

A Wearable Multimodal Ultrasound+Inertial System for Real-Time Virtual Reality Interaction

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* Equal contribution

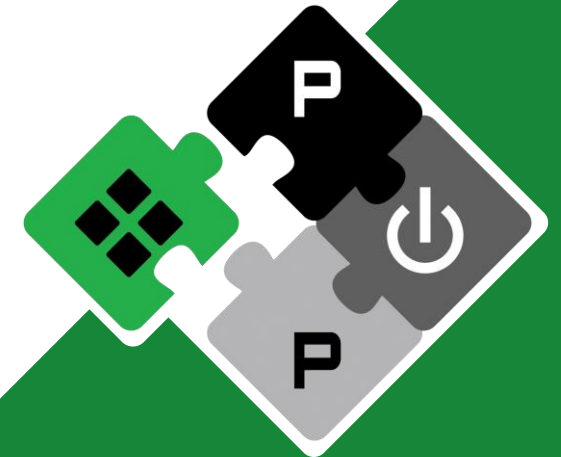
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* Equal contribution

PULP Platform

Open Source Hardware, the way it should be!



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Hand-Gesture Interfaces for Immersive VR



Immersive VR

Gaming


Meta Connect 2026

75+ VR games playable with
hand gestures alone
no controllers

Vision

- ✗ Constraints on user freedom
- ✗ Complex algorithms required



SENSING TECHNOLOGIES

Mechanical



- ✗ Sensor drifts over time
- ✗ Not suitable for impaired

BioSignals

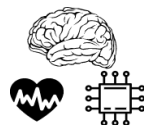
- + Bio-Inspired Human machine interaction strategies
- + Wearable and low-power
- + Hands-free control



EMG



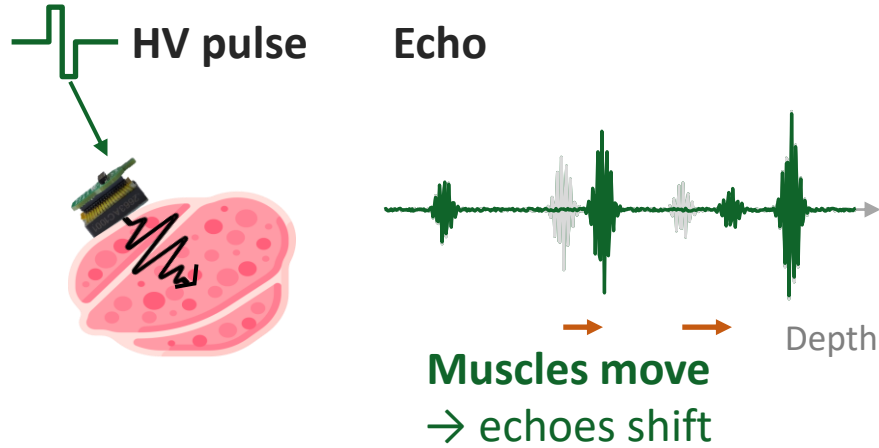
Ultrasound



Multimodal Wearable US + Accelerometer Sensing for Novel Human Machine Interfaces



A-mode Ultrasound



✓ Superficial and deep muscles

Why US alone?

Previous works have shown benefits of multimodality [Yin 2025; Spacone 2025]

US

Muscle deformation

ACC

Arm orientation

Complementary

Limitations of Previous Solutions

- ✗ Not fully wearable (up to 610 g, 12 W)
- ✗ Single body site
- ✗ Single modality

[Sgambato, 2025]

This work: A Wearable, Distributed, Multimodal End-to-End Framework for VR interaction

Hardware

WULPUS
US &
Accelerometer

Wearable
ARMBANDS

Software

BIOGUI

VR
Interaction

Algorithmic Pipeline

US + ACC
CNN

Few-shot
Fine-Tuning

Live Validation



A Spotlight on the System



Hardware

WULPUS

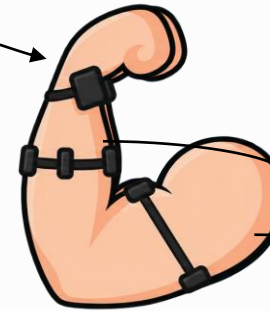
- 8 US channels (6 used)
- Accelerometer
- 19.9 mW → 2.5 days



