

Towards Low-Power Multimodal Wearable HMI: EOG-Based Gaze Estimation and Visual Sensing

PhD Student Presentation IWES 2026

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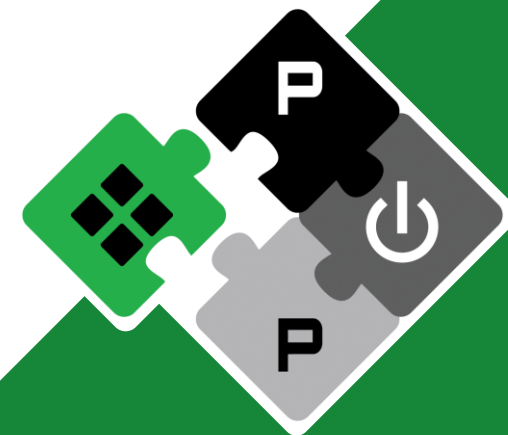
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PULP Platform

Open Source Hardware, the way it should be!



@pulp_platform



pulp-platform.org



youtube.com/pulp_platform

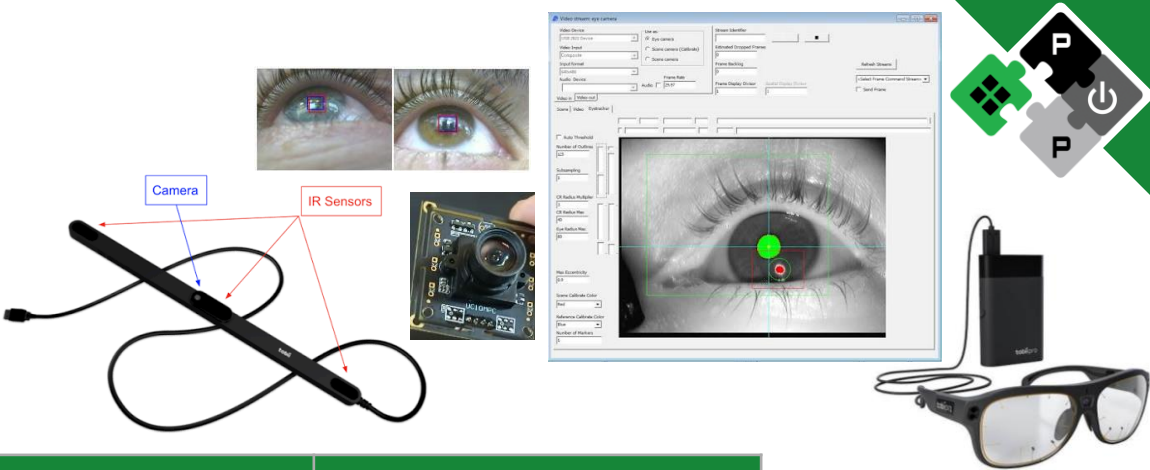


Efficiency starts from what we sense

Eye tracking?

CAMERAS!

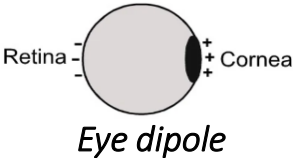
IR RGB
low-res gray-scale



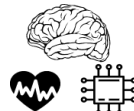
Examples	Pixel Resolution	Frame Rate	Byte/s
Standard low-res camera	400 x 400	60	9.6 MB/s
Standard camera + ROI	100 x 100	60	0.6 MB/s

Do we really need cameras for tracking the eyes?

- ❖ **EOG: Electrooculography**, measures the electrical activity associated with eye movements
- ❖ The **eye** acts as a **dipole**: the cornea is positively charged, while the retina is negatively charged
- **Electrodes placed around the eyes** capture the electrical potential generated by eye movements



Example	Channels	Sampling Rate	Byte/s
EOG	3	500	1.5 KB/s



Can we estimate gaze from EOG?



Glasses-based acquisition methods:

- ❖ **3 dry electrodes** integrated into the glasses:
 - Central electrode (V_C), positioned on the bridge of the nose
 - Left (V_L) and right (V_R) positioned on the sides of the nose

