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Instrumentation for EEG-based monitoring of the executive functions in a dual-task framework

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Abstract – **Instrumentation for electroencephalographic (EEG)-based monitoring of the executive functions in a dual-task framework is proposed. The proposed system integrates in a single solution (i) the administration of the cognitive task, (ii) the EEG signal acquisition and processing, (iii) the data storage synchronized whit an external Gait Analysis system. The system is based on a wearable passive brain computer interface solution that allows EEG monitoring during gait, by means of acoustic stimuli. The centralized platform guarantees the synchronization of all the processes, and therefore, improves the state of the art accuracy in measurements related to executive functions and gait. An experimental validation demonstrated the feasibility of the proposed solution in terms of execution of cognitive tasks during gait, real-time monitoring of EEG signals, and synchronized storage of EEG data, gait and cognitive task performances.**

I. INTRODUCTION

The role of executive functions in motor tasks is widely investigated due to their involvement in initiating, planning, organising and regulating behaviour [1]. Dysfunctions in cognitive processes are strongly linked to a decrease in gait performances highlighting the strong interrelation between cognition and gait [2]. In particular, monitoring cognitive disorders helps to predict future loss of mobility or the risk of fall. Among biosignal-based systems, neural-based are the most informative ones in order to monitor cognitive activity due to their high temporal resolution and good real-time performance [3].

The devices currently available to measure neural activity (magnetoencephalography, magnetic resonance imaging, functional near-infrared spectroscopy, traditional electroencephalography) are mostly not compatible with a condition of movement. Only recently, wireless EEG solutions have become commercially available but often not yet approved for clinical use and requiring complex bureaucratic processes for permission to use in experiments. However, nowadays, no integrated instrument allowing a subject to undergo a dual task while the EEG signal is monitored exist. The electroencephalography (EEG) is widely used to study the brain organization of cognitive processes such as perception, memory, attention, language and emotions in healthy adults and children [4]. In particular, the most used signal for EEG-based analysis of executive function are the Event-related potentials (ERP). ERPs are EEG-patterns in time domain occurring after sensorial stimuli recognised by the subject and can be characterized by (i) amplitude and (ii) latency. Amplitude provides an index of the intensity of neural activity and latency reveals the timing of neural activation [5]. Measuring neural activity during walking is a challenging task. A wearable passive brain computer interface solution allow EEG monitoring during gait, by means of acoustic stimuli is proposed. [6]. The proposed architecture guarantees the synchronization of all the processes, and therefore, improves the state of art accuracy in measurements related to executive functions and gait.

The paper is structured as follows: Section ii. reports the system design; Section iii. describes the system realization; Section iv. reports the feasibility experimental campaign.

II. DESIGN

In this Section the architecture and the operation of the system are presented.

A. Architecture

The architecture of the proposed system is shown in Fig. 1. The system can be synchronized with a Gait Analysis system via a trigger input port. A *Cognitive Task Manager* (CTM) can be set by the operator to configure a desired cognitive task. The tasks consist in reacting to acoustic

