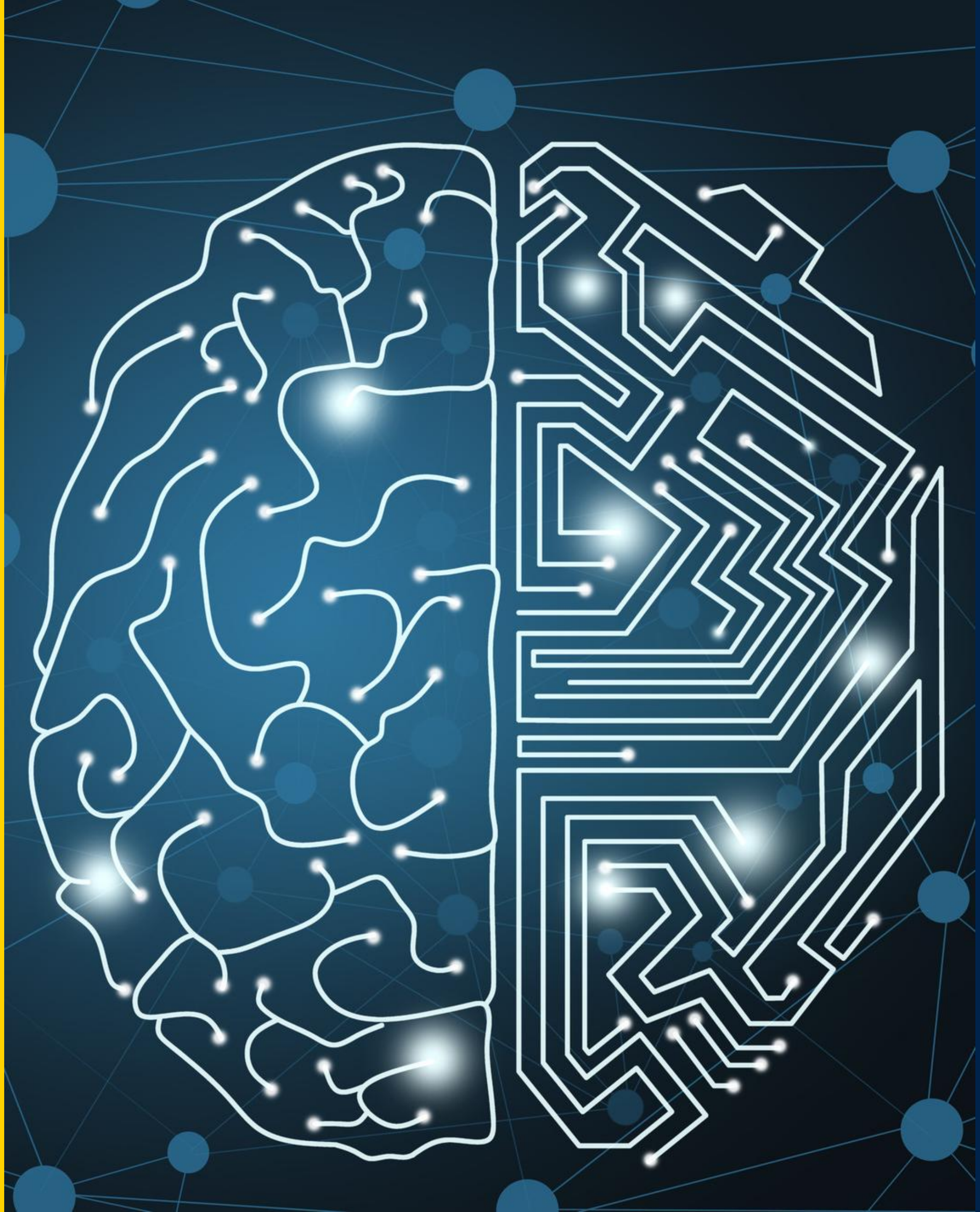
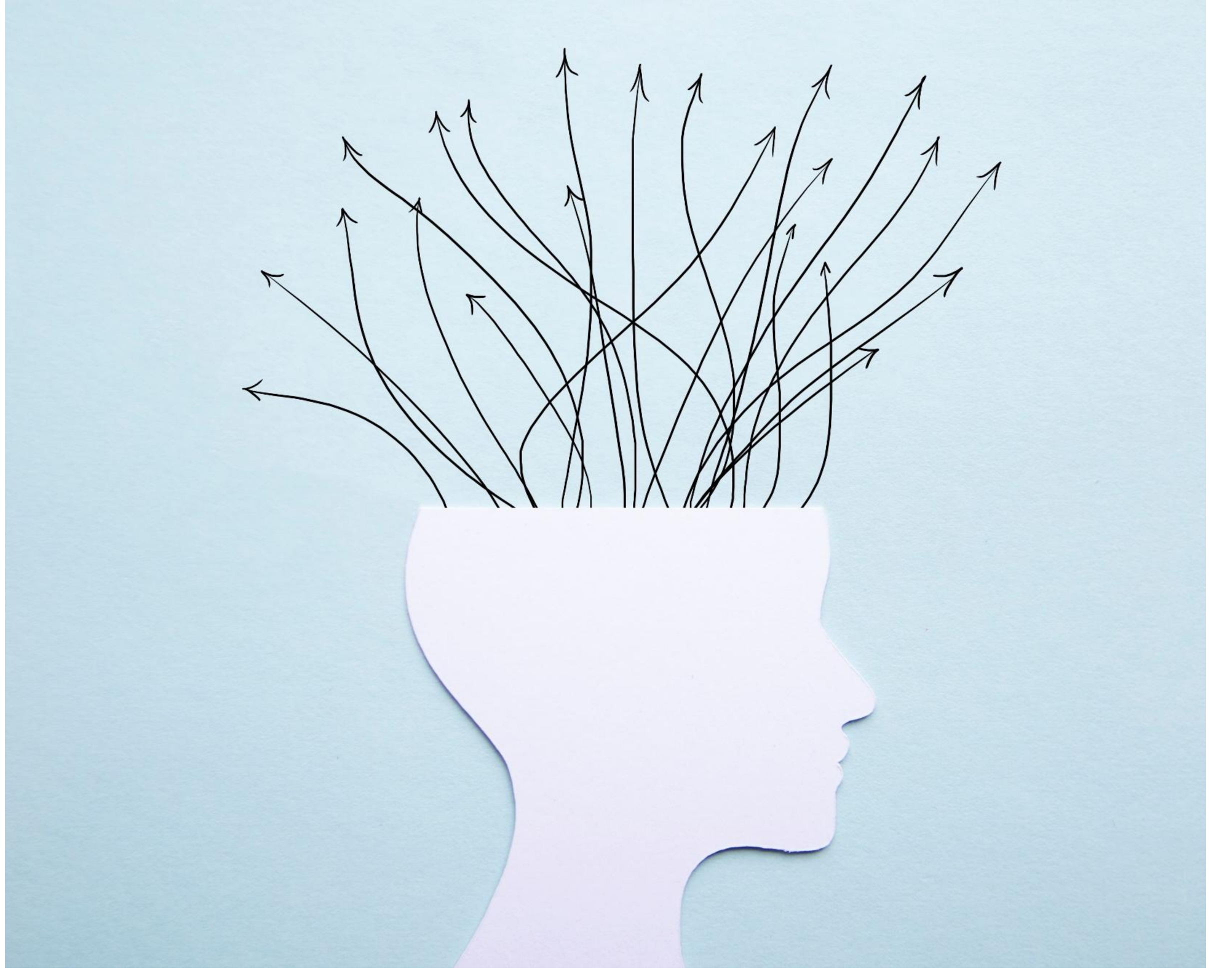


Brain Computer Interface

Vincenzo Mazzullo (AI Tools and Frameworks Architecture Specialist)

