Wearables and at-body AI for next generation human-machine interfaces: an arm-centric approach

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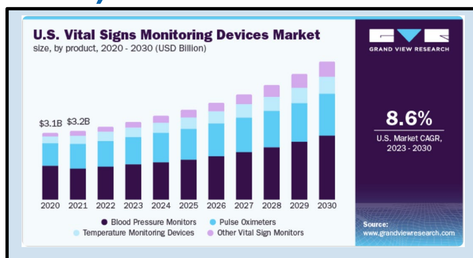
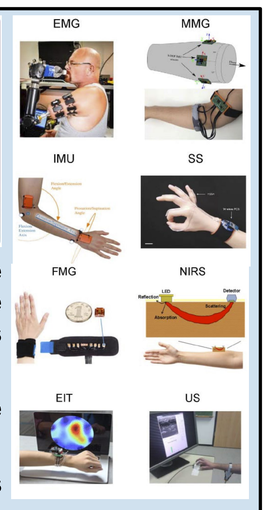
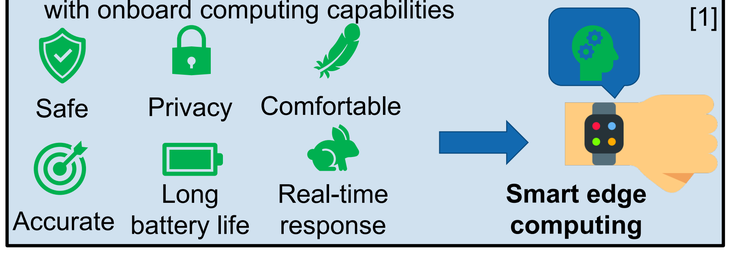
1) Wearable Devices as HMIs





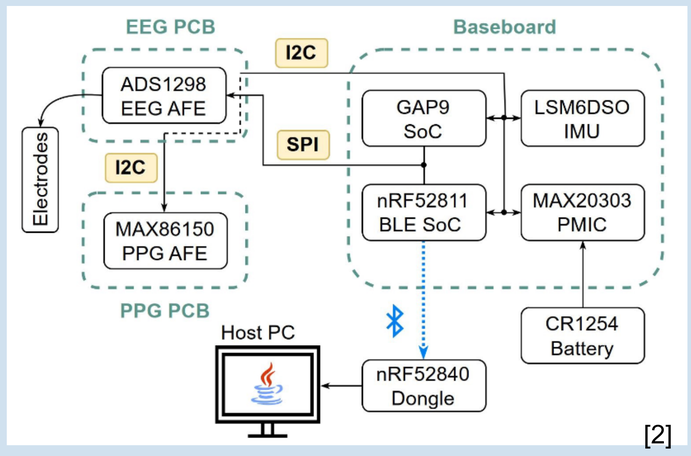
- Multiple sensing modalities are being explored for Human-Machine Interfaces (e.g. for prosthesis control)
- EMG and ultrasound exhibit huge potential [1]
- Need for truly-wearable systems with onboard computing capabilities

[1]



2) From data acquisition platforms…

BioGAP - ExG Acquisition



[2]

Key components

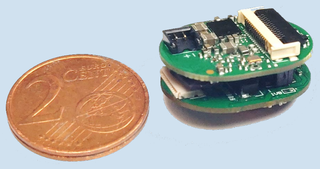
ADS1298
- ADC for biopotentials
- Up to 8 ExG channels
- 24-bit of resolution
- 0.5 to 32 – Ksps.
- PGA up to 12x.
- Dry active electrodes compatible.

nRF52832
- MCU for BLE connectivity
- ARM Cortex-M4.
- 64 MHz.
- Bluetooth 5 capable + NFC-A.
- 512/64 KB Flash/RAM.

