Meaningful Human-Computer Interaction Using fNIRS Brain Sensing

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Abstract

Functional near-infrared spectroscopy is an emerging non-invasive brain sensing technique that can provide valuable cognitive state information to a user interface. In this paper, we describe fNIRS technology, consider important attributes of fNIRS data, and propose some suggestions for using fNIRS for meaningful interaction.

Keywords

fNIRS, near-infrared spectroscopy, multitasking, brain computer interface, human-robot interaction

ACM Classification Keywords

H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

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General Terms

Human Factors

Introduction

Functional near-infrared spectroscopy (fNIRS) is an emerging technique for sensing brain activity. Like most brain imaging techniques, fNIRS was designed primarily for laboratory and clinical settings. However, it avoids many of the restrictions of other techniques (figure 2), and therefore has promise for human-computer interaction research [17]. Despite being less restrictive than most other brain-sensing technologies, the signals generated from fNIRS sensors (and most brain and body sensors) still have characteristics that make them challenging to use as input to an interactive system. With these characteristics, can we still build meaningful user interfaces? How should they be designed? What domains could use this type of input? By considering the unique properties of fNIRS brain input, these questions can be addressed and new paradigms for meaningful interaction can be developed. Thus, it is important to understand the physiology behind the sensor as well as the limitations. In this paper, we describe fNIRS technology, consider important attributes of fNIRS data, and propose some suggestions for using fNIRS for meaningful interaction.

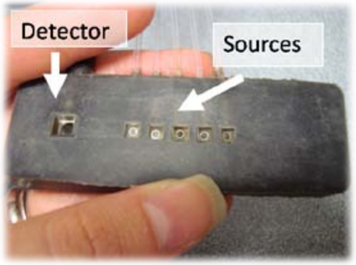

figure 1. fNIRS probe with five near-infrared light sources and one detector.

figure 2. fNIRS probes are placed on forehead (and secured with headband). The setup does not restrict the user's computer usage.

fNIRS Technology

The fNIRS system is made up of probes (figure 1) that send light at two wavelengths in the near-infrared range. Biological tissues are relatively transparent to light at these wavelengths. The main absorbers of the light are oxygenated hemoglobin and deoxygenated hemoglobin. These act as relevant markers of hemodynamic and metabolic changes associated with neural activity in the brain. The reflected light is then picked up by the detectors on the device. Depending on the amount of light that is reflected, we can get a measure of brain activity in the area beneath the sensors.

Designing Interactive Systems with fNIRS

Using fNIRS sensor data as input could augment interactive systems with useful cognitive state information. However, because fNIRS sensor data is different from most existing input modalities, the system must be designed carefully to take advantage of the information. The properties of fNIRS data must be considered as well as the cognitive states that can be measured successfully with fNIRS.

fNIRS Characteristics

An important characteristic of fNIRS data is that the hemodynamic response being measured is a ***slow response*** which occurs over 5-8 seconds. This is in contrast with electroencephalography (EEG) which measures brain activity in a few milliseconds. It should be noted that some studies have reported measurement of a fast fNIRS signal [19], which would provide near instantaneous measurements, but it has not been extensively explored and most studies look at the slow response. Due to this latency, it does not make sense to design interfaces that require immediate action from brain activity or to use fNIRS sensor data as direct, explicit input to the system as can be done with EEG. Instead, recognition of a particular cognitive state can be used as implicit, passive input and intelligent changes to the interface can be made.

When designing for ***implicit, passive*** input (unlike explicit input devices such as a mouse or keyboard), care must be taken to avoid surprising or confusing the user by making unexpected changes to the interface. In addition, fNIRS data is often ***noisy***, and is ***constantly changing***. Plus, machine learning classification algorithms are unlikely to be perfect, leading to ***imperfect cognitive state classification***. Although challenging, it is still possible to use fNIRS data in a meaningful way. The adaptive interfaces should make subtle, helpful changes to the interface that would not be too disruptive if the user's state is misinterpreted. For example, the cognitive state information may be used to change future interactions, or to pre-choose defaults. Other potential types of interfaces would be those with multiple views or with limited screen real estate. The brain data could be used to make tradeoffs based on the user's cognitive state. In addition, the brain signal offers a ***continuous*** measure of cognitive states. This is different from discrete input such as a menu selection or mouse clicks.

Cognitive States Measured with fNIRS

While it would be nice to sense any and all cognitive states that might prove useful for an interface, this is not feasible in practice. To design interfaces using fNIRS data as input, it is critical to identify cognitive states that can actually be detected with fNIRS.

Because fNIRS brain sensing is relatively new, there is not a great deal of prior work demonstrating easily detected signals. We have had good results measuring cognitive workload [3, 5-7], and have been able to distinguish between cognitive resources (spatial and verbal working memory) [7]. Recently, we have investigated specific cognitive multitasking states and have successfully distinguished them with fNIRS [18]. These states had been previously distinguished in fMRI studies [12, 13], but fMRI is impractical for HCI research. Because the fMRI studies showed activation in the anterior prefrontal cortex, we hypothesized that our fNIRS probes (which are designed for the forehead) would be able to detect these changes as well. Our experiments showed that the fNIRS signal had significantly different profiles in the four cognitive multitasking scenarios described in [12] and [13]. These states have direct relevance to many HCI scenarios involving multitasking, interruptions and information overload. Researchers have also explored the fNIRS response during mental arithmetic tasks [8], changes in workload [9-11] and affect [14], and motor tasks [1, 16].

Further research is necessary to identify additional cognitive states that can be detected with this novel device. To do so, it makes sense to start with the probe placement and look to prior fMRI studies to understand what types of tasks may activate the region being probed as in [18]. The fNIRS sensors cannot probe deeper than a few centimeters into the brain cortex. Thus, activity deep in the brain will not be easily detected. In addition, the placement of the probes will impact the signals detected. There are many possible placements of fNIRS probes (which depend on the design of the probe), but the most common placements are on the pre-frontal cortex (PFC)[2, 7, 15, 17, 18], and the motor cortex [16], although other regions have also been explored [4]. Because hair absorbs light, areas without hair work best, and this is why the PFC (behind the forehead) has been explored most.

Toward Meaningful Interaction with fNIRS

To demonstrate that fNIRS could be used as meaningful input to an interactive system, we built a system that takes streaming fNIRS data, classifies it (based on the cognitive multitasking scenarios described in [18]), and sends it to an adaptive robot system. This system changes the robot behavior based on the cognitive multitasking state of the human operator. With the platform in place, we can conduct more in-depth studies to understand the benefits and drawbacks of various adaptation schemes. For example, we can alter the robot's level of automation, or change the tone of the robot's voice to indicate urgency. The suitable adaptive behavior will depend on the situation and our studies will uncover insights into designing meaningful interaction using fNIRS sensor data as input.

Conclusion

Because fNIRS is non-invasive, portable, and easy-to-use, it can continuously provide valuable information about the user's cognitive state. This implicit input can improve interactive systems by better supporting the user during complex tasks, particularly those involving multitasking, information overload and interruptions. However, to provide meaningful interaction with the system, the information must be used appropriately. We are currently exploring meaningful and appropriate use of fNIRS in interactive user interfaces.

Our experimental scenarios examine human-robot team tasks that inherently involve multitasking as the human must carry out tasks as well as monitor the robot behavior. However, we see a broader scope for this research to support any situation involving multitasking, information overload and interruptions. In addition, these paradigms may be useful for designing meaningful interaction in other situations with implicit, noisy input, in addition to fNIRS brain-adaptive interfaces.

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