SRA AI SW & Tools
STMicroelectronics

AI-driven brain-computer interface (BCI): unlocking the mind’s potential



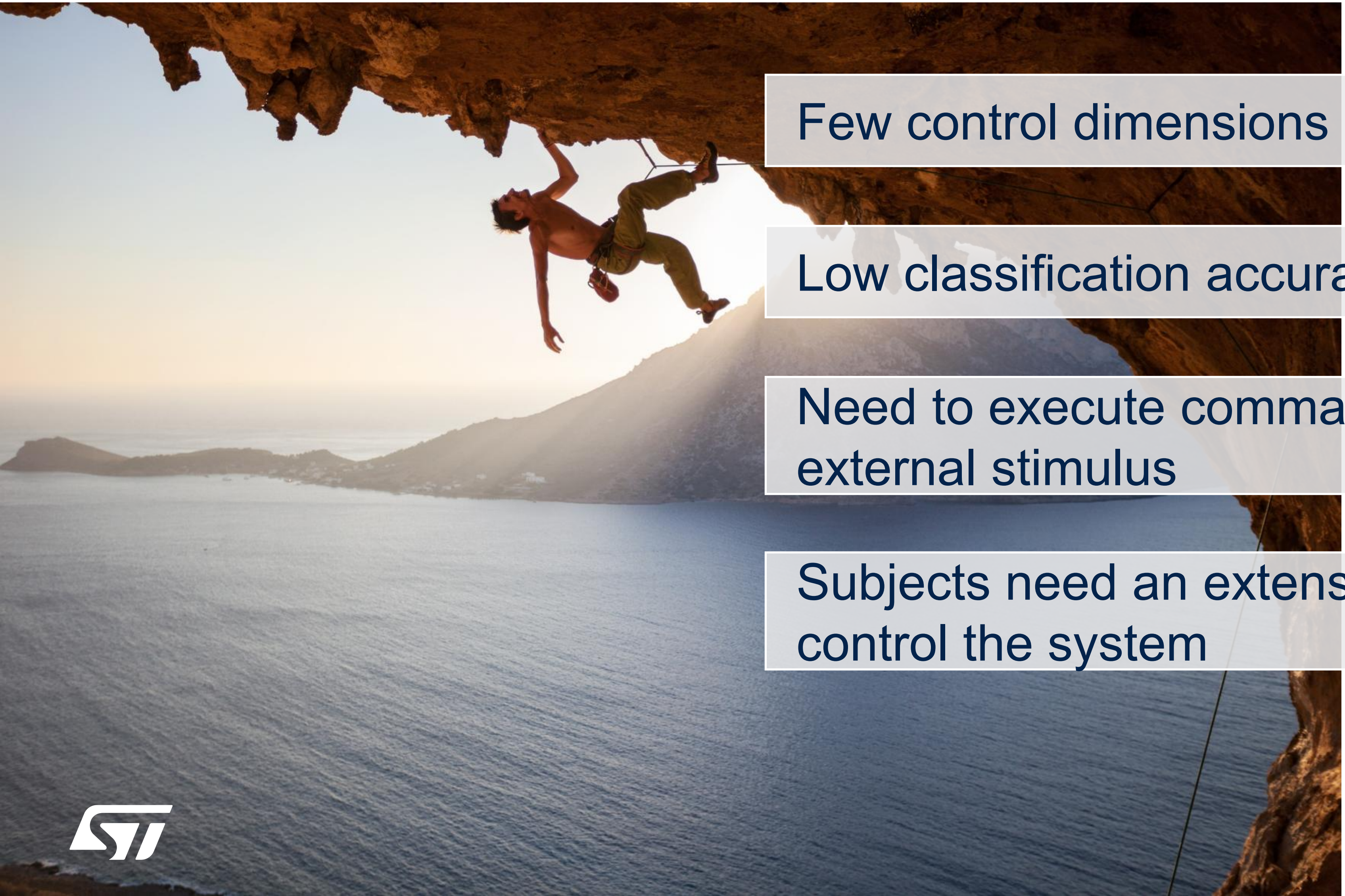
Why BCIs matter?

BCIs enable direct communication between the brain and external devices

Life-changing potential for individuals with motor disabilities, who retain eye movements

Applications in assistive devices, gaming, and more

Challenges of BCI systems

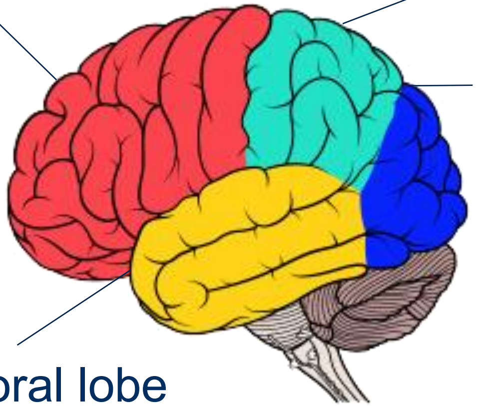


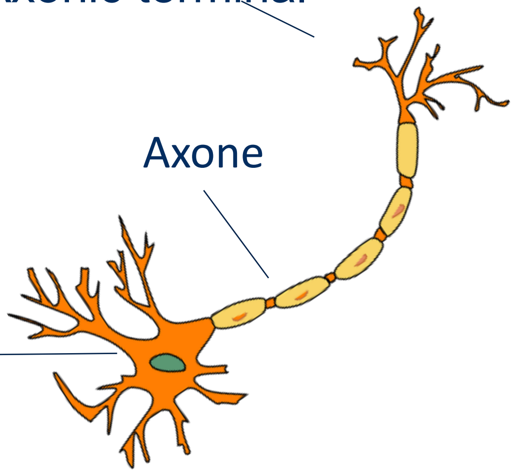
- Few control dimensions
- Low classification accuracy
- Need to execute commands synchronously with an external stimulus
- Subjects need an extensive training to be able to control the system

The nervous system and the brain-computer interface

The Nervous System: structural unit specialized in receiving, transmitting, controlling and processing the internal and external stimuli of the body.

- **Central Nervous System**
- **Peripheral Nervous System**





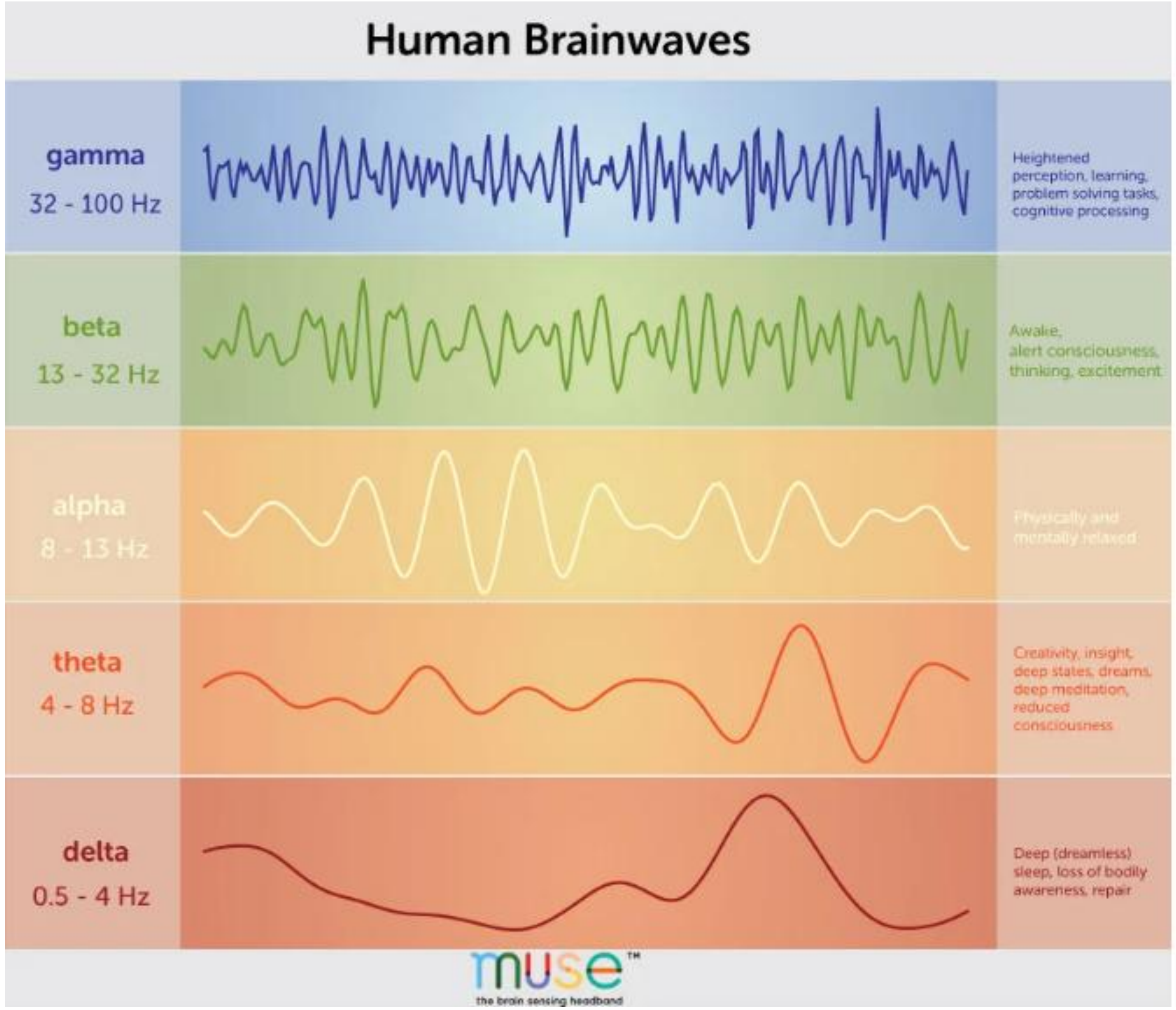
Neuron: basic cellular unit that characterizes the nervous tissue

Synapse : point of contact between two nerve cells; propagates nerve impulses

Electroencephalography and Brain Waves

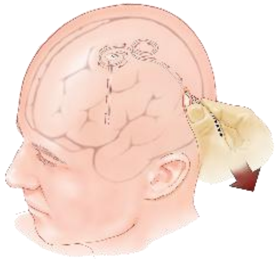
Electroencephalography (EEG): one of the most popular, cheapest and least invasive methods for detecting brain activity, through electrodes placed on the scalp.

