Leveraging brain connectivity networks to detect mental states in brain-computer interfaces

Résumé du projet de recherche (Langue 1)

A brain-computer interface (BCI) is a device that can decode brain activity alone, thus creating an alternate communication channel between a person and the external environment. BCIs are increasingly used for control and communication, and for treatment of neurological disorders. Despite its potential societal and clinical impact, BCI performance still remain relatively low and/or unstable with several weeks needed to reach relatively high-performance (>90%) and a non negligible portion of users (15-30%) that won’t be able to achieve control (ie, BCI illiteracy phenomenon). Current evidence shows that, even if the use of a BCI only requires the activity modulation of a few sensor/motor areas - typically captured by magneto/electroencephalographic (M/EEG) power spectrum - a larger distributed network of remote areas, including frontal and subcortical regions, appear to be involved in the acquisition of BCI control. Recent studies using noninvasive neuroimaging techniques in healthy subjects have also reported significant changes in amplitude and spatial distribution of task-related brain activity after MI-based BCI training. Taken together, these findings suggest the use of standard signal processing methods that only capture local brain activity changes could underestimate connectivity phenomena which could instead play a crucial role in improving BCI accuracy. Project’s goals and impact Contrary to many approaches in BCI having mainly focused on improving the classification block through advanced machine learning algorithms (eg, common spatial filter, Riemann geometry), this project aims to primarily operate on the feature extraction block of a BCI system. In particular, the project is tightly focused on the following questions: - Which are the brain regions and network mechanisms involved in a BCI task? - Can we reliably estimate network-based features in real time to achieve effective online control? - What is the potential of such features to improve BCI accuracy? By providing fresh knowledge on the neural circuits and the dynamic mechanisms that are involved in BCI tasks this project has the potential to identify new features/biomarkers that can be used to foster the development of coadaptive frameworks and make BCIs more reliable for control and communication in healthy and diseased conditions.

Résumé du projet de recherche (Langue 2)

To answer the above questions, the PhD project is organized around three Thrusts: Thrust 1: Development of graph metrics capturing brain network changes in BCI-related mental states. In recent years, graph analysis of functional brain networks has been widely applied to discriminate different mental states (eg, resting states versus motor/cognitive tasks or healthy versus diseased subjects). Despite its potential, graph theoretic approaches as a possible tool for extracting new features from brain connectivity in BCI has been poorly explored. The first part of the work will consist in developing new network metrics that can increase the separation of BCI mental states (eg, motor-imagery tasks) and that can be associated to known neurophysiological processes (eg, ERD/ERS). Thrust 2: Development of methods to infer time-varying connectivity between brain signals. In the previous thrust, brain connectivity networks will be estimated by integrating the data points available in the entire temporal windows (typically few seconds for several epochs). The second methodological part of the work will consist in elaborating new signal processing methods to infer time-varying connectivity patterns during BCI tasks based on short-time and adaptive estimations. This way, the graph metrics identified in Thrust 1 can be naturally extended to temporally dynamic brain networks. Thrust 3: Validation on real-data recorded in healthy subjects. To validate the methodological approaches of Thrusts 1 and 2, this third part of the work will consist in designing an off-line framework that simulates realistic BCI scenarios by re-using longitudinal and multimodal neuroimaging data recorded a standard 1D, two-target, motor imagery BCI task. Different connectivity methods will be explored to construct brain networks taking into account (non)linear and bi/multivariate temporal dependencies. The resulting BCI accuracies will be statistically compared with commonly used features to determine whether, and to what extent, the inclusion of such new features improve the overall performance.
The PhD project will be realized in the Inria ARAMIS team “Algorithms, models and methods for images and signals of the human brain” at the Institut du Cerveau et de la Moelle (ICM) in Paris. In particular, the data necessary for the validation of the methods (Thrust 3) are already available in the ARAMIS team consisting of simultaneous high-density EEG and MEG recordings in a group of healthy subjects. Key interactions with other national and international teams working on BCI are envisaged in the course of the PhD project.

Informations complémentaires (Langue 2)

The ideal candidate should have a solid background in signal processing, machine learning and/or brain-computer interface, enjoy high comfort levels when dealing with mathematical abstractions/modeling as well as programming (Matlab, Python, or C). A background in network/graph theory is welcome but not necessary. The ability and willingness to learn will do equally well. An excellent level of spoken/written English is mandatory. Strong communication skills in reporting the results of the project and interact with other team members are required.