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On the Need for Both Internal and External Context Awareness for Reliable BCIs

T. Carlson, S. Saeedi, R. Chavarriaga and J. d. R. Millán
Chair in Non-Invasive Brain-Machine Interface, Center for Neuroprosthetics, EPFL, Lausanne, Switzerland

Correspondence: T. Carlson, Ecole Polytechique Fédérale de Lausanne, STI-CNBI, Station 11, Lausanne, Switzerland.

E-mail: tom.carlson@epfl.ch

Abstract. In this paper we argue that for brain-computer interfaces (BCIs) to be used reliably for extended periods of time, they must be able to adapt to the user's evolving needs. This adaptation should not only be a function of the environmental (external) context, but should also consider the internal context, such as cognitive states and brain signal reliability. We demonstrate two successful approaches to modulating the level of assistance: by using online task performance metrics; and by monitoring the reliability of the BCI decoders. We then describe how these approaches could be fused together, resulting in a more user-centred solution.

Keywords: BCI, Context-Awareness, Shared Control, Adaptation, Information Theory

1. Introduction

Brain-controlled assistive technology, such as wheelchairs, telepresence robots and neuroprostheses offer promising solutions to the problems suffered by people with severe motor disabilities. However, in order to reliably operate such devices using a BCI in real-world environments, some degree of assistance (shared control) is required to compensate for the relatively low information transfer rate and performance variability of the BCI. The level of this assistance is usually only a function of the external context (i.e. the surrounding environment) [Tonin et al., 2011]. However each person has different needs and abilities, which in turn change over time. We refer to this as the internal context, which encompasses cognitive states and changes in the user's brain patterns. Therefore, we are investigating how we can capture the instantaneous needs of users, such that we can adjust the level of assistance accordingly. We propose to achieve this, by using a combination of online task performance metrics and by simultaneously characterising the reliability of the BCI decoders.

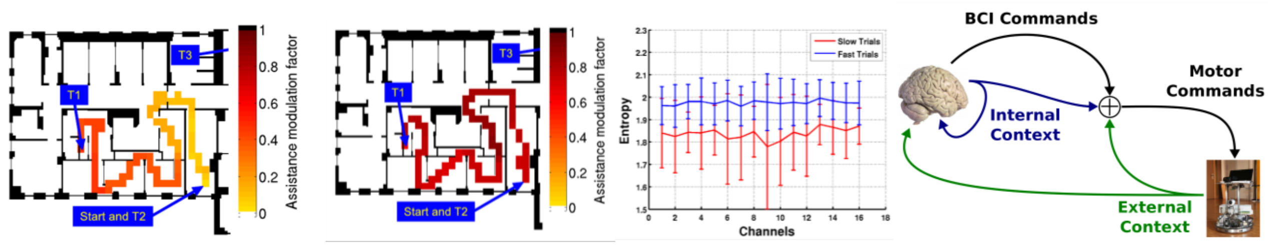
2. Material and Methods

2.1. Online task performance metrics

We propose to use online task performance metrics to modulate the level of assistance provided by a shared control system, such that it is well-matched to the user's current and ever-evolving needs. These consist of metrics commonly used (post-experiment) to evaluate shared control systems. In this experiment, subjects were instructed to navigate around a complex simulated environment, using their left hand to operate a time-restricted 2-button input, which emulated the output decisions of our motor imagery-based BCI. Periodically, subjects were asked to simultaneously perform a demanding secondary (reaction) task with their right hand, which was designed to increase their workload. 18 healthy subjects participated in this part of the experiment [Carlson et al., 2012]. During the experiment we computed online the assistance modulation factor (AMF), based on the number of commands generated by the user, the number of times assistance was required and the effective navigation time.

2.1. Online estimation of brain signal reliability

We also assess the user's current ability to operate a motor-imagery based BCI through the online estimation of the accuracy and command delivery speed. The time to deliver a command (trial length) varies, since we accumulate evidence until we are confident about the classifier output [Tonin et al., 2011]. This variation can occur for many reasons, such as changes in attention, fatigue, stress etc. Shared control could compensate for this by, for example, altering the speed or reaction time of a robotic device according to the predicted BCI trial length. In a separate five subject study, we found that the entropy rate of the EEG signals while subjects control a motor imagery BCI is lower



(a) (b) (c) (d)

Figure 1. *Assistance modulation factor when:* ***(a)*** *driving only,* ***(b)*** *driving + secondary task.* ***(c)*** *typical entropies for fast and slow BCI trials across EEG channels.* ***(d)*** *Proposed context-aware adaptive shared control architecture for BCI.*

when subjects take a long time to deliver a command. Based on this, we developed a method to predict whether the current command will be emitted quickly or slowly according to the entropy of the first few samples of each trial.

3. Results

3.1. Online adaptation

Our assistance modulation factor (AMF) was able to reliably track the user's workload, see Fig 1. (a,b). The median level of assistance increases significantly ($p < 0.001$) from 0.687 to 0.985 when the user has to additionally engage in a demanding secondary task. Furthermore, we found a large range of AMF values when the users are only driving (no secondary task); this reflects the variability across subject as some participants yielded a much better level of control than others. Conversely, some participants found the driving task alone to be extremely demanding and to require a high level of assistance even when they were not engaged in a secondary task. We also see an improvement in overall task performance (e.g. completion time) and a high user-acceptance [Carlson et al., 2012]. Altogether, the AMF provided an online measure of the task difficulty–and therefore the amount of assistance required— depending on both the subject and the particularities of the task.

3.2. Online estimation of brain signals

We also found that we can reliably predict the trial length class (i.e. fast or slow) based on the Entropy of the EEG using a LDA classifier, see Fig. 1 (c) [Saeedi et al., 2012]. Performance for all subjects (AUC) exceeds 0.7 based on the data samples acquired before the subject median delivery time. This is especially important in a non-cued, asynchronous protocol; since we don't know when the user began trying to deliver a BCI command, there is no definitive method for measuring how long it took to actually deliver the command.

4. Discussion

In this paper, the two approaches to context-awareness are considered separately, but the results suggest that in the future it would be interesting to combine them. Fig. 1 (d) depicts how we envisage combining both external context, such as environmental features and task performance metrics, with internal context, such as cognitive states and brain signal reliability metrics. Using the results of the online performance metrics experiment, we have shown how we are able to modulate the proactivity of the robotic device, by changing the effective operating distance of the robot's sensors. Simultaneously, we could modulate the physical speed of the device, according to the brain signal reliability, thus matching the speed at which the user can issue commands with the speed of the device, resulting in a more reliable and usable BCI system. We are currently developing some experiments to test the efficacy of such an integrated approach.

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