Waves of different frequency and amplitude are distinguished, which are called **brain waves (or rhythms).**



What’s available in the market?

INVASIVE



Neuralink, Braingate, Synchron

PRO	CONS
• High accuracy and resolution • Real-time performance • Suitable for complex tasks like robotic arm control or communication	• Requires surgical procedures • Expensive and inaccessible to most users • Ethical and regulatory challenges

NON-INVASIVE

Emotiv, NeuroSky, Muse, OpenBCI

PRO	CONS
• Non-invasive and safe • Easy to deploy and use • Cost-effective for basic applications	• Limited signal resolution and accuracy • Susceptible to noise and artifacts (e.g., muscle movements) • Not suitable for real-time critical applications like assistive devices

Non-invasive Headset: Key Differentiators

1. Number of Channels & Their Position

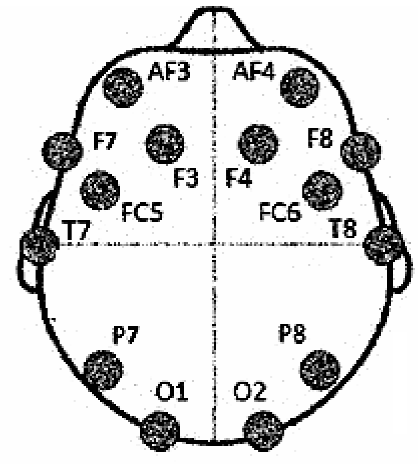
- Channels range **up to 256**
- Channel placement determines brain coverage:
  - From **specific brain regions** to **whole-brain monitoring**

2. Sensor Type & Electrode Contact

- **Low impedance contact** with the scalp is essential
- Conductive agents (e.g., gel or solution) often applied for better signal detection
- Some companies (e.g., **NeuroSky**) use **dry, inexpensive sensors:** no gel needed

3. Signal Quality Enhancement

- Use of **very low noise amplifiers** and **filters** to improve Signal-to-Noise Ratio (SNR)



AF3: Attention
AF4: Judgment
F3 : Motor planning
F4 : Motor planning for left upper
F7 : Verbal Expression
F8 : Emotional Expression: Anger, Happy
FC5: Right Body controller
FC6: Left Body controller
T7 : Verbal memory
T8 : Emotional memory
P7 : Verbal understanding
P8 : Emotional: Understanding, Motivation
O1 : Visual processing
O2 : Visual processing

Non-invasive BCIs systems




Feature	Emotiv	NeuroSky	Muse	OpenBCI
On-Board AI	Partial	Minimal	Minimal	None
Real-time capability	Limited	Limited	Limited	Limited
Portability	High	High	High	Medium
Cost	Moderate	Affordable	Moderate	Expensive
Applications	Gaming, meditation, research	Education, gaming, wellness	Meditation and mental health	Research, Do It Yourself projects

Main limitations

Dependence on external systems
Limited real-time performance
High costs
Narrow applications

How Biosensors + AI solution stands out in a competitive market





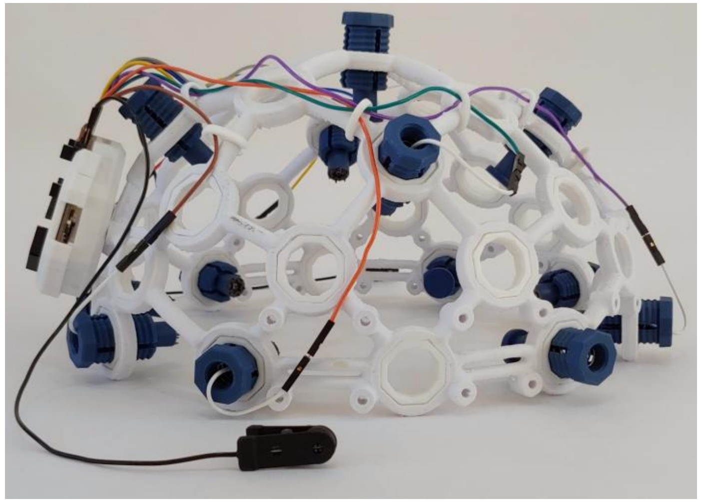
Feature	Emotiv	NeuroSky	Muse	OpenBCI	Biosensors + AI
On-Board AI	Partial	Minimal	Minimal	None	Yes
Real-time capability	Limited	Limited	Limited	Limited	Yes
Portability	High	High	High	Medium	High
Cost	Moderate	Affordable	Moderate	Expensive	affordable
Applications	Gaming, meditation, research	Education, gaming, wellness	Meditation and mental health	research, Do It Yourself projects	Assistive devices, gaming

Biosensor Meets Eye Movement Recognition

Why biosensors?

Advantages

- Greater **wearability** and **comfort**
- **Complex winks** not executable by everyone
- Better **user experience** in terms of comfort
- All components are produced by **STMicroelectronics**



System based on OpenBCI project

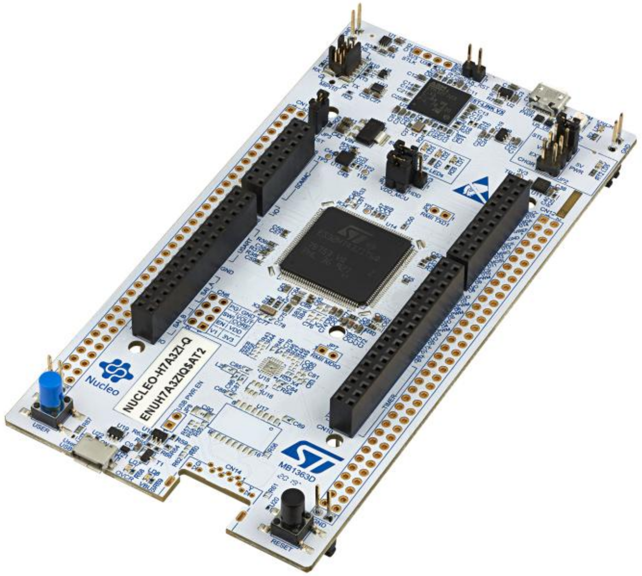
System based on ST biosensors

Proposed system: BCIs meet Biosensors and AI

SENSING

Biosensor
on STEVAL-MKI249KA board

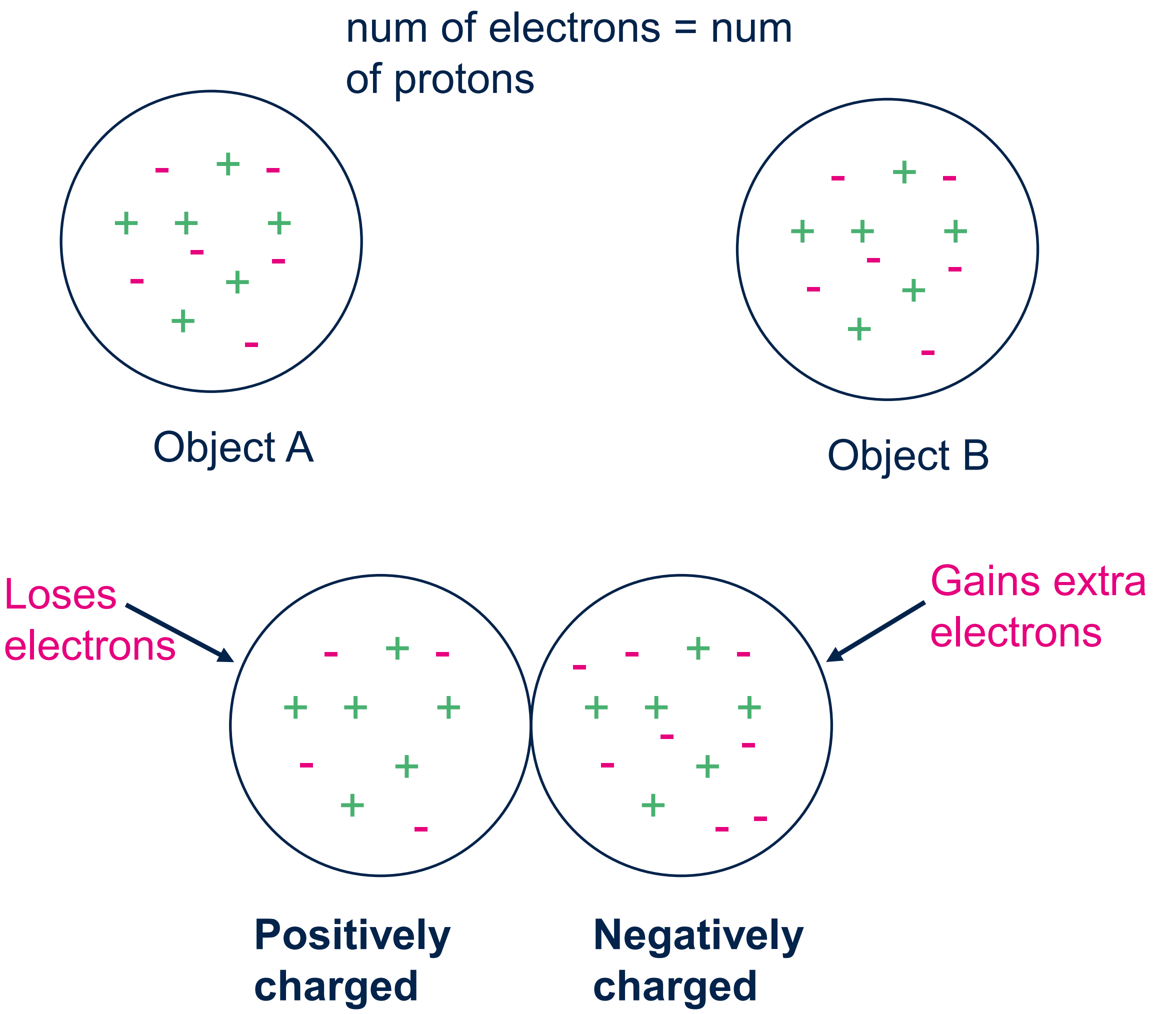
PROCESSING



NUCLEO-H743ZI2

REAL-TIME OUTPUT

Biosensor: electrostatic charge sensing principle



Electrostatic charge generation

When two materials touch and separate, electrons move: one material becomes **negatively charged**, the other becomes **positively charged**