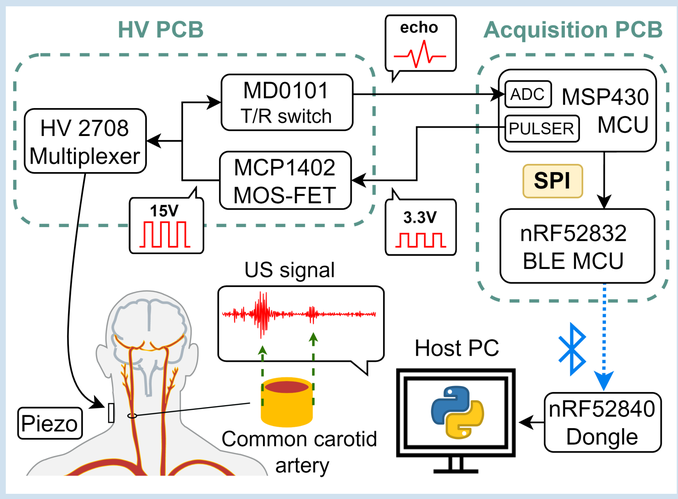
GAP9 SoC
- 10 RISC-V cores (9-core cluster with AI accelerator, 1-core controller)
- Transprecision floating-point support
- Up to 15.6 GOPs (DSP) and 32.2 GMACs (ML)
- System performance of 330µW/GOP
- Up to 370 MHz internal clock
- 1.6MB retentive L2 RAM

State-of-the-art SoC for tiny-ML

PCB implementation



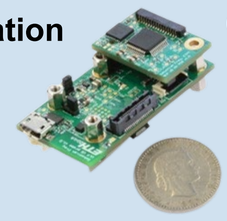
WULPUS: Wearable Ultra Low Power UltraSound



- **Wearable probe** for continuous monitoring
- **Ultra low-power** consumption **(< 25 mW) → battery lifetime of ~ 2 days** with a 320 mAh Li-Po.
- **Open and configurable** system → access to raw data to develop algorithms for automatic analyses
- **Design modularity** → integration of additional sensors (EMG).

State-of-the-art truly wearable ultrasound probe

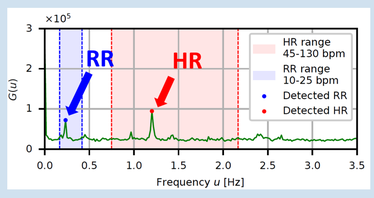
PCB implementation



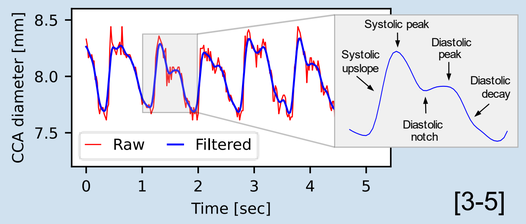
Open Sourced

Example use-cases

Measurement of heart rate (HR) and respiration rate (RR)



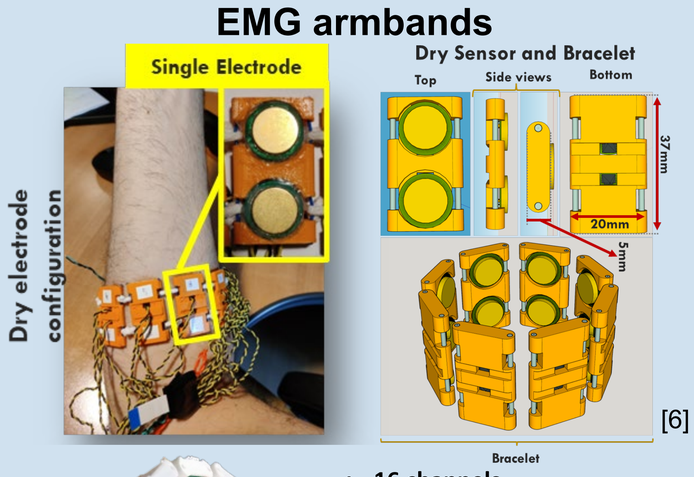
Tracking of common carotid arteries diameters



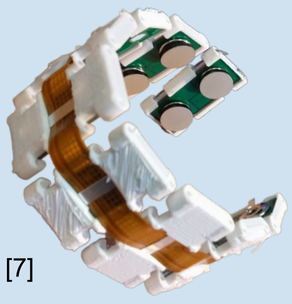
[3-5]

3) … to complete systems…

EMG armbands



[6]

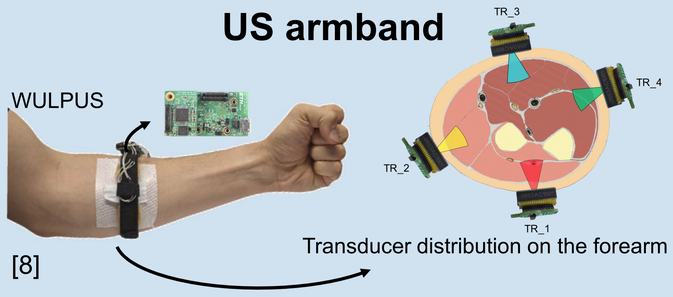


[7]