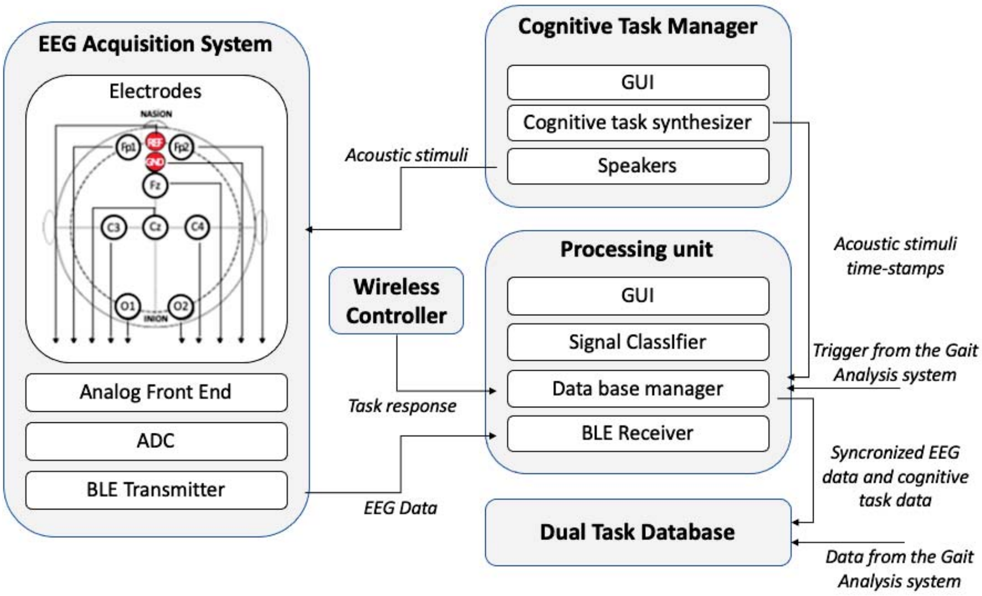

Fig. 1. System architecture.

stimuli by means of a *Wireless Controller* (WC), according to a proper rule. A wireless *EEG Acquisition System* (EAS) acquires user's EEG signal during cognitive task execution and gait. A *Processing Unit* (PU) receives EEG data from EAS, cognitive task responses from WC, acoustic stimuli time-stamp from CTM, and the trigger from the Gait Analysis System. The PU processes data and plots the EEG feature values and the cognitive task scores in real time; in the meanwhile, it manages all the data and send them to the *Dual Task Database* for off-line analysis based also on data from Gait Analysis System.

B. Operation

Before starting, the participant is explained the cognitive tasks to be performed.

After the EEG acquisition system montage, the contact impedance of the electrodes is checked and the Wireless Controller is given to the participant for the cognitive task execution. The operator, through the Cognitive Task Manager GUI, can set the type of cognitive task and its difficulty by acting on: stimulus frequencies, stimulus duration, inter-stimuli time interval. The Processing Unit is connected via Bluetooth to the EEG acquisition system and signal acquisition starts just before the cognitive task during gait. In the meantime, the Gait Analysis system starts and a trigger signal is sent to the PU.

III. REALIZATION

In this section, details about hardware and software are provided.

A. Hardware

The wireless AB-Medica Helmate system Class IIA is employed for the EEG signal acquisitions [7]. Unlike other wireless EEG signal measurement devices such as the B-Alert X systems [8], the Helmate system acquires the signal through dry electrodes. These electrodes, not requiring conductive gel, are faster to set up and can be used for longer times since there is no loss of transductive properties linked to gel dryness [9]. In addition, the Helmate monitors several cortex areas differently from similar acquisition systems based on few channels.

The electronics of Helmate is mounted on an ultralight structure and the device also includes accessories for use on a single patient: under-helmet, under-throat and electrodes. The under-helmet and under-throat are disposable and both contribute to the stability of the system, so that movement of the patient's head does not risk causing artifacts during signal acquisition.

Ten dry electrodes placed according to the 10/20 International Positioning System are provided: Fp1, Fp2, Fz, Cz, C3, C4, O1, O2, AFz (reference electrode), and Fpz (Ground). The electrodes made of conductive rubber with ends covered in Ag/Ag-Cl. Three different electrode shape are available in order to minimize the contact impedance:

- Electrode with flat contact surface, useful for placement in the frontal area;
- Small electrode with 5 legs, allows each single leg to pass through normal hair;
- Long, rigid 3-leg electrode, useful for passing through particularly thick hair, or for placement in the occipi-

tal area.

The sampling rate of EEG signals is 512 Sa/s. EEG data are transmitted by Bluetooth Low Energy protocol in packets of 32 samples.

The hardware components of the system user interface are:

- a system of Logitech speakers useful to improve the audio of cognitive tasks especially during the walking activity.
- A wireless pen (NORWII N27 Wireless Presenter, Hyperlink Volume Control Presenter RF 2.4GHz) allows the subject to respond to the cognitive task on the move. The subject presses the pen button when required by the specific cognitive task.

