fNIRS-based BCI for Robot Control (Demonstration)

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ABSTRACT

Brain-Computer Interfaces (BCIs) are playing an increasingly important role in a broad spectrum of applications in health, industry, education, and entertainment. We present a novel, mobile and non-invasive BCI for advanced robot control that is based on a brain imaging method known as functional near-infrared spectroscopy (fNIRS). This BCI is based on the concept of "automated autonomous intention execution" (AutInEx), that is, the automated execution of possibly very complex actions and action sequences intended by a human through an autonomous robot.

Categories and Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics—*operator interfaces*

General Terms

Algorithms, Experimentation, Human Factors, Measurement

Keywords

Robotics, Brain-Computer Interface, fNIRS

1. INTRODUCTION AND MOTIVATION

In recent years Brain-Computer Interfaces (BCIs) have received an increasing attention due to their broad range of potential usage in domains such as support of patients, training, education, and gaming. Generally speaking, a BCI is a system that records and translates signals produced by the human brain into control commands used by external applications [1]. There is a wide variety of technologies that can in principle be used for recording brain signals and thus for implementing BCIs. Among them are, for instance, electrocorticography (ECoG), functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), and functional near-infrared spectroscopy (fNIRS). These technologies differ from each other in properties such as portability (ability to move around with equipment), accessibility (the "cost" of using the system), reliability (precision and accuracy of signals), and responsiveness (reaction speed).

In this paper we focus on *mobile* and *non-invasive* BCIs for physical robot control based on fNIRS. So far only very few such systems have been described in the literature [3]. We present a novel conception and an implementation of a BCI that is based on the idea that a robot executes autonomously the actions intended by a user. In this way, execution control is handed over to the robot, which can significantly relieve an user's effort to carry out desirable tasks and to achieve certain states through the robot. This property of autonomous intention execution, in combination with mobility and non-invasiveness, gives this interface a very high application potential.

The paper is structured as follows. Section 2 provides the necessary background in fNIRS. Section 3 outlines the developed BCI interface, including its conceptual structure and signal/data processing cycle.

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2. fNIRS

2.1 Working Principle

fNIRS is a neuro-imaging method that makes use of hemoglobin (Hb) properties. The light emitted at wavelengths about 800 nm can pass through living tissues, almost without loss in intensity. However Hb contained in blood circulating in the tissue attenuates light differently depending on the oxygenation state. Thus, it is possible to emit light at two wavelengths around the isosbestic point - where attenuation is the same for both oxygenated (HbO) and deoxygenated Hb. The intensity of the light emitted by the *sources* and absorbed by the *detectors* (together - the optodes) for each of the wavelengths is used to estimate Hb and HbO concentrations at a specific time.

The tissue blood inflow signalizes of the activation in this region of the tissue and causes the Hb level to drop and the HbO level to increase. Knowing this, it is possible to detect brain activations based on the observed intensity of the light absorbed by the detectors.

2.2 Hemodynamic BCI

For the use of fNIRS in BCIs, the optodes are fixed to the cap which is worn by the subject, and the measured tissue is the brain. Basic fNIRS settings with a few sources and optodes already are able to provide reliable signals for simplistic BCIs [2]. As described in the literature, the applications vary, e.g., from alternation of music performed by an artist based on their cognitive load state to enhancement of cognitive abilities of BCI subjects.

However, until recently only very few hemodynamic BCIs were used for robot control and manipulation. It can be expected that this will change as physical robots penetrate into people's everyday lives – for instance, they are used as a means of interaction for kids and elderly and they help to compensate for lost human capabilities (motorized wheelchairs, robotic prostheses, etc.) [4]. Apparently most of these everyday-life applications require mobile and non-invasive BCIs.

A key challenge in bringing together fNIRS and robotics is to make sure the BCI is sufficiently responsive. This is because the time it takes to observe changes in Hb and HbO (and thus the time it can take to produce robot-control signals) is in the range of several seconds. Our research aims at tackling this challenge in a principal way through the concept of "automated autonomous intention execution" (AutInEx), that is, through the automated execution of the actions intended by a human through an autonomous robot. This may require the usage of AI-related techniques and methods such as machine learning, planning, intention modeling, behavior prediction, image interpretation, path planning, and environmental mapping and robot localization. By using this concept, fNIRS-specific delays in responsiveness can be avoided or compensated because the robot takes care of planning and carrying out even complex actions and action sequences on behalf of the human user. (An example of such a complex action is shown in the demo: "monitor the entrance and give the alarm if somebody enters".)