- **16 channels**
- **Dry, active electrodes** (Datwyler Schweiz AG)
- **4 kSPS** sampling rate
- Adjustable length, fits most arm sizes
- Integrated with readout platforms (BioWolf, BioGAP)

The first EMG armband with parallel ultra low-power (PULP) computing capabilities

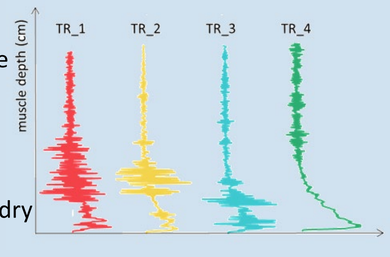
US armband



[8]

- **4 transducers**
- **A-mode**
- **50 Hz** pulse repetition rate (8 MHz sampling)
- Sensing depth > 4 cm
- Acoustic coupling: US gel (can be replaced by semi-dry gel-pads)

Ultrasound signal from each transducer



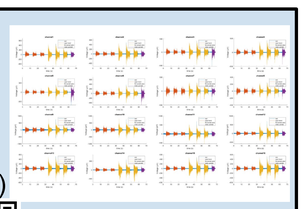
The first ultra low-power ultrasound armband

4) …and tinyML on the edge

Gesture classification from EMG

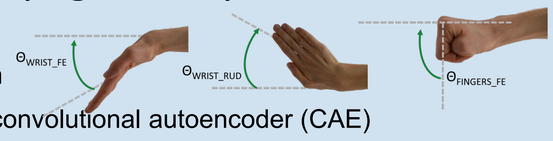
[6]

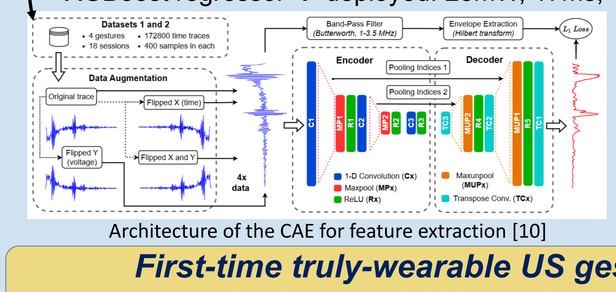
- 9 gestures
- SVM classifier, >90% accuracy
- 16mW power consumption (57h of continuous operation) when deployed on a PULP chip
- Demonstration of real-time control of a drone [9]



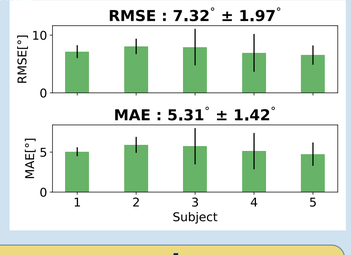
Continuous movements (regression) with ultrasound

- 3 degrees of freedom
- Multi-output regression problem
- Feature extraction based on a convolutional autoencoder (CAE)
- XGBoost regressor → deployed! 28mW, 17ms, 156kB





Architecture of the CAE for feature extraction [10]

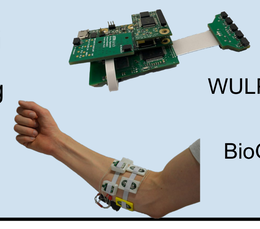


First-time truly-wearable US gesture regression (sub-30mW, MAE=5 degrees, R^2>0.8)

5) The future: heterogeneous sensing and sensor fusion

US meets EMG

- **Heterogeneous** sensing platforms **(US + EMG)**
- **Sensor fusion**



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3. S. Frey et al., “WULPUS: a Wearable Ultra Low-Power Ultrasound probe for multi-day monitoring of carotid artery and muscle activity,” Proc. IEEE IUS, 2022.
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9. https://www.youtube.com/watch?v=iwvMsAhdQEA
10. S. Vostrikov et al., “Unsupervised Feature Extraction from Raw Data for Gesture Recognition with Wearable Ultra Low-Power Ultrasound,” under submission.

The authors acknowledge support from the Swiss National Science Foundation (Project PEDESITE) under grant agreement 193813, and from the ETH Research Grant ETH-C-01-21-2 (Project ListenToLight)