A Mobile-Health Neurodiagnostic System based on Spatio-Temporal P300 Monitoring: Design, Development and Test in vivo

V. F. Annese, G. Mezzina, D. De Venuto
Dept. of Electrical and Information Engineering (DEI), Politecnico di Bari, Via Orabona 4, 70125 Bari – Italy

Introduction. The increase in the average lifespan of the population has brought with it a proportional increase in the diagnosis of neurological disorders (Alzheimer's and Parkinson's diseases, etc.), recognized to be the reason for 11.67% of all the worldwide deaths (2005), reaching the projection of 12.2 % by 2030. This work presents the design, development and testing in vivo of an innovative cyber-physical system based on cortical event-related potentials (ERPs) characterization for the early *diagnosis of neuro-cognitive impairments* and for *neuro-rehabilitation*. The diagnosis is based on the spatio-temporal characterization of the P300 component, positive ERP deflection pattern, which plays a key role in cognitive disabilities diagnosis.

The architecture. The developed m-Health system, called t-RIDE (tuned-Reside Iteration decomposition), is made up by two sides bridged by cloud storing: the patient and the medical parts.

The patient side performs the test and data processing. On the hardware side, the wireless electroencephalogram (EEG) system g.Nautilus by g.Tec (32 channels, 24-bit resolution, sampling frequency 500Hz) was used for cortical data collection. Data are routed by a gateway and transmitted in real time to a PC which runs the diagnosis algorithm and completes the sensing system. The hardware is non-invasive and remotely working.

The medical side of the m-Health system is made up by a smart-device (i.e. smartphone, tablet, etc.) with proper Internet connection. The doctor has a twofold possibility of interaction with the system: on one hand, he can modify the parameter cloud-shared file (.txt) which is loaded by the gateway before each test (i.e. window of interest, channels, etc.); on the other hand, he can consult output files presenting spatial (topography i.e. brain mapping) and temporal (latency, peak, etc.) features of the P300 available in pdf from everywhere and anytime.

On the software side, a first phase of 'artifacts-rejection' (bandpass filtering 0.5-30Hz, Butterworth, 8th order; low-pass filtering at 15 Hz, Butterworth, 6th order; 'signal de-trending' by 8th order polynomial fitting) is performed. The study of the P300 is done during protocolled cognitive tasks (visual or audible) generated according to the odd-ball paradigm, in order to stimulate the ERP. The diagnostic core is based on an iterative algorithm of Residue Iteration decomposition, and optimized, through a step of window-tuning for P300 analysis in order to perform spatial analysis (topography of scalp, sources of potential, etc.) and time (latency, amplitude, etc.). This approach consists of a first decomposition (3 components) and a reliable reconstruction of the ERP pattern based on statistical median analysis of the amplitudes and latencies of the most likely core component in question, eliminating the problem of amplitude broading caused by the latency jitter. The t-RIDE method exploits the Woody's method for the latency estimation of a single-trial and the template matching by cross-correlation. A user-friendly application with a GUI has been developed.

Main Results. The m-health system has been developed and tested on 13 healthy subjects (aver. age 25) which have been proposed three cognitive tasks of increasing difficulty. The *algorithm validity* was demonstrated by fully matching the results obtained by t-RIDE (amplitudes 3.6μV to 11μV; latencies: 298ms to 390ms; topographic concentration along the central parietal line i.e. F_z, C_z, P_z), with the medical literature. The diagnostic tool *overcomes the limits of the competing approaches*, such as ICA, PCA by reducing the number of electrodes required from a minimum of 22 channels (for topographical analysis) to 8, reducing the number of trials needed to a suitable reconstruction of the track ERP to 24 and ensuring a rapid numerical convergence (10 iterations in the channel) when compared with other iterative methods related (i.e. Takeda et al.). T-RIDE reached convergence on 8 channels after 148 iterations based on 24 trials and 90 non-target stimuli, returning however an accuracy > 80% after only 13 trials (worst case) on a single channel.

Conclusion. T-RIDE, the *neuro-diagnostic* developed *tool*, meets the guidelines of bio-marking of neural disorders. It overcomes the limits of the approaches currently in use and achieves an appropriate balance between high reliability of results, reducing the cost of health care (favoring de-hospitalization) and improves the quality of life of the patient.

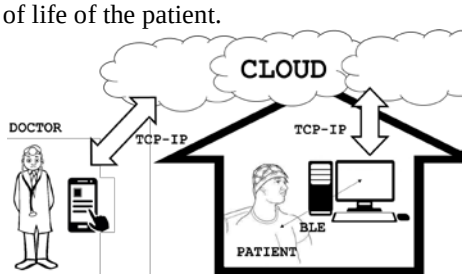

Fig. 1. Architecture of the m-health system.

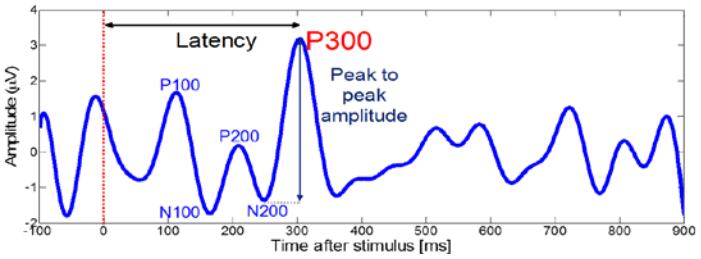

Fig. 2. Time-domain P300 waveform.

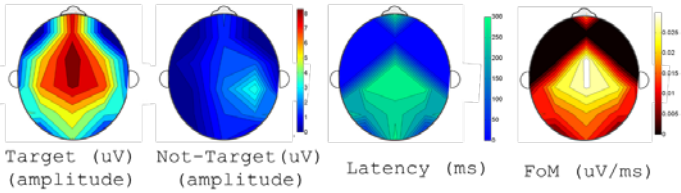

Fig. 3. Demonstrative picture of P300 analysis.