Frey et al., 2022

DISTRIBUTED SENSING

- Hydrogel pads, no US gel
- 2.25 MHz Transducers
- Sensing Units:
 - 4x Forearm
 - 2x Upper Arm

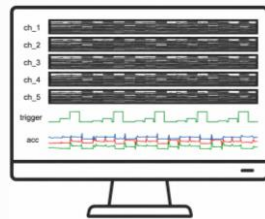


Software

HW

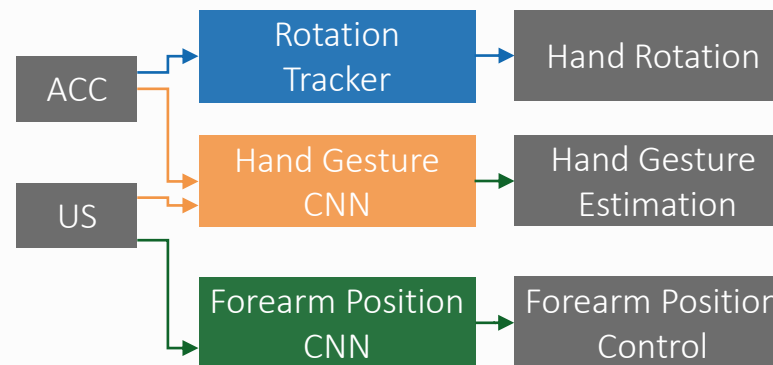


BIOGUI



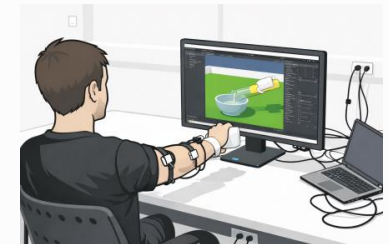
Raw
Data

PROCESSING LAYER



Control
Commands

APPLICATION LAYER



Phase 1: Offline Data Collection



5 subjects

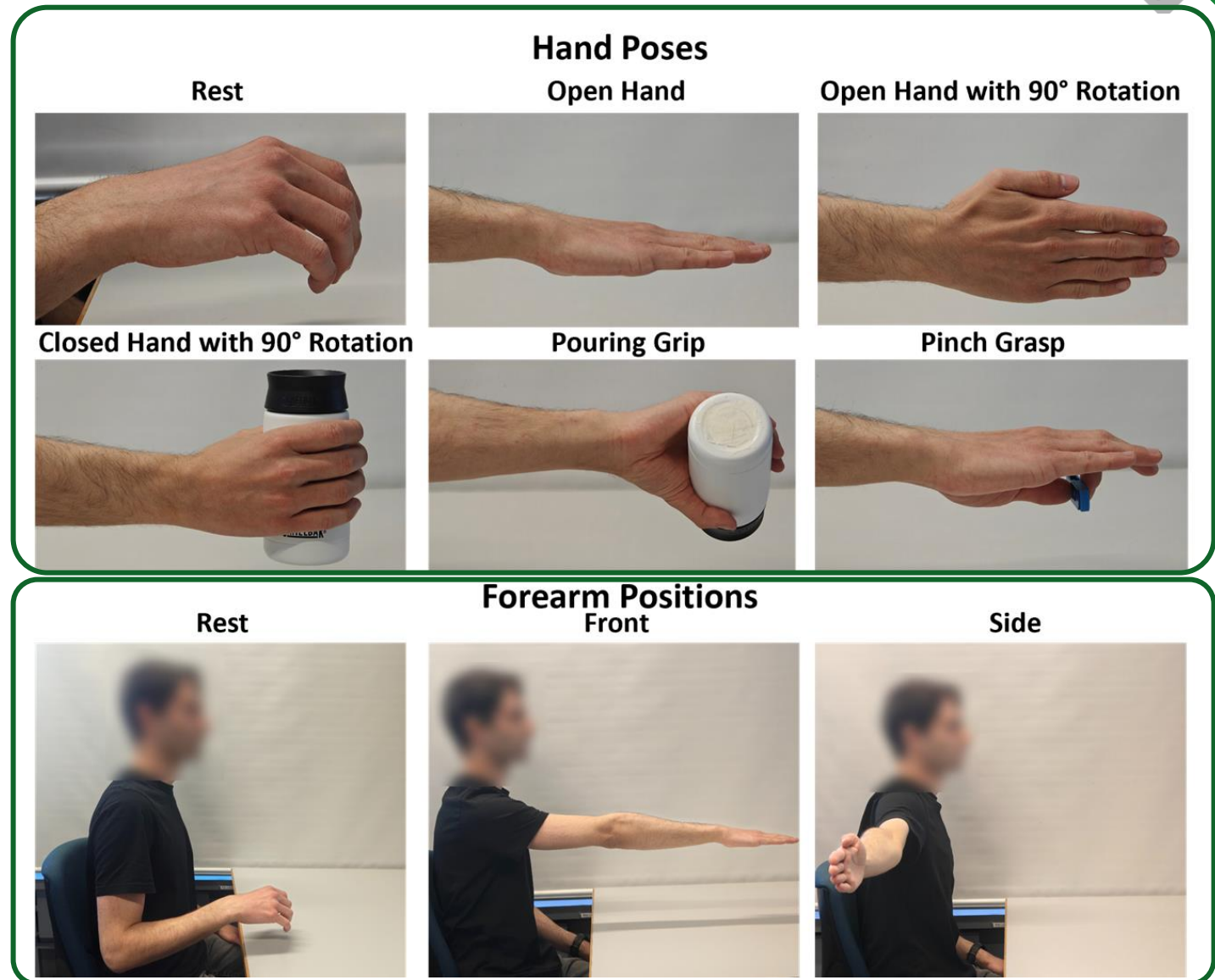
3 tasks

- Functional for VR: **manipulate objects and relocate them**
 - Cylinder manipulation and relocation
 - Liquid Pouring
 - Object pinching and relocation
- Movements repeated 5 times



