

ENOBIO: Wearable, Wireless, 4-channel electrophysiology recording system optimized for dry electrodes.

Ivan Cester¹, Stephen Dunne², Alejandro Riera³, Giulio Ruffini⁴

Starlab Barcelona s.l.

Observatori Fabra, camí del observatori s/n, Barcelona (Spain)

¹ivan.cester@starlab.es

²stephen.dunne@starlab.es

³alejandroriera@starlab.es

⁴giulio.ruffini@starlab.es

Abstract— ENOBIO is a 4 channel wireless EEG/EOG/ECG/EMG system. We recorded EEG signal with ENOBIO and the benchmark ActiveTwo system from Biosemi simultaneously. Although ENOBIO was performing at its lowest gain setting, the quality of both signals is very similar and the peak for alpha band has similar amplitude for both systems.

I. INTRODUCTION

This document gives an overview of the main features of ENOBIO wireless EEG/EOG/ECG/EMG system. It also compares the performance of the system with the ActiveTwo system from Biosemi. The ActiveTwo system is state of the art commercial equipment that is proven to have very good performance and has been used in many studies. A list of some works can be found in [1]. So far 3 demonstration applications have been developed using the system. EOG based Human Computer Interface (HCI), EEG and ECG based Biometry for Authentication (presented at pHealth as a poster) and an EEG based Sleepiness Prediction system for drivers. In all cases the applications are designed around the same 4 channel system.

ENOBIO has been developed with the help of the SENSATION FP6 IP 507231.

II. SYSTEM DESCRIPTION AND SPECIFICATIONS

ENOBIO is a wearable, wireless, 4-channel, all-digital electrophysiology recording system that has been optimised for dry electrodes.

The system has been designed in a modular way to allow researchers to build systems tailored to their needs. Robust, snap-in cables of any length allow any combination of EEG, EOG and ECG in a single wearable system without loss of signal quality.

ENOBIO employs three fundamental enabling aspects to bring electrophysiology into daily life:

- **Active digital electrodes** digitize the signal on site in order to reduce environmental noise
- **Modular design** allows users to customize a single system for various applications
- **Wireless** communication allows **wearable** recording of data away from the lab or controlled environments.

The precision of the signal that can be acquired with ENOBIO is 1-3 μVpp to 1 mV from 0.1 to 100 Hz, and the output is a digital signal at 256 Samples/s per channel, 16 bit. Up to four channels plus electrical reference can be recorded. The hardware is powered with a rechargeable Li-Ion battery for long duration. The communication of ENOBIO with the Laptop is done via ZigBee to USB receiver. The electrodes can be active Ag/AgCl or optionally dry.

We can see in Figure 1 ENOBIO recording EEG data and transmitting them wirelessly to the laptop to be processed for an on-line application.



Figure 1: ENOBIO set in a cap for EEG recording. The data are transmitted wirelessly to the laptop.

III. INITIAL SYSTEM BENCHMARKING

For the signal analysis we compared the signal recorded with ENOBIO and Biosemi simultaneously. The electrodes of every system were placed in Fp1 of 1 cm between them. We analysed the signal referenced to left ear lobe.

We recorded spontaneous EEG, 1 minute with eyes open and 1 minute with the eyes closed for 2 subjects, using wet Ag/AgCl electrodes for both systems.

Figures 2 to 5 show the power spectral density of the signals recorded with ENOBIO (blue line) and Biosemi (red line). We can see a very good match in the spectrums of both systems. Just a small peak of 50 Hz appears for ENOBIO for subject 1.

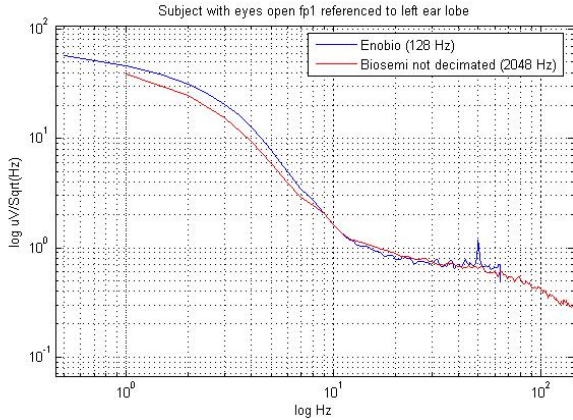


Figure 2 : Power spectral density of the signal recorded with ENOBIO and Biosemi in fp1 referenced to left ear lobe. Sample was 1 minute of spontaneous EEG with eyes open.

