Real Time fNIRS Classification for BCIs

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Abstract

Passive brain-computer interfaces are designed to use brain activity as an additional input, allowing the adaptation of the interface in real time according to the user's mental state. While most current brain computer interface research (BCI) is designed for direct use with disabled users, our research focuses on passive BCIs for healthy users. We employ functional near-infrared spectroscopy (fNIRS), a non-invasive brain measurement device, to augment an interface so it uses brain activity measures as an additional input channel. Past research has measured and classified brain signals that are interesting in HCI context, such as mental workload and difficulty level of a task. Current work focuses on developing a real time fNIRS classification system and creating an interface that responds to one of those measures by adapting the interface.

Keywords

Brain-Computer Interface, human cognition, functional near-infrared spectroscopy, fNIRS, task classification

Introduction

Brain computer interfaces (BCIs) use brain activity as an input for interfaces. Most current work allows disabled patients to communicate with their environment with the use of electroencephalography (EEG) [5, 11]. However, a new train of thought in the BCI community considers brain activity as an additional source of in-

Figure 1. A probe includes a detector (larger square) and four light sources (smaller squares).

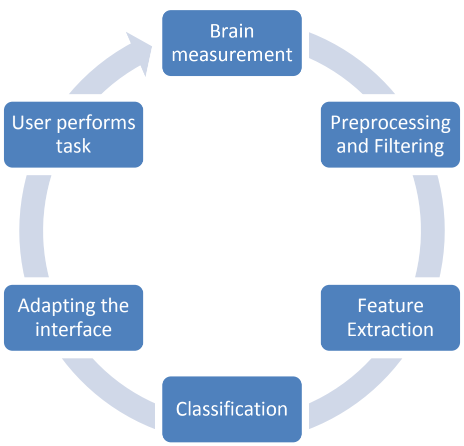

Figure 2. Basic steps in a brain-computer interface.

formation, to augment and adapt the interface instead of controlling it directly with the brain. The new methodology focuses on a broader group of users—the general population—for whom current BCIs are unpractical because of their slow speed of transfer. Passive BCIs detect brain activity that occurs naturally during a task use it as an additional input, in conjunction with standard devices such as keyboards and mice [2].

The brain measurement used in this research is called functional near-infrared spectroscopy (fNIRS). By measuring the reemission of near-infrared light sent in the brain, this device extrapolates a measure of brain activity. This non-invasive and portable technology offers interesting applications for the field of HCI, as it is relatively impervious to user movement [9]. Researchers have demonstrated fNIRS' ability to measure brain signals such as mental workload levels, emotions, or motor activity in healthy participants [4, 8].

While most work using fNIRS uses offline analyses to evaluate the data, the key component of brain computer interfaces is the ability to perform real time analyses. Many argue that their work could be done in real time [3, 8], yet we found few fNIRS systems in the literature that do [1, 6]. Figure 2 illustrates the basic steps involved in brain computer interfaces.

We have developed a software system that allows for real time fNIRS brain signal analysis and machine learning classification of affective and workload states, called the Online fNIRS Analysis and Classification system (OFAC). This system receives and processes brain signals and event markers, automatically recognizes the current cognitive or affective state using a database of previously recoded signals and machine learning techniques, and outputs the answer to the interface presently used, allowing for the creation of interfaces that adapt and change in real time.

This article presents work done with fNIRS, describes the OFAC system, and introduces preliminary work showing the reliability and potential of the system.

Exploring brain signals measured with fNIRS

fNIRS calculates change in hemoglobin concentrations [10] (Figure 1). Our probes measure the brain area called the anterior prefrontal cortex located under the forehead, an active region that deals with high-level processing [7]: working memory, planning, problem solving, memory retrieval and attention. We believe in the potential of using higher cognitive function in a passive BCI. Because of this rich area, we have investigated different signals with HCI potential, including difficulty level [3] and mental workload [4]. We observed promising results when assessing the signal of those experiments.

We have also shown fNIRS' ability to deal with physical artifacts and noise common to typical HCI laboratory settings, mainly that activities like mouse clicking and keyboard typing are acceptable [9].

Online fNIRS Analysis and Classification

We designed a flexible, modular architecture for the OFAC system (Figure 3), created using Matlab. It allows for advantageous substitution of single modules should another functionality be required, and accepts multiple input signals, such as the combination of fNIRS and EEG. OFAC contains four types of modules for data processing: modules to receive and record input data (one for each type of input); to preprocess data; to filter;

and to perform machine learning classification and output the brain signal classification to the interface. The current system takes two different types of input: the raw brain data, and external markers from the application shown to the user. The raw data (from BOXY software, ISS Inc.) also includes basic markers related to the start and stop of the real fNIRS data when the sensors are correctly in place and the experiment starts, as opposed to uncalibrated data. The external markers could contain behavioral data, for instance, intended to help with data classification.

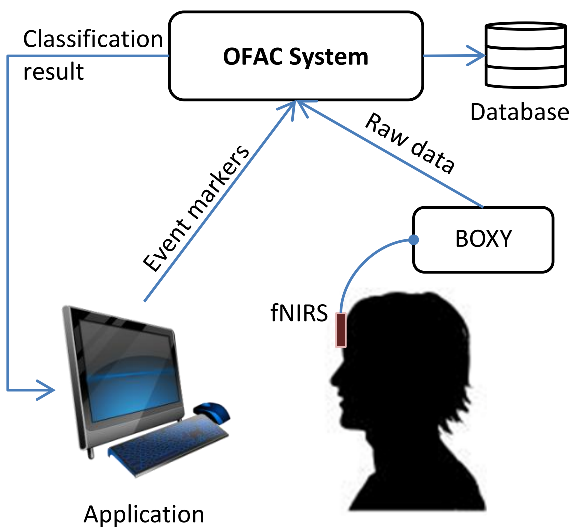

Figure 3. Architecture of the OFAC system

Our first evaluation compares a previous offline analysis with our real time analysis [3]. Results show a decrease of 10% in classification accuracy (94% to 84%), and that a minimum of 10 examples of each class is required to obtain a stable accuracy. We consider this decrease in performance is outshined by the main advantage of the analysis, classifying in real time, and the ability to reuse this information to adapt the interface.

The second study demonstrates the online features of OFAC: its ability to record, process, classify cognitive state signals and adapt simple interfaces in real time. We selected two tasks that activate and deactivate the prefrontal cortex, respectively playing a game of Tetris and showing calm videos. In a first step, we classify the data in real time. In the second part, background music varies according to the predicted task: slower music for relaxing videos, and faster for the game task. We are currently evaluating this system through classification accuracy, as well as using user satisfaction of the adaptation. We believe that user satisfaction is at least as important as speed and accuracy, especially for passive BCIs, as their main goal is not always to increase productivity.

Conclusion

Measuring brain signals related to interfaces can lead to applications such as interface evaluation and adaptation. Our work explores brain signals measured with fNIRS, use them to adapt the interface and close the loop by connecting brain signals to the adaptable interface. We are really enthusiastic about the potential for fNIRS and similar techniques to greatly enhance how people interact with computers. The creation of a brain-computer interface will open opportunities for adaptation on different brain signals, with a device that is portable, non-invasive and safe.

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Audrey Girouard is a graduating PhD candidate in Computer Science at Tufts University. Audrey is currently fascinated by passive brain computer interfaces, studying the use of brain imagery to enhance HCI for all, with the use of functional near-infrared spectroscopy. She is the laureate of the PostGratudate Scholarship from NSERC. Audrey has a M.S. in computer science from Tufts University and a B.Eng in software engineering from École Polytechnique de Montréal.

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