B. *Software*

The software of the system consists in an app developed for the administration of cognitive tasks, the EEG data processing and visualization, and the data synchronization and storage. The software is developed in Python [10]. In the following, the functioning of the app is described.

Firstly, a GUI allows the user to insert information related to the subject's anamnesis, the session information and the data storage directory. Then, biographical data and on the current status of the patient are saved. Thereafter, the GUI allows the selection and the setting of three operating conditions:

- *EEG baseline*: the EEG signal of the patient in resting condition is recorded;
- *N-back task*: a sequence of letters is played and the subject has to indicate when the current stimulus matches the one from N steps earlier in the sequence. The load factor N changes according to the task difficulty;
- *Go-Nogo task*: a sequence of two sounds is presented and the partecipant has to respond to certain frequent stimuli (go stimuli) and makes no response for rare others (nogo stimuli). An example sound of the frequent stimulus is played before trial starts. Task difficulty increases by reducing the inter-stimulus time.

Then, the streaming of data related to the helmate channels and the extracted EEG features are displayed. Afterwards, the streaming of the EEG signals acquired, the communication with the wireless pen, and communication with the external gait analysis system for synchronization are enabled and the trial starts.

Once the trial is completed, all the communications with external devices are disabled. Finally, data are stored on the filesystem, allowing the user to use this information for off-line analysis.

IV. EXPERIMENTAL VALIDATION

In this section an experimental validation of the proposed system is reported. Ethical approval was obtained from the Ethics Committee of Psychological Research of University of Naples Federico II. All experiments were performed in accordance to the declaration of Helsinki. Subjects were asked to sign the informed consent form before their inclusion in the experimental campaign.

A. *Experimental protocol*

Four experimental sessions were realized and EEG signal was recorded in four conditions:

- In the first session, one minute EEG signal is recorded in resting state;
- In the second session, the subject is seated while performing a Go-Nogo task for the response inhibition assessment; The subject provides his/her answers via the wireless pen.
- In the third session, the subject is required to walk on a platform equipped with force-feeders at their preferred speed;
- In the last session, the subject is required to walk on the platform equipped with force-feeders and, at the same time, performs the cognitive task, providing his or her answers via the wireless pen.

B. *Data analysis*

Data were filtered by a fourth-order bandpass Butterworth filter [1.5 - 30] Hz; then, grand average method is applied in order to extract the ERP.

A preliminary comparison is carried out between EEG data acquired by AB-Medica Helmate and Mitsar-EEG 201 in order to assess the suitability of the proposed device in acquiring ERPs. Mitsar-EEG 201 is a 19-channel electroencephalographic system. EEG recordings were obtained using a cap with 19 electrodes positioned according to the 10/20 International Positioning System. The two devices differ also in the type of reference adopted: AB-Medica Helmate has Fpz as its reference while Mitsar-EEG 201 has the the earlobes (A1-A2) as its reference. EEG data of a subject (female, 25 years old) while performing a Go-Nogo task using the two devices are acquired. Data are divided in 1 second epochs and ERPs are calculated. Results are shown in fig. 3 and 2. The ERP phenomenon is observable using both devices. Differences in the amplitudes of the two phenomenons are observable and are due to the different referencing system.

Another analysis is carried out to test the AB-Medica system during movement. One subject (male, aged 28) is involved in the system experimental validation.

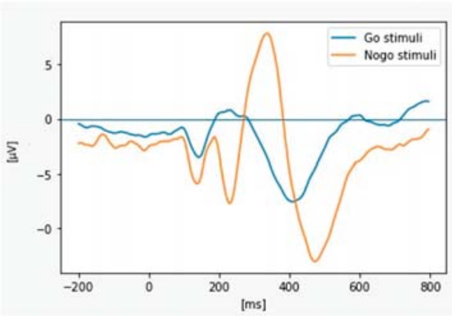

Fig. 2. ERP from 22 channel EEG device at Cz.