3. SYSTEM OUTLOOK

The developed BCI system as shown in Figure 1 may be divided into three blocks: the data collection, the data processing and the action control. This differentiation reflects the separation of the underlying components and shows that each of the blocks may for instance run on a different PC and therefore is physically detached from the others.

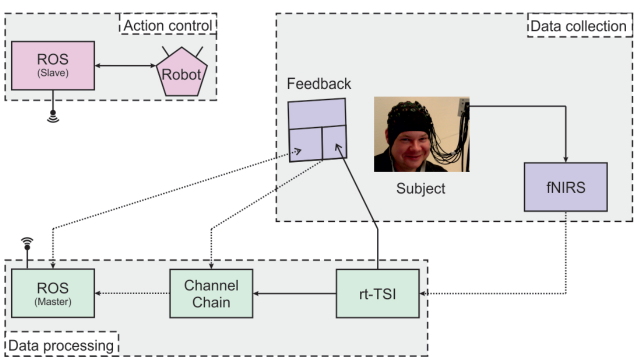

Figure 1: BCI system schema

Sub-blocks are connected together either by wires (solid links) or via the TCP (dotted links). A master Robot Operating System (ROS) node is connected with a slave wirelessly as well, but the connection is shown symbolically different to emphasize the autonomy of the action control block.

The system loop starts with the data collection block. Subject receives instructions about the system settings (e.g. encoding type, time for each encoding literal), mental tasks to be performed and current robot status through feedback displays. Prior the recording s/he wears the fNIRS cap and the desired number of optodes are attached to the cap. The optodes are connected to the fNIRS system (NIRScout 816 by NIRx Medizintechnik GmbH, Germany), which collects optical signals attenuated in the subject's cortex and translates them into the format of clocked data packages holding the source-detector pair id and the value (amplitude) of the optical signal. Note that fNIRS system is comprised of the optodes, an optical signal processing device, a network switch and a PC running a software of the manufacturer.

Further processing starts when the data packages from fNIRS system arrive to the real-time Turbo-Satori (rt-TSI) software package (by Brain Innovation BV, Netherlands). In rt-TSI they are filtered, aligned and translated to the absolute Hb and HbO values. These values are used both to provide a neurofeedback to the subject, demonstrating how "well" s/he performs the mental task (how strong are the activations), and to feed the developed ChannelChain software package. ChannelChain performs data processing on package, channel and encoding levels generating a high-level interpretation of the input values. When the encoding is recognized, ChannelChain sends the corresponding command to the master ROS node. This node, running on the data processing PC, translates the received command to the proper format suitable for robot control - the command needed to achieve the goal underlying the initial encoding (e.g. "go open the door", "find the pen").

Finally, once the master ROS node formulated the commands, it sends them via network to the action control PC placed on-board of a robot. Its own slave ROS node makes sure that the commands are correctly transferred to the robot actuators and processes the robot's sensory input. In accordance with the AutInEx the robot is aimed to be as autonomous as possible, so that when it receives a command for execution it does not need any further guidance from the rest of the system.

4. DEMONSTRATION

The demonstration[1] explains and illustrates the conception of AutInEx and the implementation of our fNIRS-based robot-control BCI. This includes details on fNIRS and its link to robotics, the encoding of tasks to be executed by a robot, and the necessary signal processing and data transfer to ROS. It is also shown how real robots (TurtleBots) carry out user-intended action sequences.

REFERENCES

[1] H. Ayaz, P. Shewokis, S. Bunce, and B. Onaral. An optical brain computer interface for environmental control. In *Engineering in Medicine and Biology Society,EMBC, 2011 Annual International Conference of the IEEE*, pages 6327–6330, Aug 2011.

[2] S. M. Coyle, T. E. Ward, and C. M. Markham. Brain-computer interface using a simplified functional near-infrared spectroscopy system. *Journal of Neural Engineering*, 4(3):219–226, 2007.

[3] B. Graimann, B. Allison, and G. Pfurtscheller, editors. *Brain-Computer Interfaces - revolutionizing Human-Computer Interaction.* The Frontiers Collection. Springer Verlag, Berlin, 2010.

[4] C. Urdiales. *Collaborative Assistive Robot for Mobility Enhancement (CARMEN): The bare necessities: assisted wheelchair navigation and beyond.* Intelligent Systems Reference Library. Springer, 2012.

[1] http://youtu.be/q2qa0YiGsF8