Detection mechanism

The **electrostatic charge** creates fluctuations in the surrounding **electric field**

The **Biosensor** detect these changes using:

- **Electrodes** to sense the charge
- An **electronic circuit** to amplify and process the signal

STEVAL-MKI249KA board

Features

- Complete **ST1VAFE6AX** pinout for a standard DIL 24 socket
- The ST1VAFE6AX is a **biosensor** with vertical analog front-end (vAFE) for biopotential signals and 6-axis inertial measurement unit (IMU) with AI and sensor fusion.

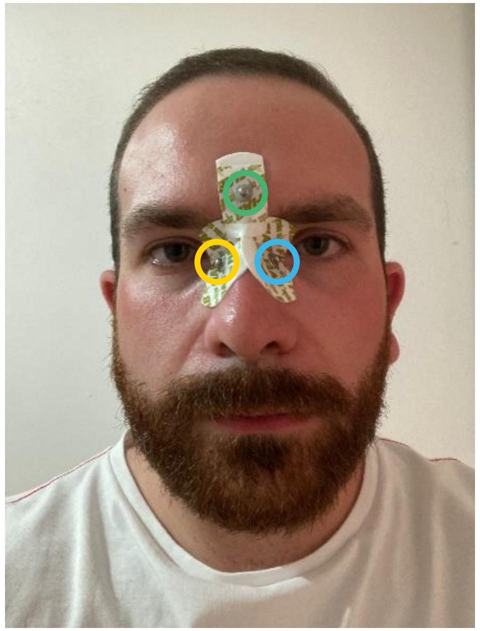
Electrodes configuration preliminary study

CH1 CH2

V1 CH1

V1 CH2

V2 CH1/CH2



Configuration 1 **Configuration 2** **Configuration 3**

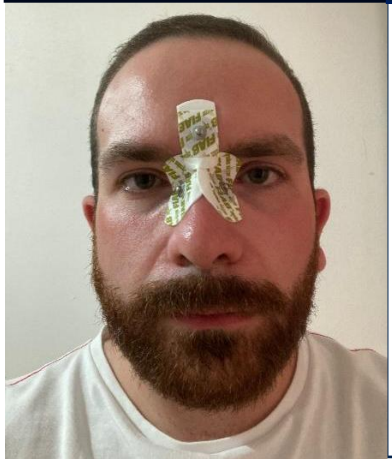
Electrodes configuration preliminary study

