Brain-Computer Interfaces: Real-time monitoring of cognitive functions using sensory evoked potentials

Mots clés :
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Résumé du projet de recherche (Langue 1)

Development of technologies such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), high-speed echography and near-infrared spectroscopy (NIRS) allow us to collect information about the inner activity of the brain with a high temporal resolution. Therefore, it has become possible to study the short-term neuronal synchrony and their correlations with cognitive functions such as decision making, language, attention, pattern recognition, memory, planification etc. Brain–Computer Interfaces (BCI) are communication systems that enable users to send commands to a computer by using only their brain activity (Nicolelis 2011 for an introduction about BCI). This activity is generally measured using EEG , which is convenient and non-invasive, has a high temporal resolution (in the millisecond range) and is powerful despite its low spatial resolution. Most EEG-based BCI are designed around a pattern recognition approach. First, features describing the relevant information embedded in the EEG signals are extracted. Then, an algorithm converts these features into a command that the computer can interpret in order to provide an adapted response. EEG signals have been shown to contain information correlated to cognitive functions (see e.g. Gazzaniga, 2009), which could be observed even in single trial acquisitions, for instance using time-frequency representations (Vialatte et al., 2007; Vialatte et al., 2009). Our working hypothesis is that it is possible to monitor the markers of such cognitive activity on short time scales (between 0,1s and 10s) with sufficient reliability. Therefore, we want to monitor and interact with cognitive functions in real-time and design what we could call a cognitive brain-computer interface. The first purpose of this research project is the characterization and modeling of sensory evoked potentials (visual, auditory, or others), i.e. electrical potentials that are recorded in the brain as a consequence of sensory stimuli; we will focus on steady-state evoked potentials (SSEP). These potentials are useful to monitor changes over time in the brain activity, such as fluctuations of attention (Kim et al., 2007) or of emotions (Keil et al., 2006). These potentials appear when a sensory stimulation is sustained at a constant frequency for a sufficient time duration (over 200~350 msec). Although SSEPs have been described and studied for more than 40 years, their properties are still poorly understood (Vialatte et al., 2010). We will specifically study the local and large-scale synchrony effects (time-frequency structure, complexity measures, stationarity and nonlinearity measures, mutual information, coherence and correlation, state-space based synchrony, etc.), as they are likely to convey key information about the neural correlates of cognition. EEG data collection will be performed using a BrainAmp acticap system recently acquired by the SIGMA laboratory. EEG signals will then be modelled in three steps: - Feature design. We will identify the most significant properties for the real-time detection of cognitive correlates. - Supervised feature investigation and machine learning. Machine learning algorithms (e.g. artificial neural networks, see Dreyfus 2005) will be used to create semi-physical models for prediction of the brain state in regard to a given cognitive function. - Experimental tests. The cognitive BCI will be tested, while objective and subjective reports of the subject experience are monitored. This step will validate the models developed. The second goal of this research project is to apply these SSEP/synchrony measurements to monitor the neural correlates of cognitive functions in real-time. We will focus our investigations more specifically on the real-time monitoring of attentional levels (vigilance, arousal, sustained attention, attention control/focus, etc.). The advantage of being able to monitor such functions in real-time is that we can observe the influence of external stimuli, or conscious modifications of the subject’s cognition.

Résumé du projet de recherche (Langue 2)
Steady state evoked potentials, and particularly SSVEP are commonly used in cognitive psychology studies and neuroengineering research, and can be useful for vision-based BCI. Getting a better understanding of this EEG activity and better methods to extract these signals could offer new possibilities in these fields and open the way to new applications. From an engineering perspective, developing processing methods for multiple channel EEG recordings can lead to the creation of new models for related problems such as online artifact rejection using blind source separation (BSS), independent component analysis and temporal concatenation applied to multiple channel detection to increase signal to noise ratio, time-space-frequency representation, etc. Real-time attention monitoring could be of use in several domains. First, the monitoring of attention and other cognitive functions can be used as a tool for neurological disorder diagnosis with applications to hyperactivity disorder, depression, and schizophrenia. Then, with the price fall of EEG systems and the development of dry electrodes and other innovative measurement systems, we can imagine that these sensors could be easily available in the future and could be of use for instance in any activity that requires a high attention level (such as driving). Finally, studying EEG activity in the time-space-frequency domain with synchrony measurements could help understanding the short-term dynamics of neural synchronization, leading to substantial progress in the understanding of "how the brain works".

Informations complémentaires (Langue 1)

This project will benefit from our present network of collaborations, providing an access to support from experts in neuroengineering and psychology: - Dr. Hovagim Bakardjian, expert in neuroengineering, BCI and SSVEP (INSERM, IM2A, Pitié-Salpêtrière); - Neuropsychologists from the Centre d’Evaluation et de Recherche Clinique (Centre Hospitalier Sainte Anne); - The Dauwels lab (Singapore, NTU, EEE department), specialized in biomedical engineering; - The laboratory for advanced brain signal processing (Riken Brain Science Institute, Japan), specialized in EEG/fMRI signal modeling and processing, and data analysis; - The Department of Digital Technologies and Information (University of Vic, Spain), for signal processing.

Informations complémentaires (Langue 2)