6 hand poses

3 forearm positions



Phase 1: Offline Data Collection

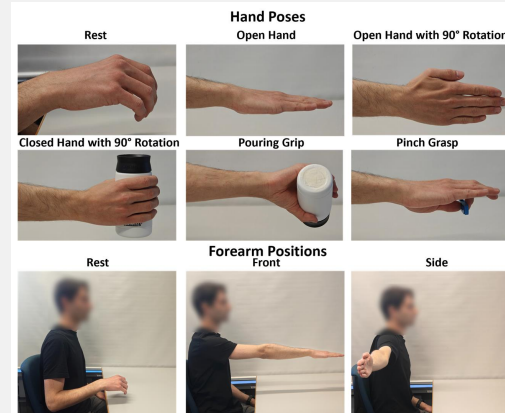


Data Collection

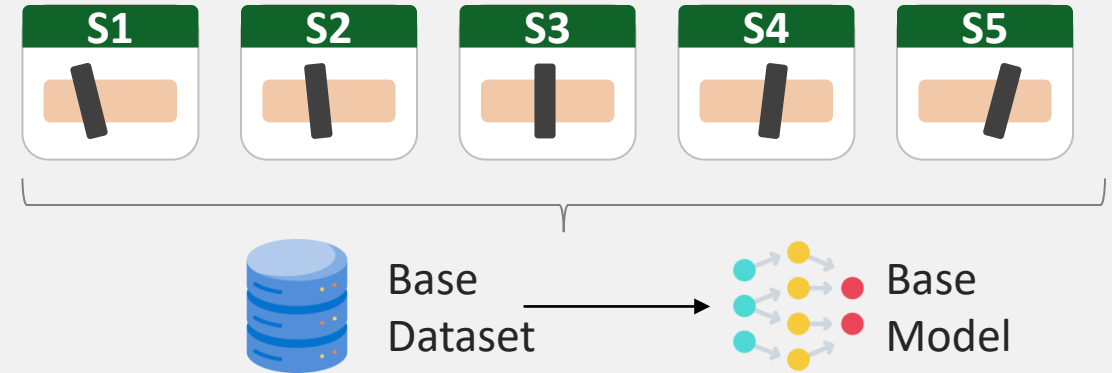
5 subjects

3 tasks: object manipulations and relocations, 5 repetitions per movement

