Towards Whole Hand and Wrist Kinematic Tracking with a Wearable A-Mode Ultrasound Probe

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INTRODUCTION

A-mode US: enabler for **wearable** Hand Gesture Recognition (HGR) [1]

Need for **continuous** hand – wrist kinematic tracking → **Regression** of multiple Degrees of Freedom (DoFs)

[2] 2 DoFs (R^2 = 0.96) [3] 4 DoFs (R^2 = 0.94)
[4] 3 DoFs (R^2 = 0.87, MAE=5.3°, RMSE=7.32°)

Prior works:

- ✗ **Low** number of **DoFs**
- ✗ **Portable** systems [6] → no wearability
- ✗ **Power-hungry** [5] → short-term use
- ✗ Lack of/ limited **AI** capabilities

Objectives

- 🎯 Whole hand – wrist kinematic tracking
- 🎯 Wearable-requirements: low power, easy to use, comfortable
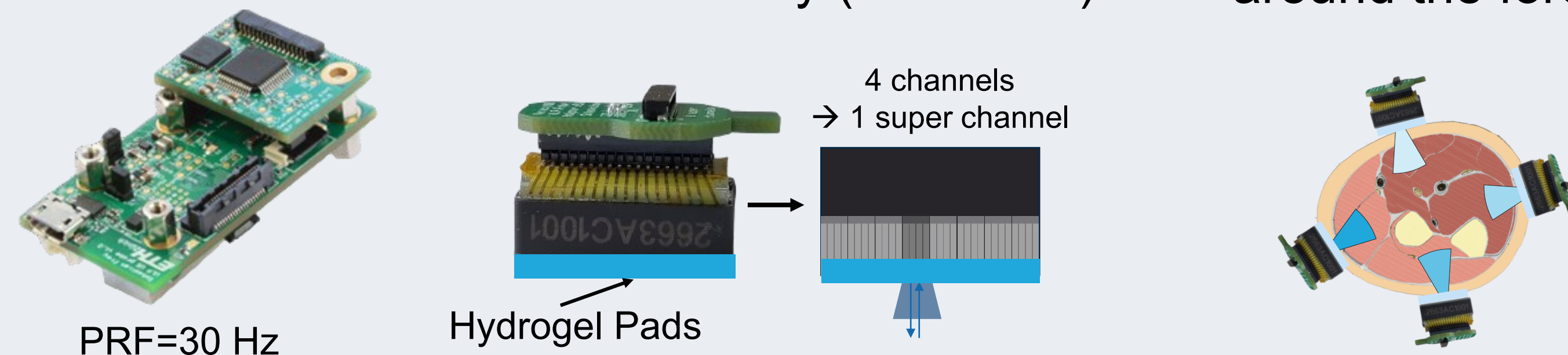- 🎯 End-to-end, on device

METHODS

Acquisition System

WULPUS [7]

32 element linear transducer array (2.25 MHz)

4 super-channels around the forearm

4 channels → 1 super channel

PRF=30 Hz

Hydrogel Pads

Data Collection

Wearable Armband

Ground Truth MANUS Glove

Acquisition Sets (S)

6 Hand Movements … 5 Wrist Movements

Session 1	Session 2	Session 3
S1 S2 S3 S4 S5	S1 S2 S3 S4 S5	S1 S2 S3 S4 S5

Sensors repositioning

Multi-Task Network Architecture for Regression

Raw Data

Ch1, Ch2, Ch3, Ch4 → CAE

Single-channel Unsupervised Feature Extraction [8]

Cross-Channel Feature Learning

Multi-Task Regression Heads

Conv 2D k_s=(4x4x3)