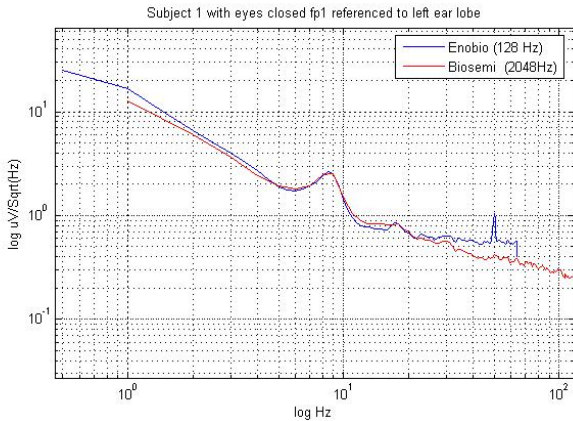


Figure 3: Spectral density of the signal recorded with ENOBIO and Biosemi in fp1 referenced to left ear lobe. Sample was 1 minute of spontaneous EEG with eyes close.

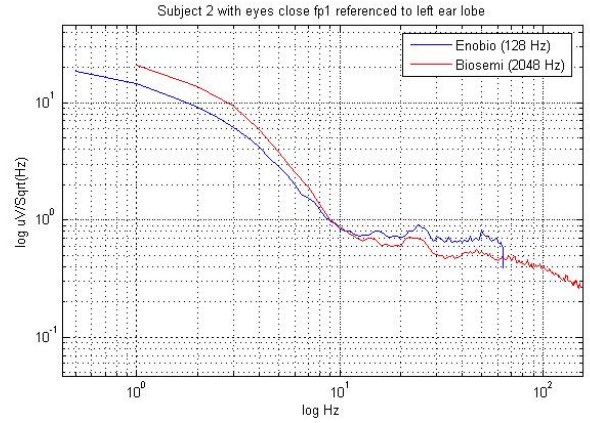


Figure 4: Power spectral density of the signal recorded with ENOBIO and Biosemi in fp1 referenced to left ear lobe. Sample was 1 minute of spontaneous EEG with eyes open.

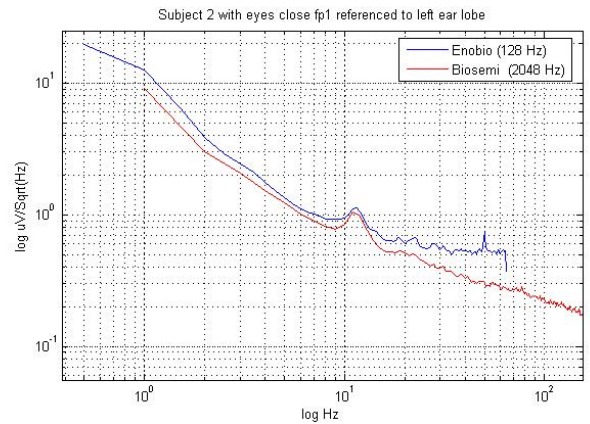


Figure 5: Power spectral density of the signal recorded with ENOBIO and Biosemi in fp1 referenced to left ear lobe. Sample was 1 minute of spontaneous EEG with eyes close.

IV. DEMONSTRATION APPLICATIONS

Three different applications have been built on ENOBIO system. In this section we make a fast overview of them.

A. EOG based Human Computer Interface.

Starlab developed a system to track eye movements. When we look at a scenario, we focus our objects of interest changing our view with fast eye movements. These movements are detected by the system and their amplitude and direction extracted from the EOG signal. The signal is acquired by ENOBIO and sent wirelessly to the ENOBIO server installed in a laptop. This raw signal can be sent via TCP/IP to any application, in that case to the EOG HCI system.

The application processes the data in real time and outputs a vector that represents the movement on the screen. The system is set on a cap as shown in Figures 1 and 8.