Configuration 1

Possible applications

- Smart glasses
- VR

Configuration 2



Possible applications

- VR

Configuration 3

Possible applications

- VR

Electrodes configuration

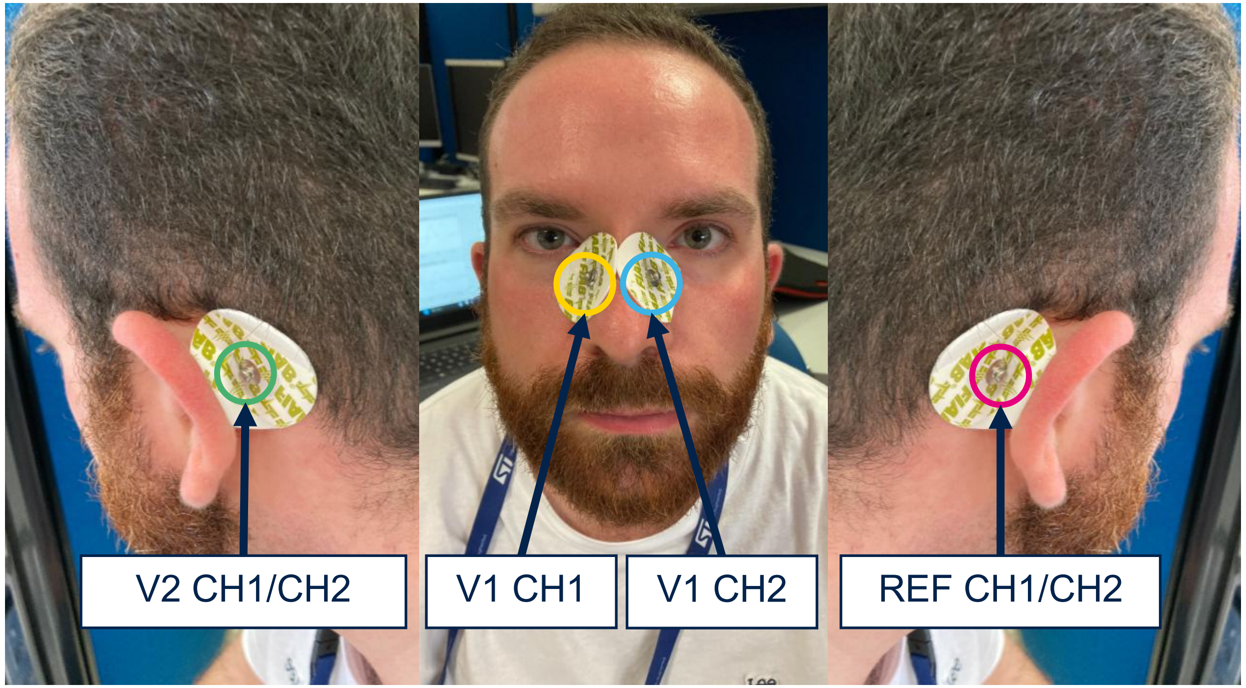
CH1 **CH2**

V1 CH1

V1 CH2

REF CH1/CH2

V2 CH1/CH2



REF CH1/CH2 is used to reduce noise and clean the acquired signal

Possible applications

Biosensors signals

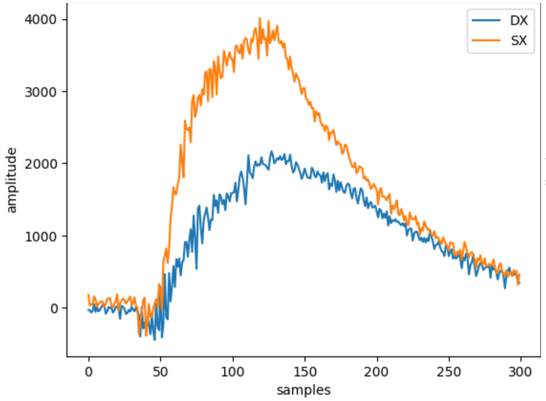
IB – Involuntary Blink

VB – Voluntary Blink

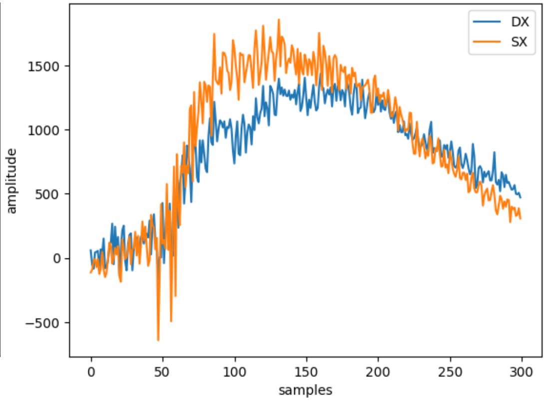
LEFT - Looking LEFT

RIGHT - Looking RIGHT

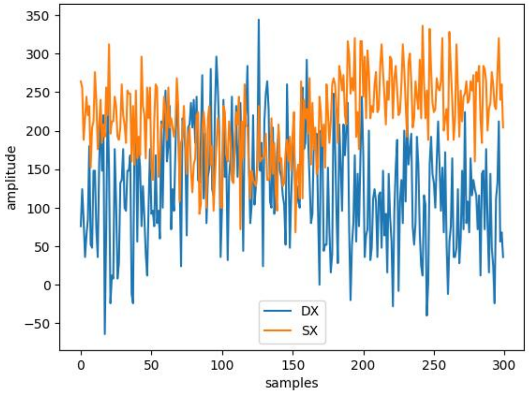
IB – Involuntary Blink



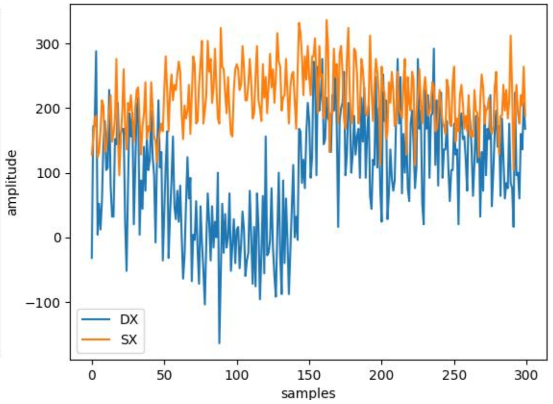
VB – Voluntary Blink



LEFT - Looking LEFT



RIGHT - Looking RIGHT

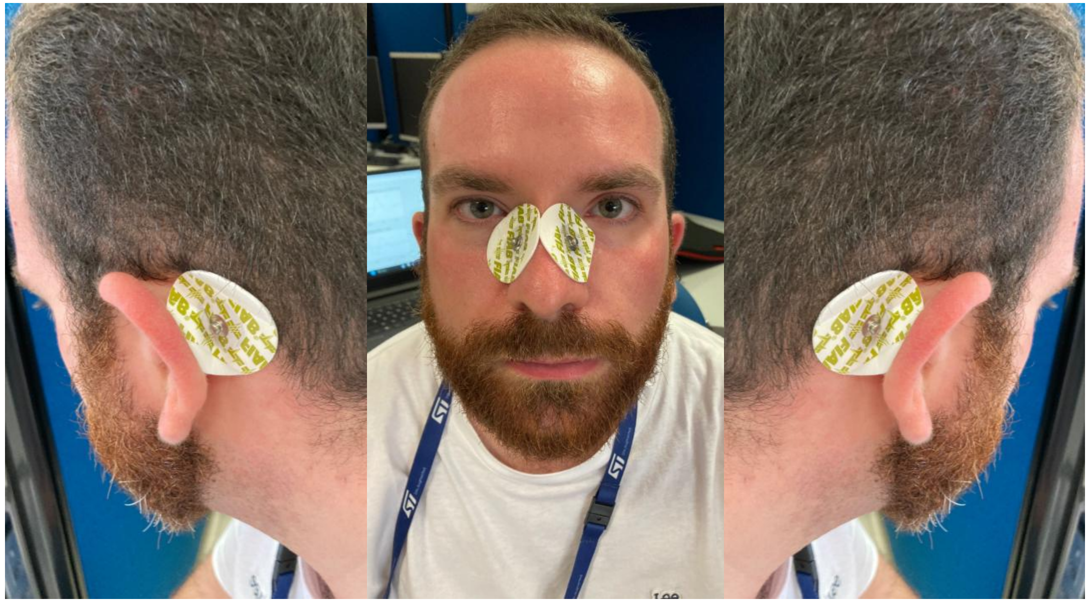


Data acquisition campaign

Methodology

- Data from **9 participants**.
- Sampling rate equals to **240Hz**.
- Recorded **eye movements**:
  - Involuntary Blink (IB)
  - Voluntary Blink (VB)
  - Looking Right (RIGHT)
  - Looking Left (LEFT)
- Each session captured **one movement type**.
- Movements paced by a **6-second metronome beep**.
- Sessions lasted **3 minutes**, timed by a countdown.

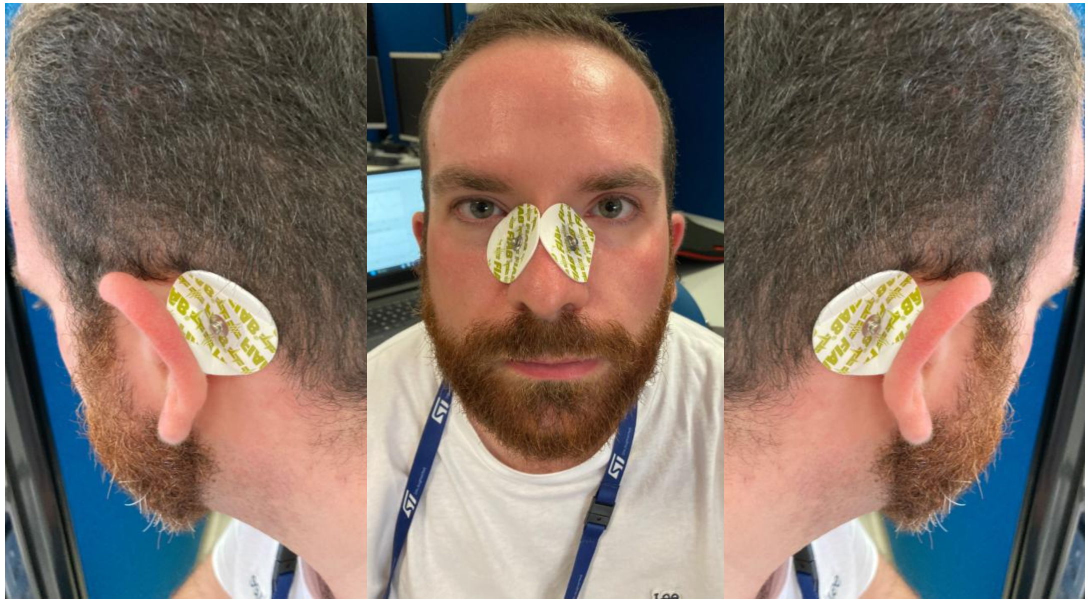
Electrodes configuration



Dataset

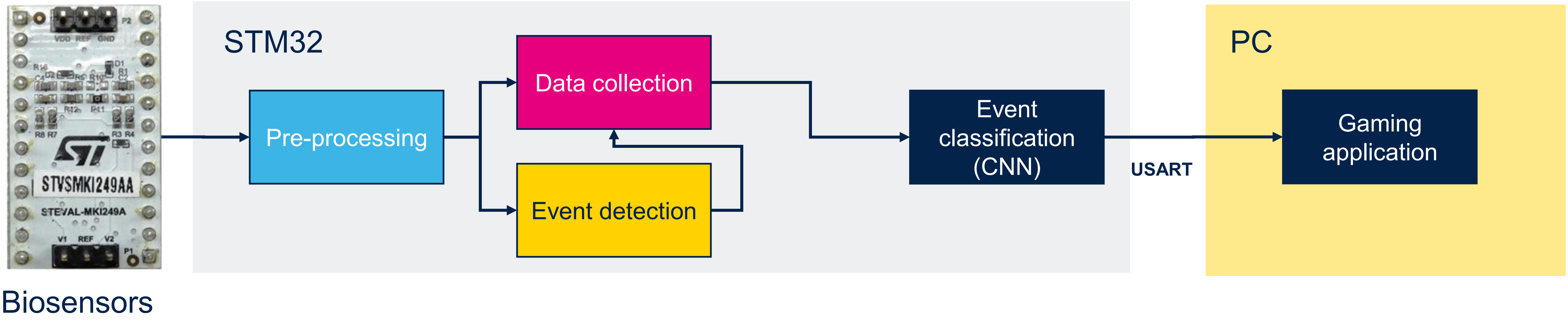
9 people (sampling rate = 240Hz)

Class	Number of samples
Involuntary Blink (IB)	234
Voluntary Blink (VB)	225
Looking RIGHT (RIGHT)	209
Looking LEFT (LEFT)	227
TOTAL	**895**