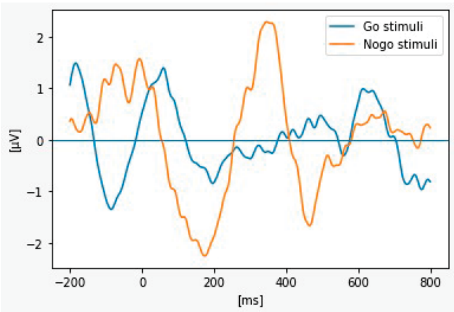

Fig. 3. ERP from Ab-Medica Helmate at Cz.

A visual comparison between EEG data recording during the first and the third session is made in order to demonstrate the usability and the effectiveness of Ab-Medica Helmate in recording EEG signal during gait. Typical signal trends over time in a resting condition and during movement are shown in Fig. 4. Due to motion arte-

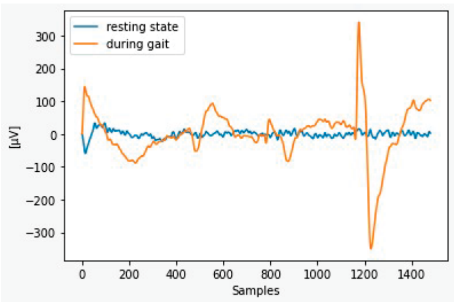

Fig. 4. 3 seconds EEG signal during walking and sitting at Cz.

facts, the dynamics of the two signals are significantly different, reaching 300 μV amplitudes during gait. A preliminary analysis is carried out to assess the performance of the system in terms of ERP extraction during gait. Fig 5 and 6 show ERP, in particular the P300 (an ERP potential occurring 300 ms after the sensorial stimulus), acquired during a Go-NoGo tasks sitting and walking, respectively. Despite the evident noise, a peak at 300 ms can be detected in both cases. Furthermore, signal amplitude of EEG recorded

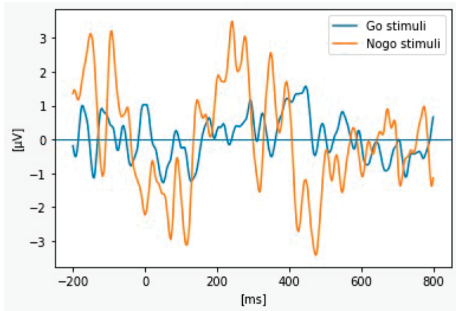

Fig. 5. ERP resulting from Go-Nogo activity while sitting at Cz.

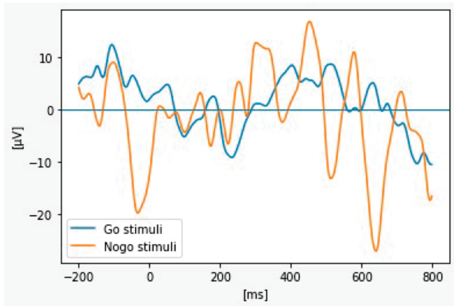

Fig. 6. ERP resulting from Go-Nogo activity while walking at Cz.

during gait is traced back to typical ERP amplitude dynamics, demonstrating that the ERP calculation also acted as a filter for artefact removal.

V. CONCLUSION

Instrumentation for EEG-based monitoring of the executive functions in a dual-task framework is proposed.

Experimental validation demonstrated the proposed system allows monitoring the EEG of individuals while they perform cognitive tasks during gait. An experimental validation demonstrated the feasibility of the proposed solution in terms of execution of cognitive task during gait, real-time monitoring of EEG signal, and synchronized storage of EEG data, gait and cognitive task performances. In future contributions, the sample size will be increased in order to understand whether the cross-subject influences the result. Another future step will involve the re-referencing of data recorded by the Ab-Medica Helmate to understand the influence of the chosen reference on the ERPs visualisation, as well as improving signal to noise ratio by applying additional filters and using new artifact removal techniques. In particular, the Artifact Subspace Reconstruction (ASR) revealed to be a promising technique for artefact removal with respect to traditional approaches such as Independent Component Analysis and Principal Component Analysis [11, 12].

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