25 x 4 x 1

MaxPool 2D

25 x 4 x 3   25 x 1 x 3

20 Hand Angles

3 Wrist Angles

75 37

400 x 1   25 x 1
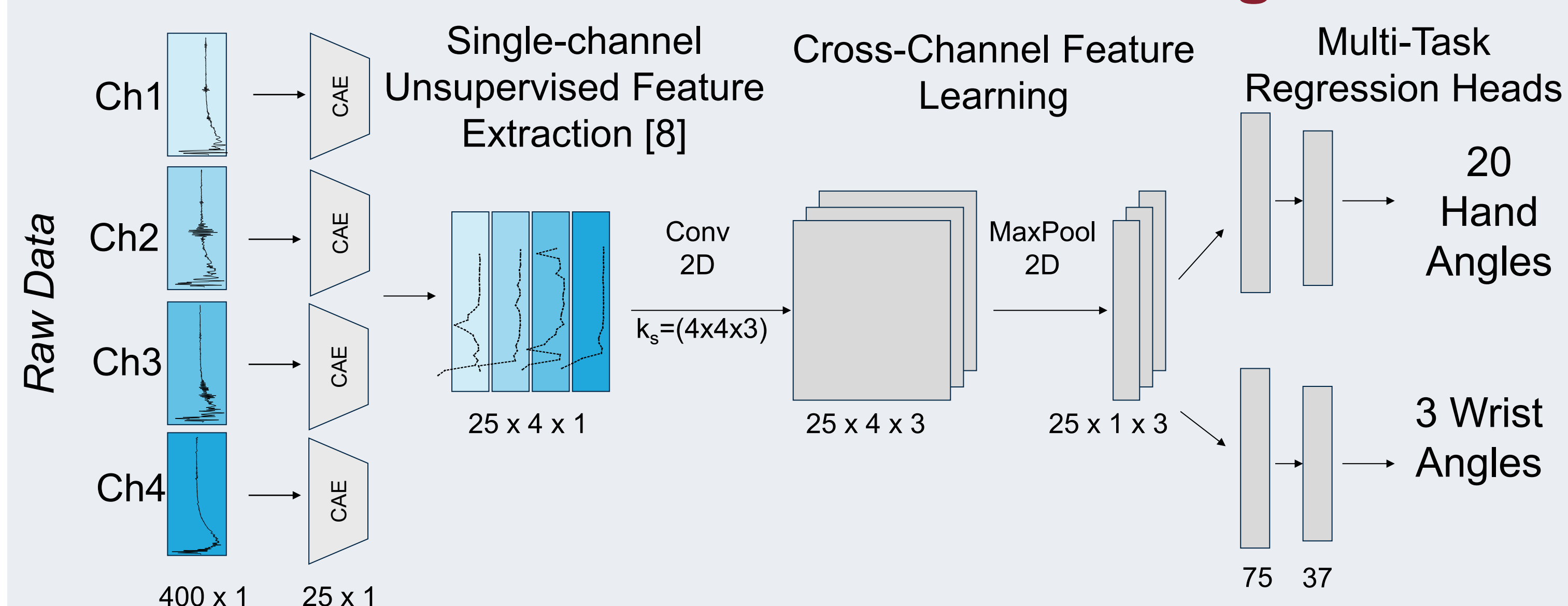
- Cross validation: 3 sets per session to train, 1 to validate, 1 to test