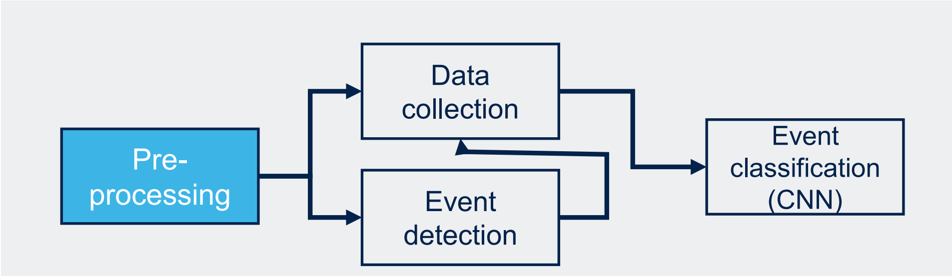


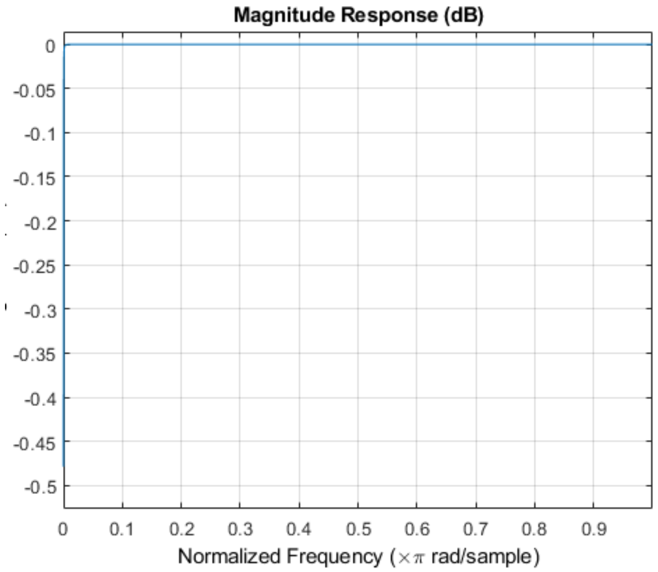
Electrodes configuration

Pipeline

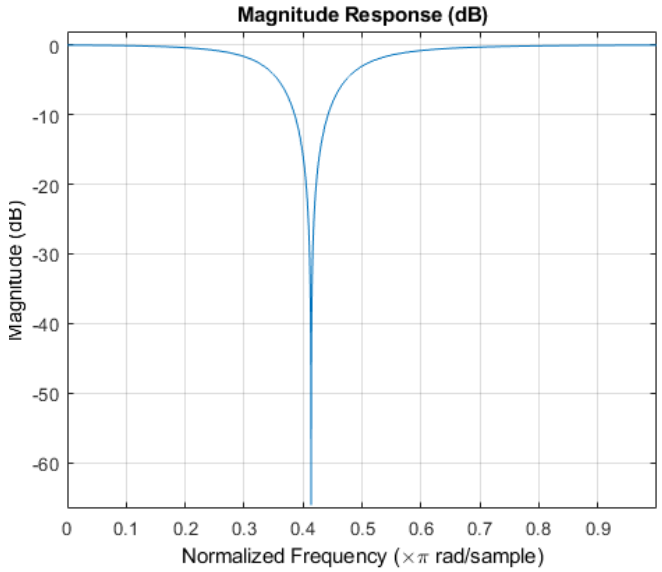

STVSMKI249AA
STEVAL-MKI249A
Biosensors
STM32
Pre-processing
Data collection
Event detection
Event classification (CNN)
USART
PC
Gaming application

Pre-processing filters

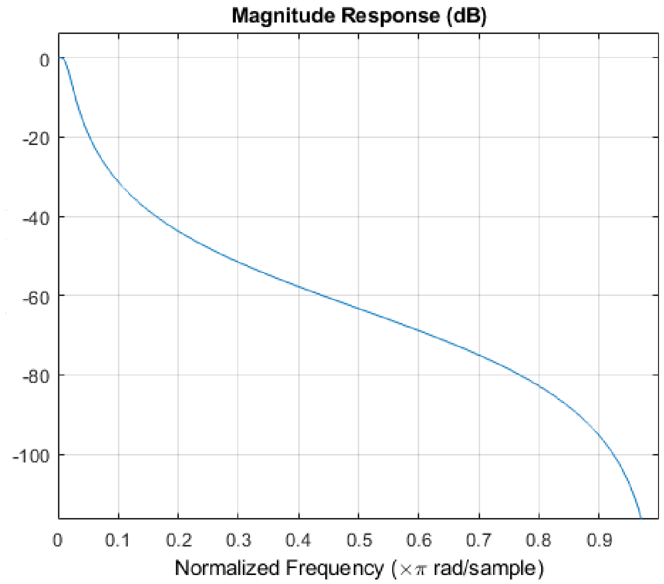




High Pass Filter
(Cut-off frequency = 0.005 Hz)



Notch Filter
(Cut-off frequencies = 40.0 Hz – 60.0 Hz)

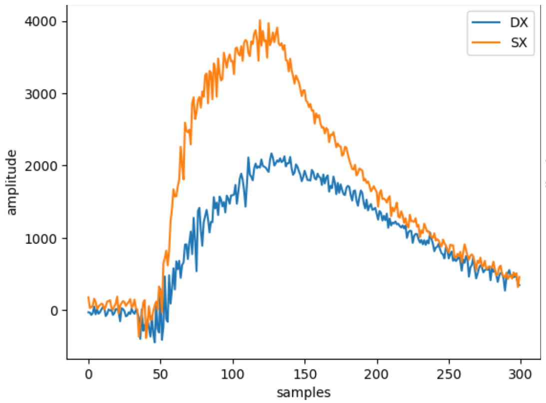


Low Pass Filter
(Cut-off frequency = 2.0 Hz)