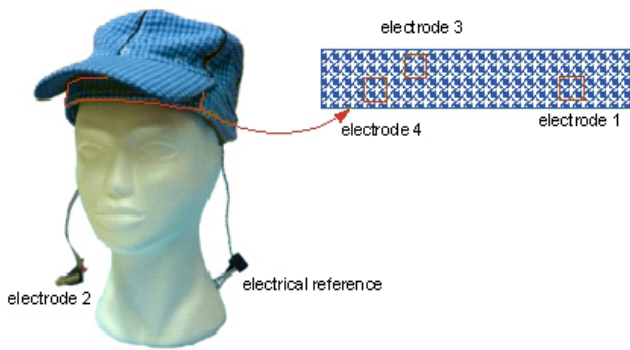


Figure 6: EOG-HMI system. 3 electrodes are placed on the forehead; the 4th one and the electrical reference are placed in the ear lobes with a clip.

Figure 7 shows a graphical representation of the output of a movement.

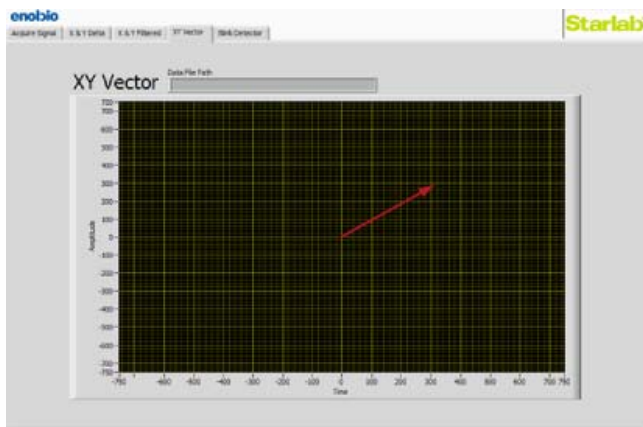


Figure 7: The vector of the picture represents the eye gaze movement of a user of the EOG Human Computer Interface.

The absolute error in the prediction for the movements is 5,9 % with a standard deviation of 6,6 for the X axe, and 9,9% with a standard deviation of 13,1 for the Y axe.

B. EEG and ECG Based Biometric System for Authentication.

Features extracted from EEG and ECG recordings have proven to be sufficiently unique between subjects for biometric applications. Starlab Barcelona s.l. developed a biometric system for authentication built on ENOBIO. Two electrodes are placed on the forehead and another one the wrist to extract EEG and ECG signal. These signals are used as a physiological signature for subject authentication. The performance is shown in table 1.

TABLE I

TRUE ACCEPTANCE RATE AND FALSE ACCEPTANCE RATE FOR EEG AND ECG MODALITIES AND FOR THE FUSION OF BOTH MODALITIES. FUSION 1 IS DONE USING THE BOUNDARY DECISION LINE 1 AND FUSION 2 USING THE BOUNDARY DECISION LINE 2. WE OBSERVE THAT THE TAR FOR THE FUSION 1 IS THE SAME THAN THE ONE OBTAINED WITH THE ECG MODALITY, BUT THE FAR DECREASES BY A FACTOR HIGHER THAN 2.

	TAR	FAR
EEG	79.2%%	21.8%
ECG	97.9%	2.1%
FUSION 1	97.9%	0.82%

More details of the system can be found in a paper presented at this conference [2]

C. EEG based Sleepiness Prediction System.

A system of sleepiness prediction for drivers has been developed by the Informatics and Telematics Institute of the Center for Research and Technology Hellas, Thessalonica, and Starlab with ENOBIO system. The EEG data are acquired with ENOBIO and sent to the application via TCP/IP. Features about alpha and theta band power are extracted online every 15 seconds and a fuzzy logic application decides the level of drowsiness of the user and triggers an alarm if the subject is too sleepy. A detailed description of the system can be found at [3].

V. CONCLUSIONS

ENOBIO is an electrophysiology recording wireless system. The quality of the signal is proven to be as good as the signal that can be acquires with state of the art wired equipment. Different applications can be built on the ENOBIO system. We presented a biometric application, a Human Machine Interface and a Sleepiness prediction system.

REFERENCES

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- [3] Damousis I, Cester I, Nicolau S, Tzovaras D. "Physiological indicators based sleep onset prediction for the avoidance of driving accidents." Conf Proc IEEE Eng Med Biol Soc 2007;1:6699-704.