Vertical Eye Movements:

$$\diamond V_V = V_C - \frac{(V_L + V_R)}{2}$$

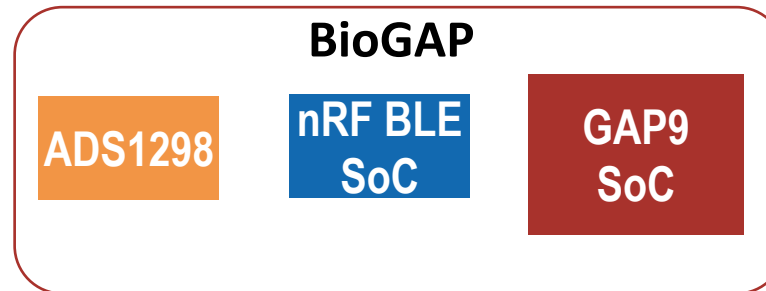
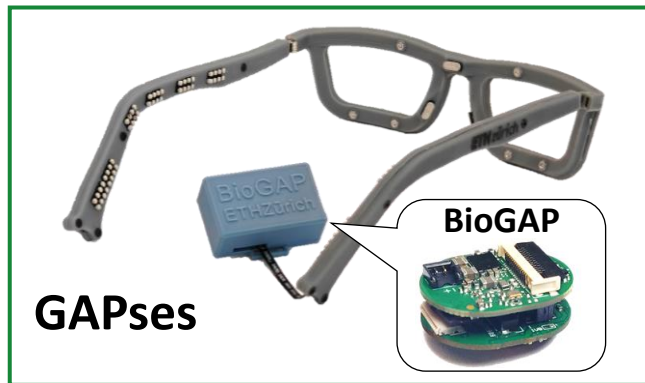
Horizontal Eye Movements:

$$\diamond V_H = V_R - V_L$$

Our device:

GAPses*: fully-dry smart glasses for EOG and EEG acquisition and processing

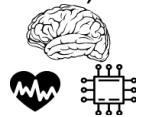
→ **BioGAP****, a biosignal acquisition platform built around the GAP9 PULP RISC-V processor for on-board processing



**11-class eye movements
classification accuracy:
96.68%**

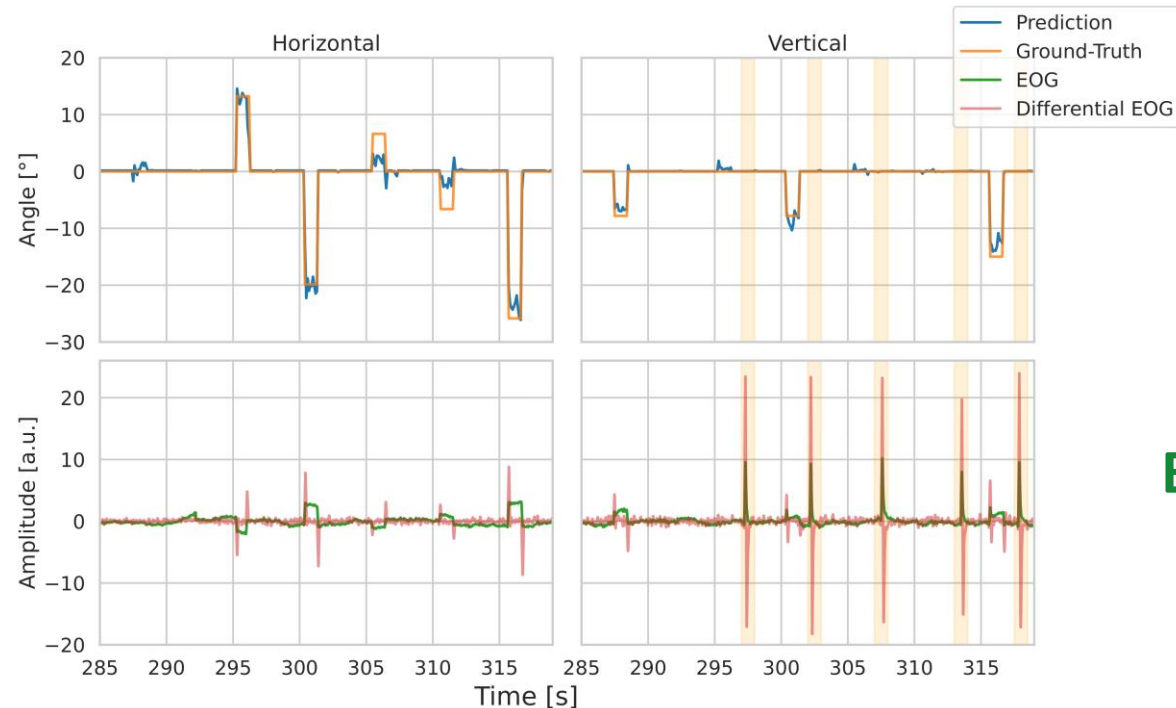
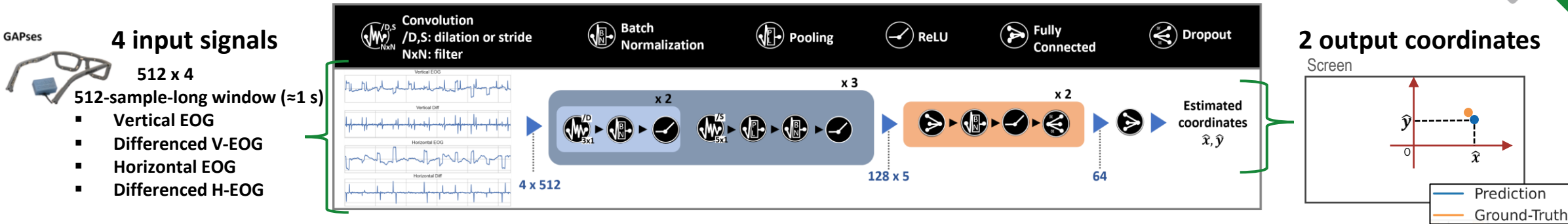
*S. Frey et al., "GAPses: Versatile Smart Glasses for Comfortable and Fully-Dry Acquisition and Parallel Ultra-Low-Power Processing of EEG and EOG," IEEE TBIOCAS, 2025