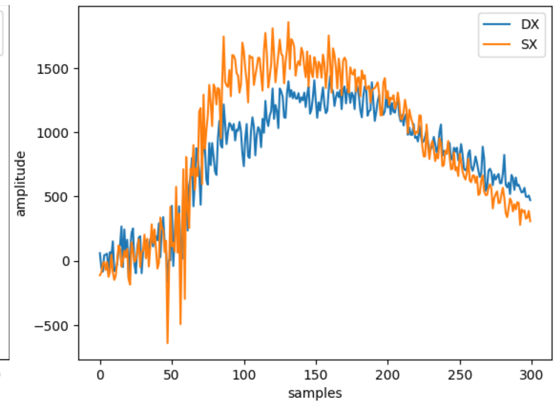
Biosensors filtered signals

Raw signals

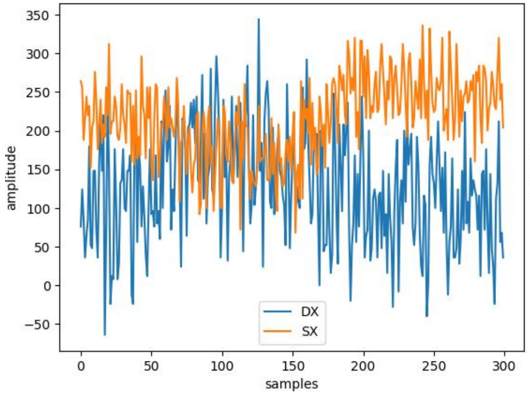
IB – Involuntary Blink



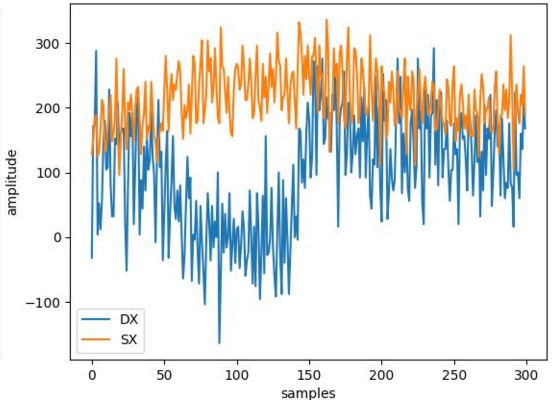
VB – Voluntary Blink



LEFT - Looking LEFT

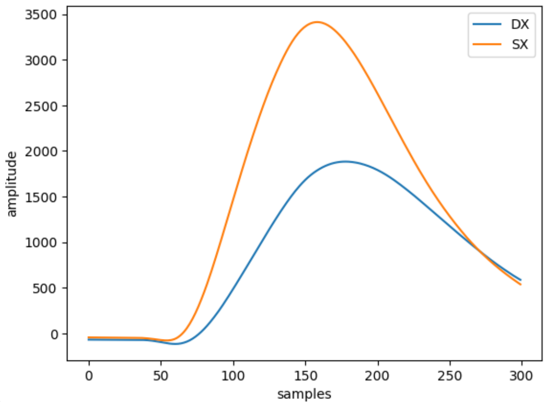


RIGHT - Looking RIGHT

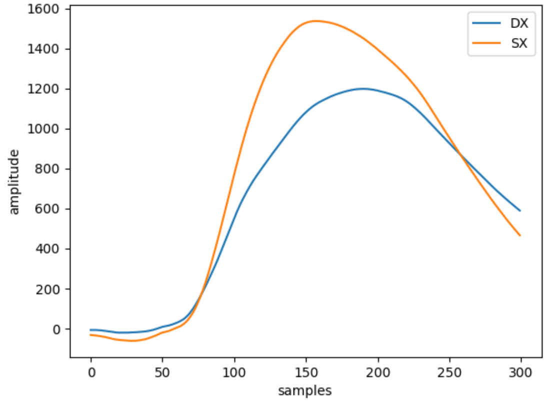


Filtered signals

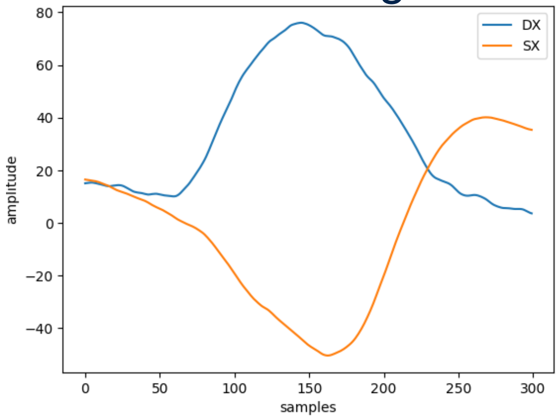
IB – Involuntary Blink



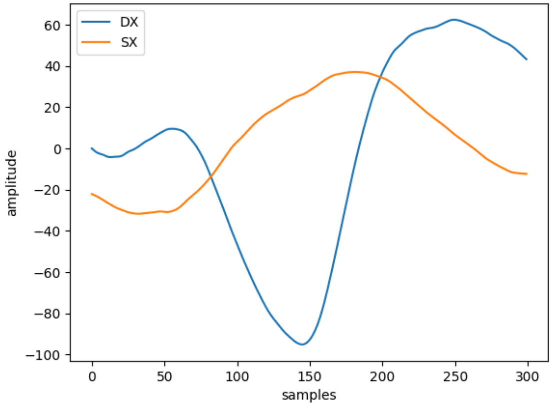
VB – Voluntary Blink

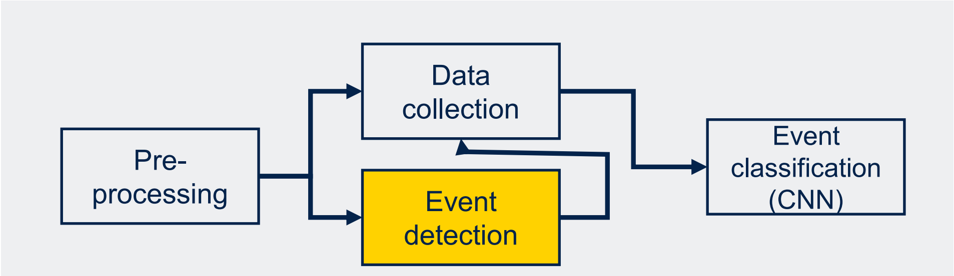


LEFT - Looking LEFT



RIGHT - Looking RIGHT





Event detection

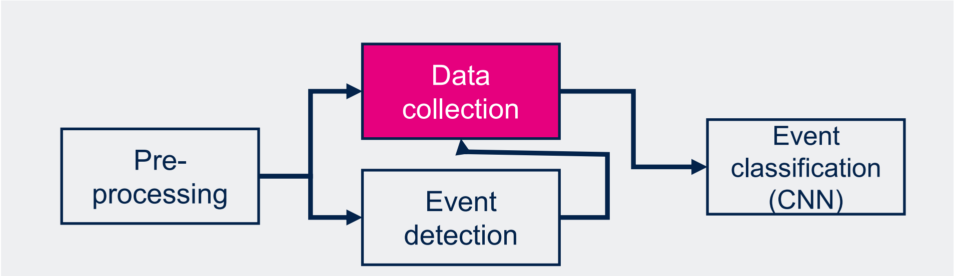
Aims to detect peaks in the signal

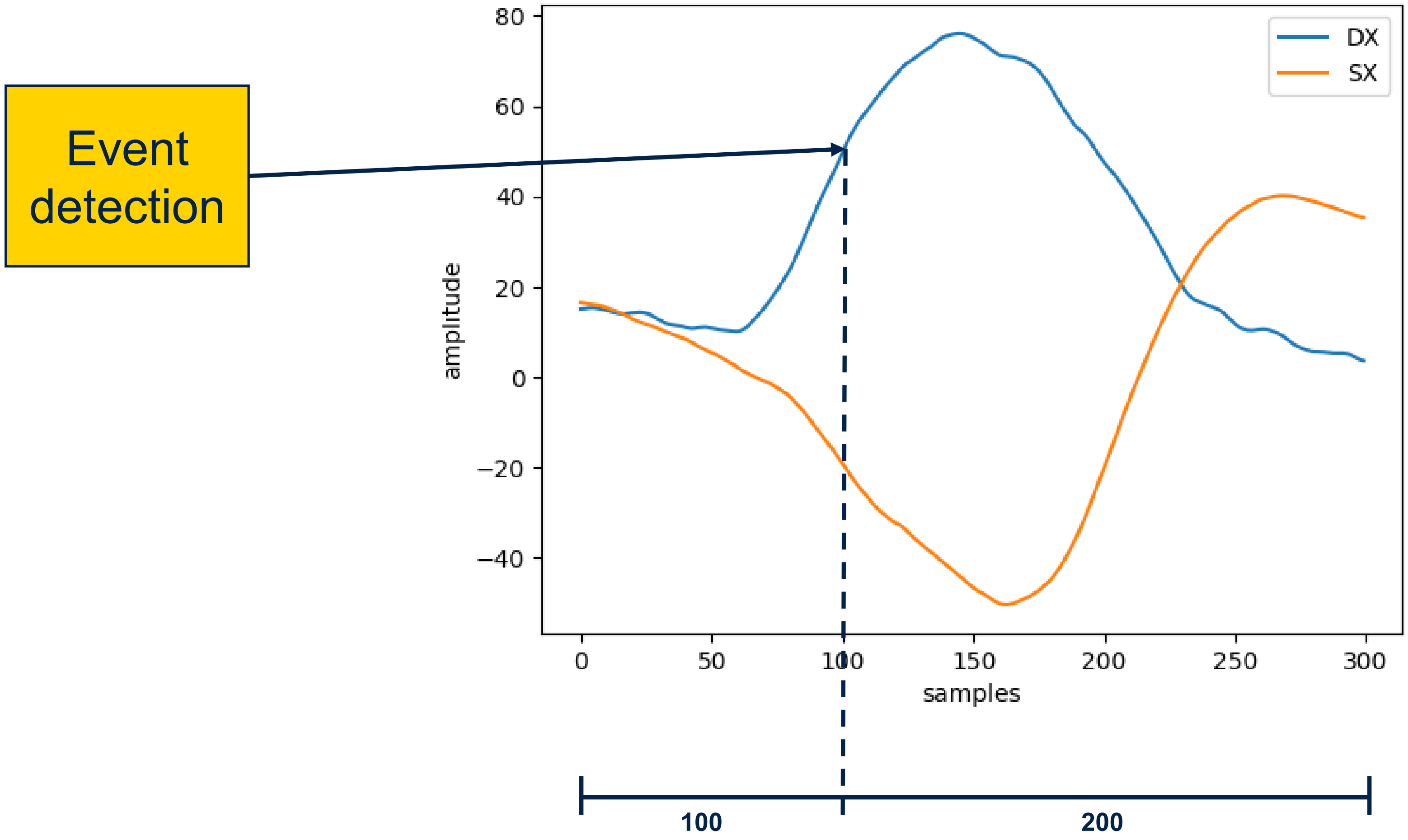
The algorithm is based on z-score

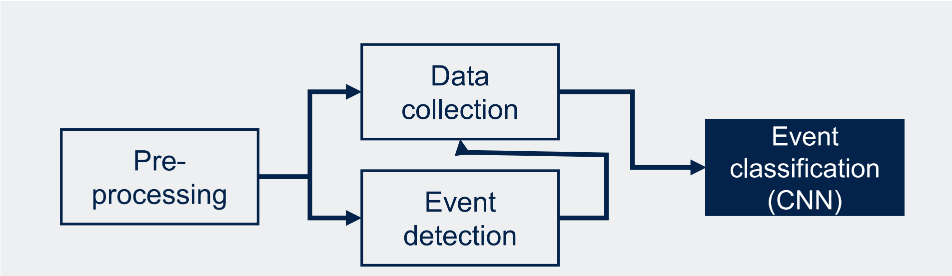
It triggers the collection of 300 samples

Ref.: JPG van Brakel. Robust peak detection algorithm (using z-scores). Stack Overflow: New York, NY, USA, 2014

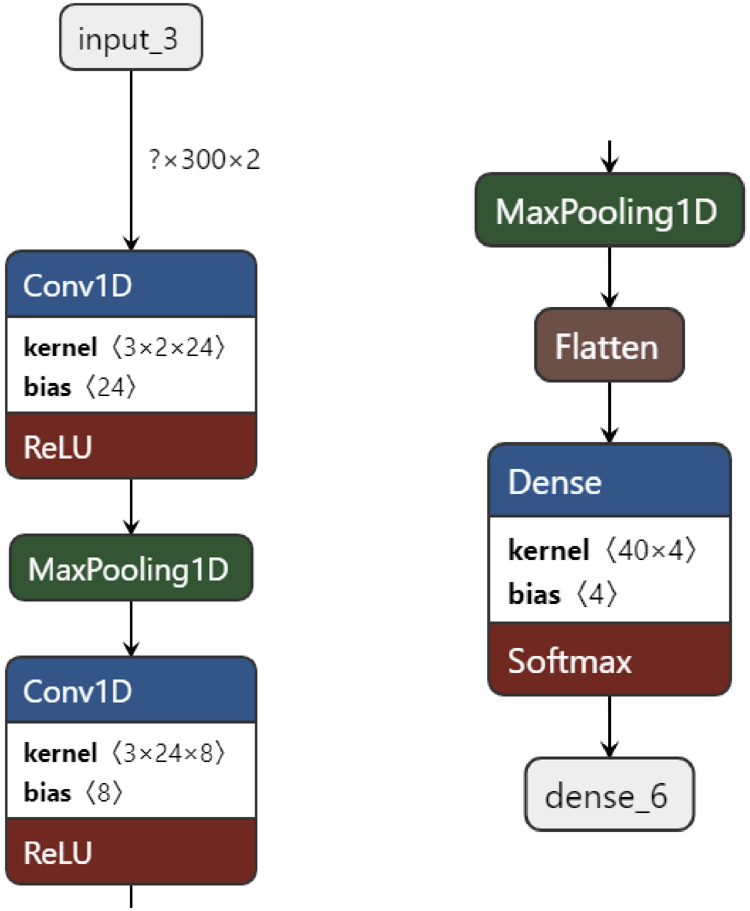
Data collection







Event classification (1D CNN)



