “A comprehensive dataset of lower-limb biomechanics and wearable sensor measurements in stroke survivors during daily living activities and clinical assessments.” Targeting *NEJM AI (Mar 2026)*

Published

- Park et al. "Human-in-the-loop optimization of hip exoskeleton assistance during stair climbing” *IEEE T-BME* 2025 (Featured Article)
- Kang, Molinaro, Park et al. “Online adaptation framework for exoskeleton assistance in stroke" *IEEE T-RO* 2025
- Choi et al. "Overground gait training with wearable robot in children with cerebral palsy” *JAMA Network Open* 2024

Total: 13 published journal papers & 10 abstracts/conference papers

Thank you

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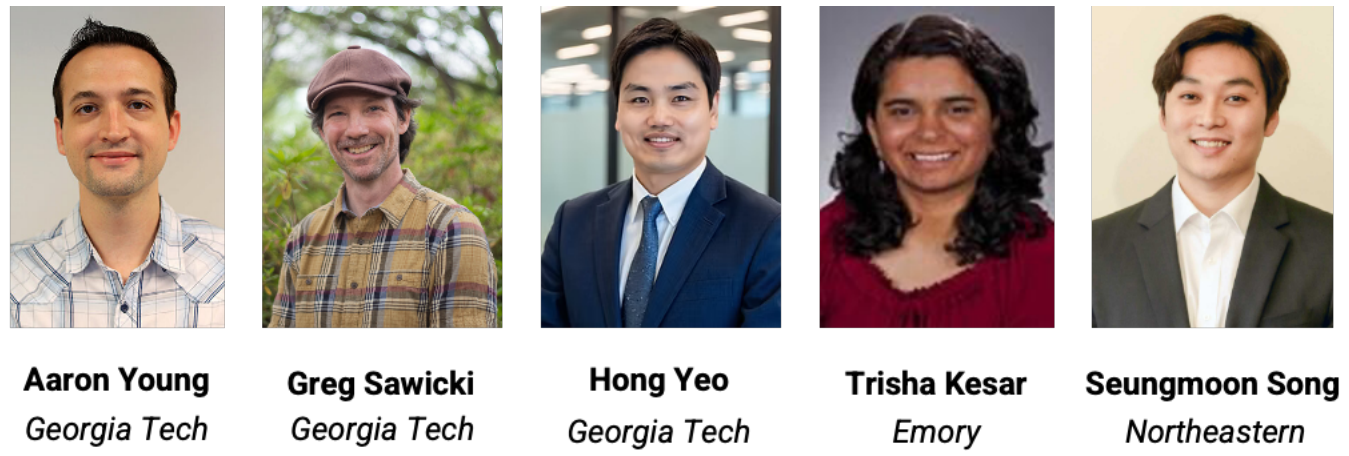
Thesis Committee



(Videos and additional details available on website)

References

- Dr. Aaron Young (Doctoral Advisor) — aaron.young@me.gatech.edu
- Dr. Gregory Sawicki (Committee & Collaborator) — gregory.sawicki@me.gatech.edu
- Dr. Trisha Kesar (Committee & Collaborator) — trisha.m.kesar@emory.edu