**S. Frey et al., "BioGAP: A 10-Core FP-Capable Ultra-Low Power IoT Processor, with Medical-Grade AFE and BLE Connectivity for Wearable Biosignal Processing," IEEE COINS, 2023



From biosignal to continuous gaze estimation

TEMPONet TCN for EOG Regression



- ❖ Computation of a differenced signal to mitigate drift
- ❖ TEMPONet network (TCN Architecture)
- ❖ Blink detection and removal are not required

Mean Absolute Error (27" screen):

- Horizontal MAE: $2.56 \pm 0.45^\circ$
- Vertical MAE: $1.74 \pm 0.34^\circ$

[*]

But can it actually run on a wearable device?

TEMPONet Deployment on GAP9:

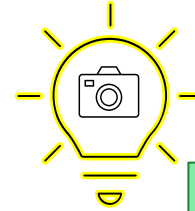
- 227 kB
- 3.38 ms/inference @240 MHz
- 79.87 μ J/inference

*A.H. Bernardi et al. – unpublished, under review

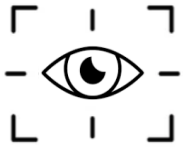
Towards Low-Power Multimodal Wearable HMI



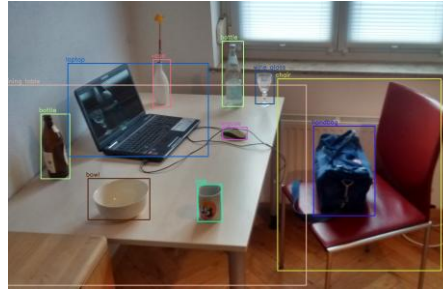
We know **where** the user looks. But **what** are they looking at?



WHERE?



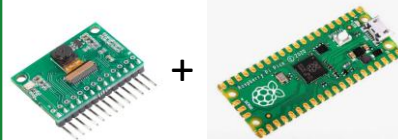
WHAT?



World-facing
camera



ARDUCAM ULP HM0360
& Raspberry Pi Pico



GAPses EOG Prototype

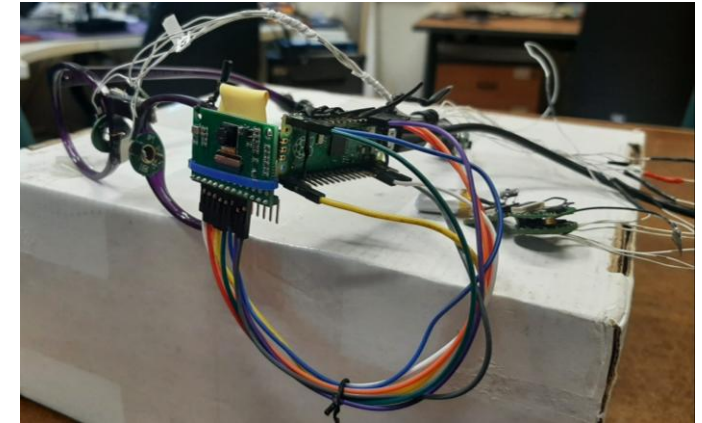


WHERE + WHAT



Context-aware HMI

Glasses Prototype



Now:

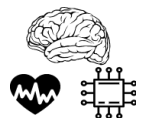
Synchronized multimodal acquisition

Next:

Protocol definition, data collection, and multimodal analysis

Goal:

Real-time low-power wearable embedded system



To conclude...

Two sensing modalities provide complementary information about the user and the environment

- ❖ *User's gaze*, from only a few low-dimensional signals



EOG

- ❖ *Environmental context*, from low-power visual sensing



Camera



*Low-Power Context-Aware Wearable HMI
Towards a smart-glasses form factor*

Contacts



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Thank you!