K-fold cross validation (K=10)	
ACCURACY	**STD DEVIATION**
89.34%	0.031

Footprint on **STM32H743ZI2** MCU:
- Flash: 18.2 KB
- RAM: 6.6 KB

Complexity
- 21K MACC

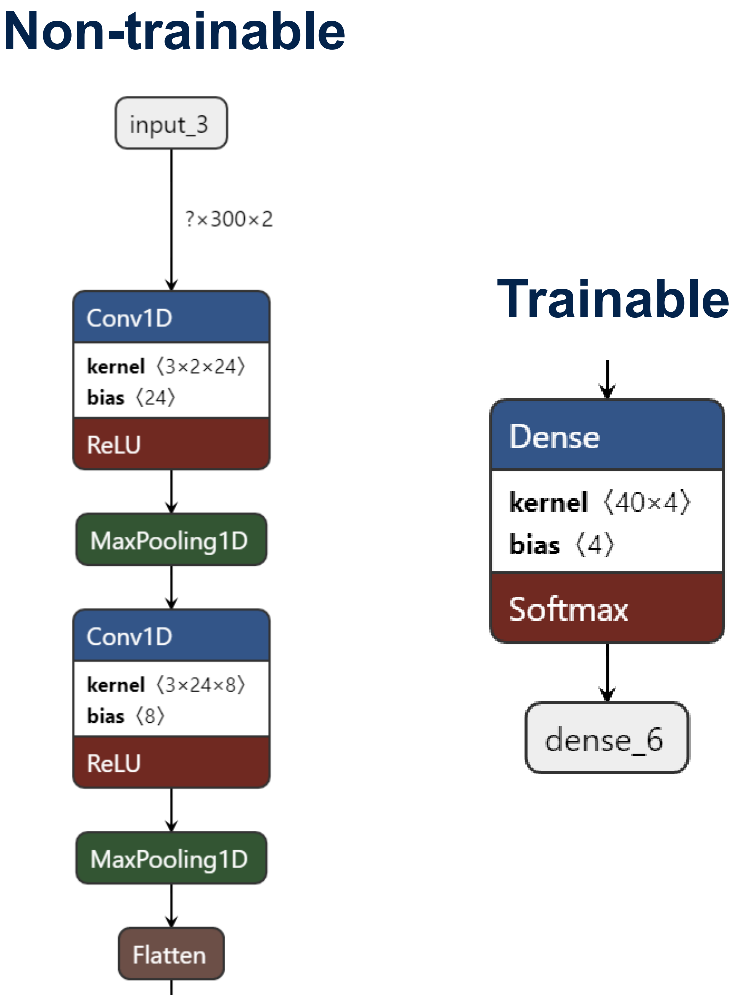
Inference time: 0.72 ms
Acquisition time: 300/240 = 1.25 s (fs = 240 hz)
Total time: ~1.26 s

Test on Unseen Person

- Test Set: 20% of Dataset from an Unseen Individual

	Test Accuracy on Unseen Individual (Excluded from Training Dataset)
Person 1	57.14%
Person 2	80.00%
Person 3	95.65%
Person 4	84.61%
Person 5	86.95%
Person 6	96.15%
Person 7	95.83%
Person 8	95.99%
Person 9	91.66%

Personalization’s methodology



Objective

Personalization aims to enhance model accuracy by fine-tuning a pre-trained AI model, initially trained on data from multiple individuals, specifically to the signals of a single user.

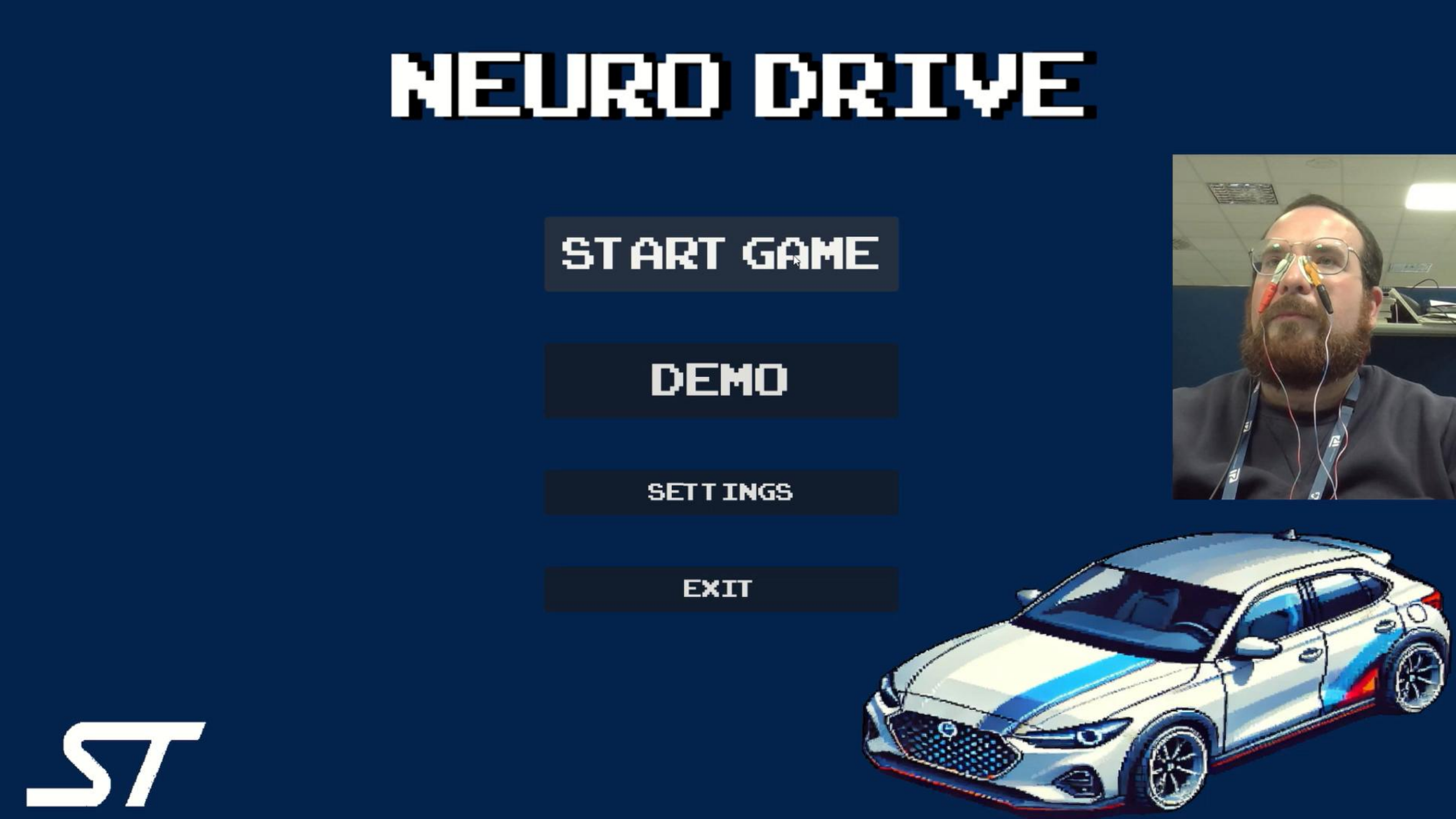
Methodology

- The non-trainable part of the model was trained using data from 8 individuals.
- The trainable part of the model was trained using data from a different individual.

Personalization’s results

- Test set: 20% of the dataset from a single individual.

	Test Accuracy before Personalization	Test Accuracy after Personalization	Difference Between Accuracies
Person 1	57.14%	100.00%	+42.86%
Person 2	80.00%	89.99%	+9.99%
Person 3	95.65%	100.00%	+4.35%
Person 4	84.61%	92.30%	+7.69%
Person 5	86.95%	95.65%	+8.70%
Person 6	96.15%	100.00%	+3.85%
Person 7	95.83%	100.00%	+4.17%
Person 8	95.99%	100.00%	+4.01%
Person 9	91.66%	95.83%	+4.17%
Mean of Diffecerences Between Accuracies			**+9.97%**


NEURO DRIVE
START GAME
DEMO
SETTINGS
EXIT

NEURO DRIVE

START GAME

DEMO

SETTINGS

EXIT

What’s next?

- Enhance reliability and accuracy
- Personalization on device
- Expand functionality
- Integrate into wearable devices
- Validate through real-world testing and feedback
- Investigate Out of Distribution technique

Questions?

Our technology starts with You