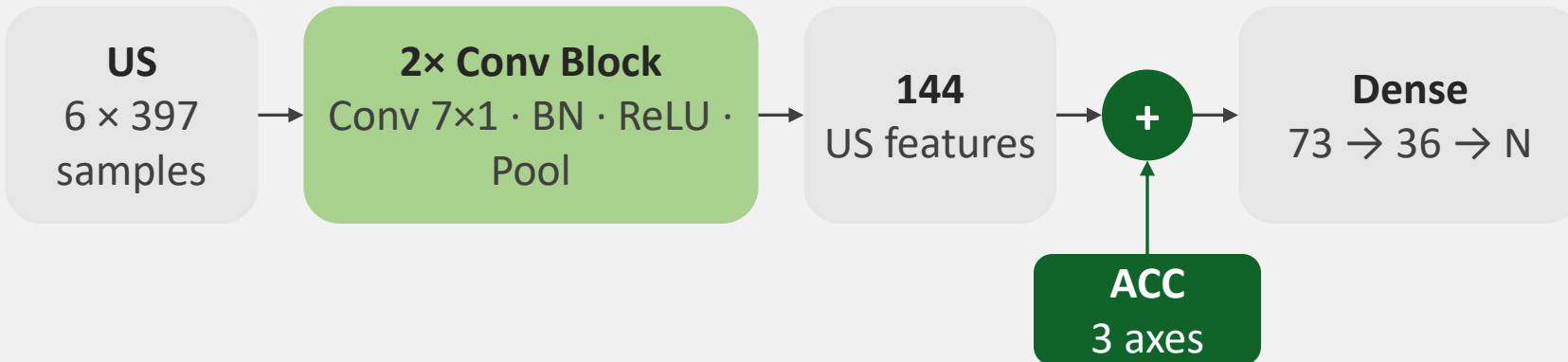
BIOGUI guided



5 sessions: Multiple Days, Armband Re-Applied



Model Architecture



< 14 k parameters

Late fusion: $144 + 3 = 147$

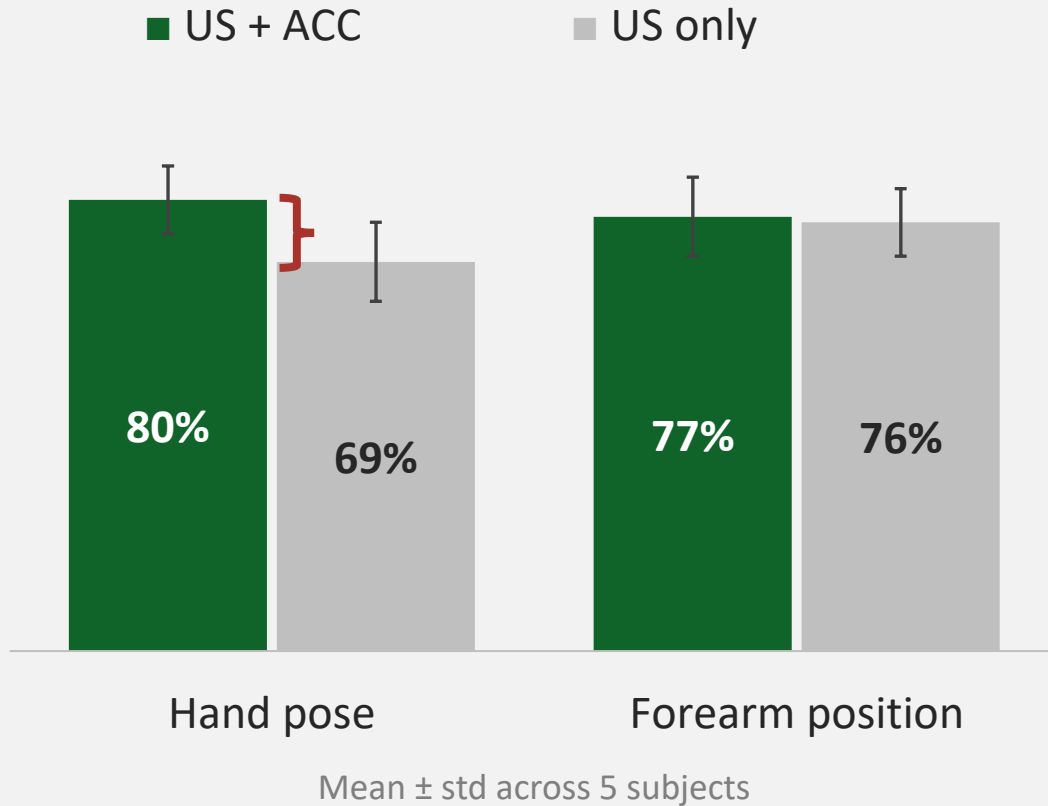
$N = 6$ hand poses

$N = 3$ forearm positions