Embedded Implementation

- Deployment on WULPUS **NRF52 MCU**

MSP430 — PULSER → MCP1416 MOS-FET → HV 2708 8:1 Mux

ADC ← PGA ← OPA 836 ← MD0101 T/R switch

SPI

NRF52

Channel c → Single-Channel Unsupervised Feature Extraction → Feature Buffer (Channel c=1, Channel c=2, Channel c=3, Channel c=4) → Regression → Result Transmission → Host PC
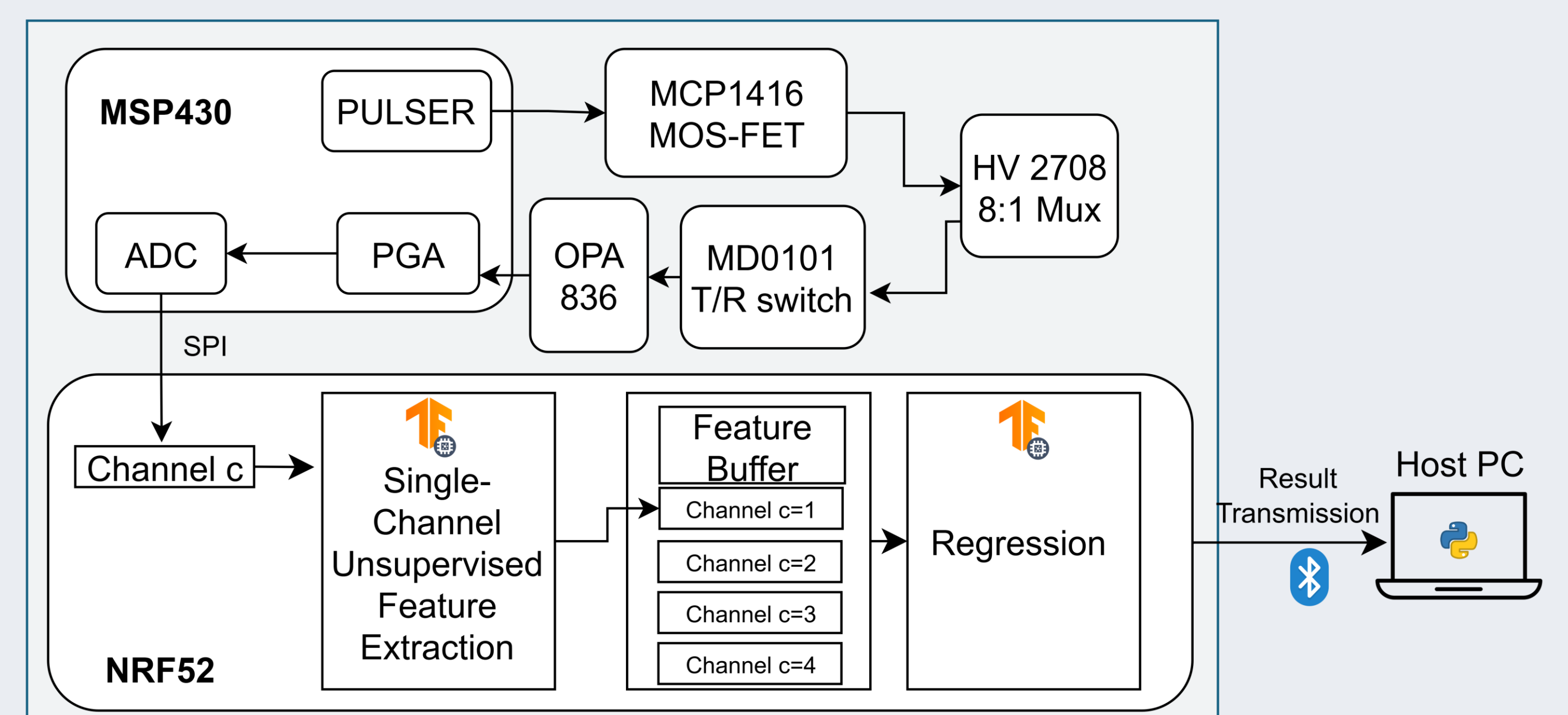
RESULTS

a) Tracking of Wrist and Hand Kinematics

- **RMSE= 10.3° ± 0.7°**
- **MAE = 6.9°± 0.6°**
- **R^2 = 0.59 ± 0.04**
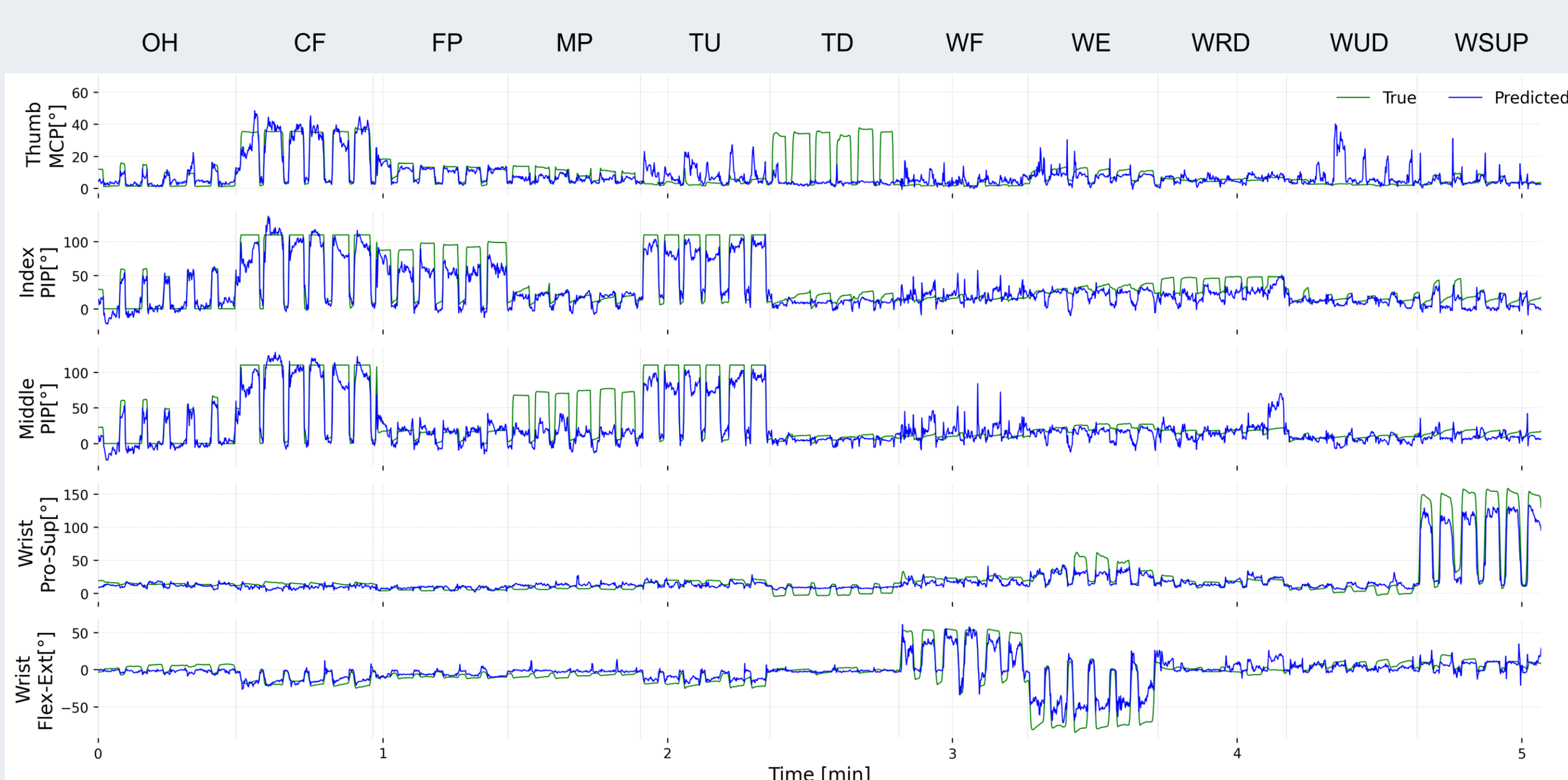
Green: ground-truth joint angles, Blue: model prediction

b) Embedded Implementation

FLASH: **14.8 KB**
RAM: **9.8 KB**

Inference Time: **23.7 ms**

Energy/Inference **0.6mJ**

CONCLUSION

First-time **whole hand-wrist kinematic tracking** with WULPUS → **23 DoFs** (only 1.4x higher RMSE than [4] for a 7x larger #DoF)

Inference time **<24ms** → meets the **latency** requirements for **embedded applications** such as prosthetic control

88% wireless link **bandwidth reduction** with results-only transmission → improved **reliability**

< 30 mW power consumption → **continuous operation** for **40 hours**

REFERENCES

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[4] G. Spacone et al., *IEEE T-BioCAS*, 2024
[5] X.Yang et al., *IEEE Trans. Syst. Man Cybern*, 2019
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