- Leave-one-session-out
- Subject-specific models

Offline Analysis Results

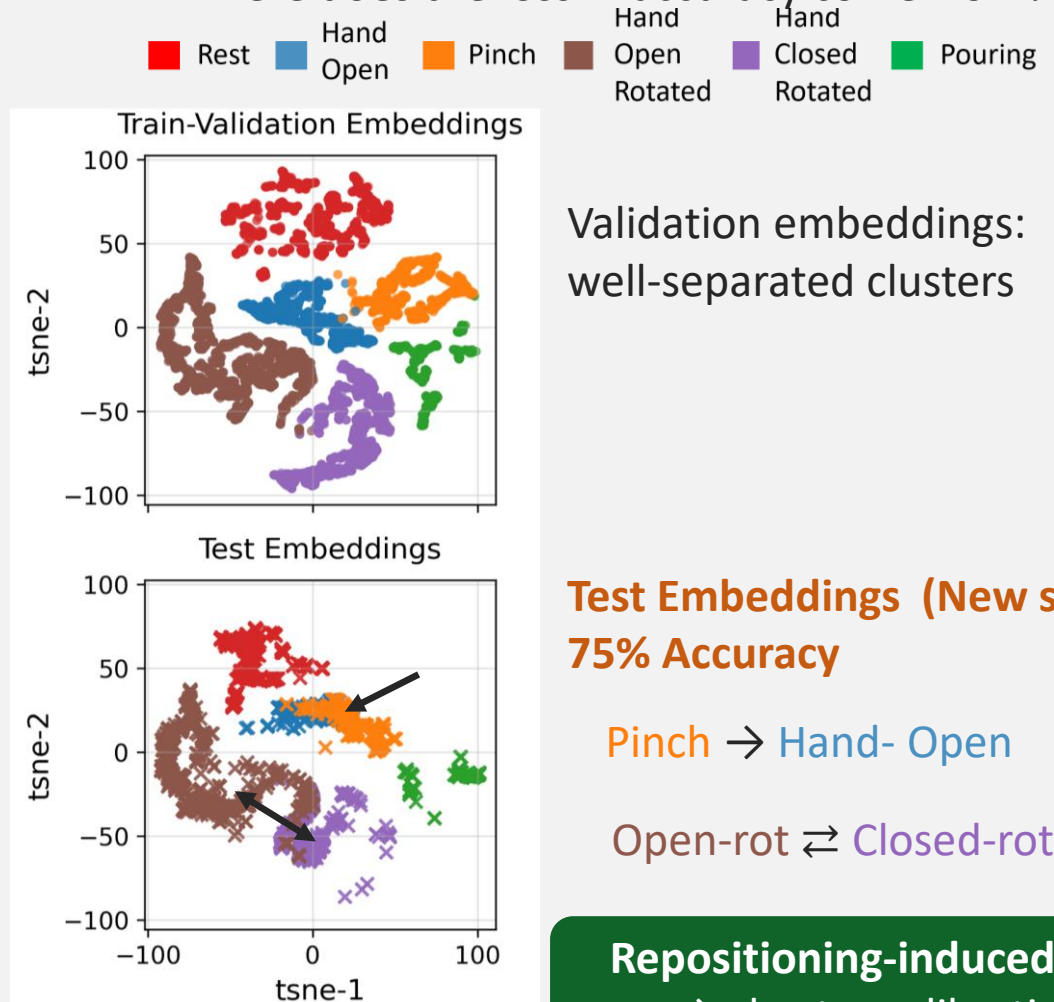
Balanced Accuracy, Leave-One-Session-Out



Multimodal > single modality: +11 pp on hand pose

Is this enough for seamless online interaction?

Where does the loss in accuracy come from?



Phase 2: Incremental Fine-Tuning

New Day, New Data Collection



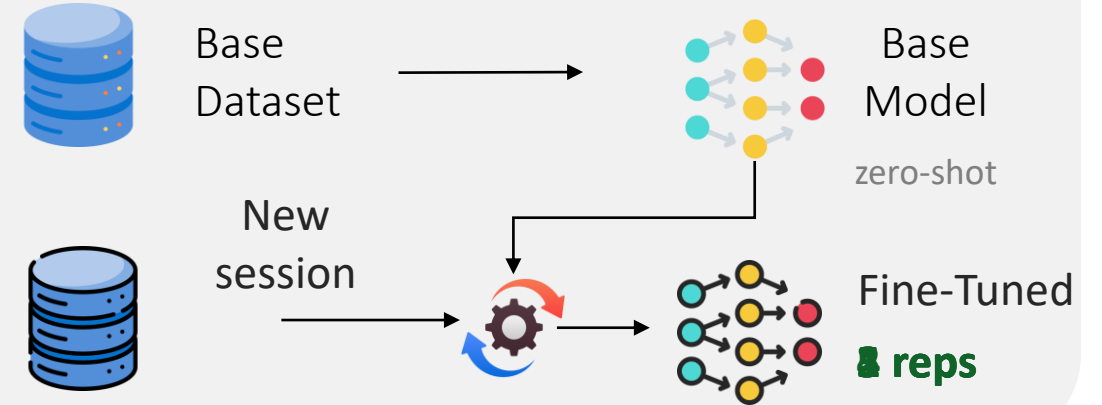
Armband re-applied

Same 3 tasks × 5 reps



→ fine-tuning
3 reps ≈ 5 min

Model Fine-Tuning



Live Evaluation Methodology



All 6 tested
randomized, blinded

fine-tuned on 1–5 reps

SR Success Rate

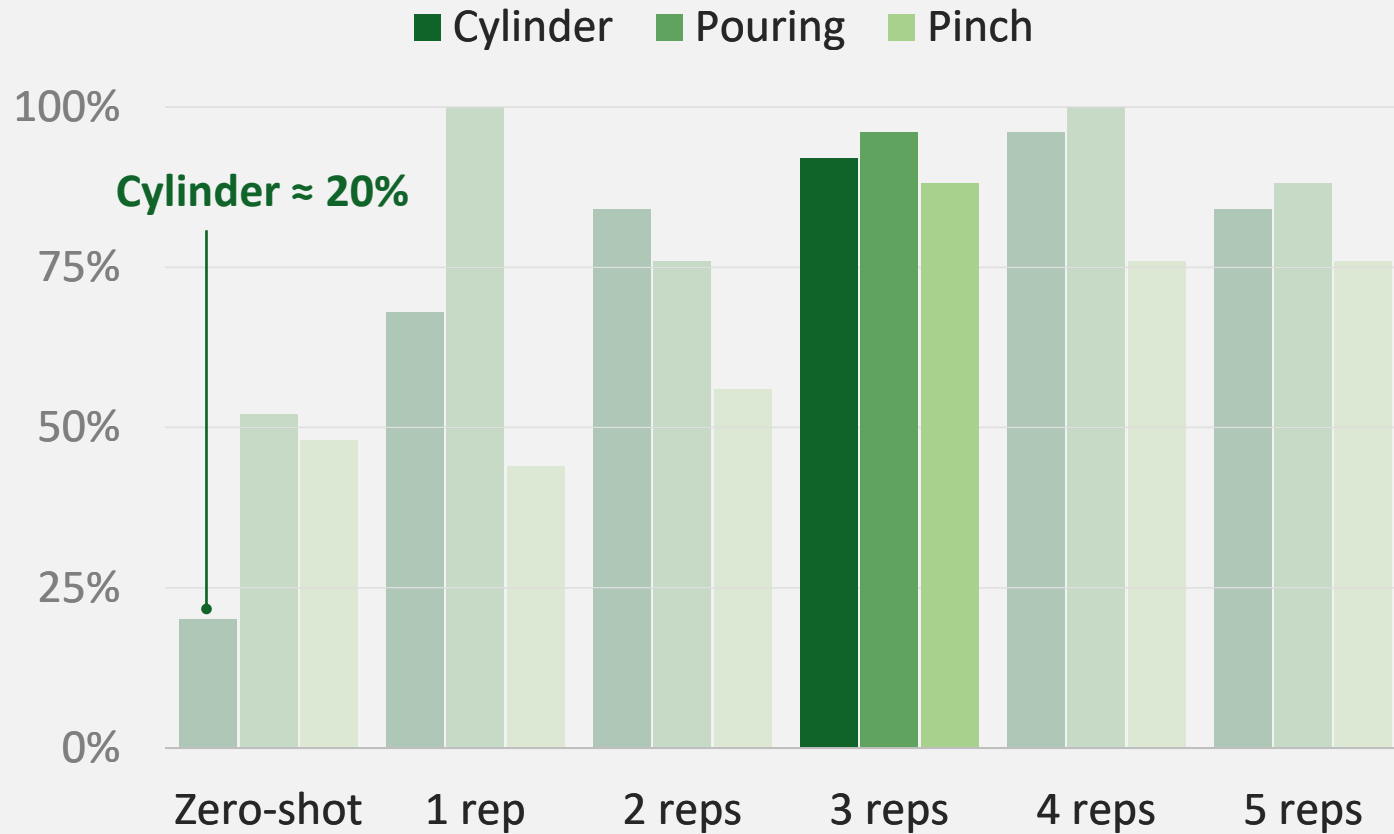
CT Completion Time

3 tasks × 5 trials
30 s timeout

Live Validation Results



Live Success Rate, 5 subjects



With 3 Fine-Tuning Reps



92%

Cylinder
CT 10.5 s



96%

Pouring
CT 8.0 s



88%

Pinch
CT 10.8 s

3 repetitions | 5 min of recalibration → ≥ 88% live success on all three tasks

Our System in Action

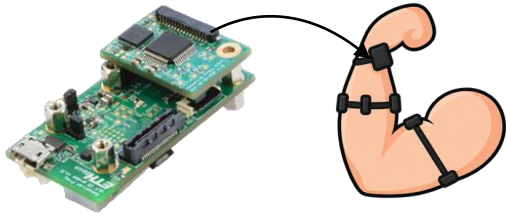


Conclusions



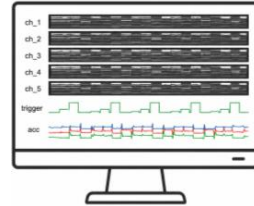
Wearable End-to-End Framework for VR

Hardware



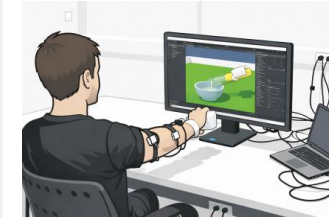
- Wearable, wireless, **19.9 mW**
- Wearable and distributed sensing

Software



Open-source, modular stack
BioGUI + Unity: data collection & live processing

Results



80% offline
accuracy 6 hand poses
≥ 88% task
success rate
after ~5 min recalibration

Limitations and Future Work



Few channels



**More channels
& new sites**



Model architecture



**Larger model
capacity**



US + ACC only



+ EMG fusion



Discrete, ~1 s latency



**Proportional
control**



5 subjects, 3 tasks



Larger cohort

Thanks for Your Attention!

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BIOGUI

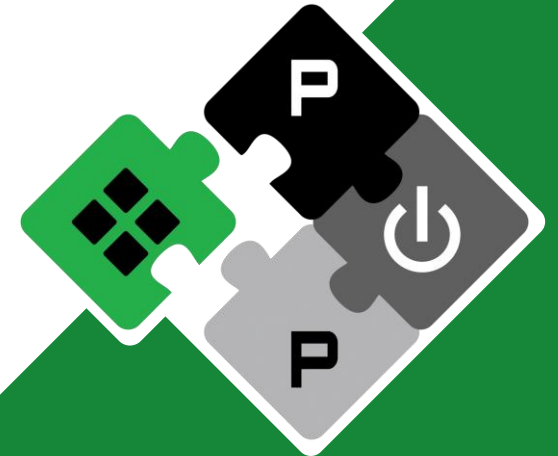


WULPUS



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