The Sensorium

Research teams from around the world reflect on their brain sensing setups.

By Evan M. Peck and Erin T. Solovey

DOI: 10.1145/2000775.2000783

Brain sensing hardware is as varied as it is important to the research. Here we ask representatives of five research groups about their current hardware and brain sensing setups of the future.

- **Mick Grierson**, Embodied Audiovisual Interaction (EAVI) Group, Goldsmith College.
- **Kiel Gilleade** and **Stephen Fairclough**, School of Natural Science and Psychology, Liverpool John Moores University (LJMU).
- **Sebastián Mealla** and **Sergi Jordà**, Music Technology Group, Universitat Pompeu Fabra; **Aleksander Väljamäe**, Laboratory of Brain-Computer Interfaces, Graz University of Technology.
- **Lennart Nacke**, Interaction Lab, University of Saskatchewan.
- **Erin Solovey**, Human-Computer Interaction Lab, Tufts University.
- **Chi Thanh Vi,** Interaction and Graphics, University of Bristol.

WHAT DEVICE ARE YOU USING?

Mick Grierson: The Embodied Audiovisual Interaction group has been doing a range of research across new interaction technologies, including professional/medical, commercial and DIY, in many cases attempting to get comparisons between professional and commercial hardware. The EAVI lab has a g.Tec mobilab+, a nine-channel research-grade electroencephalograph (EEG) that allows for real-time acquisition of EEG data over Bluetooth connections. This device has been used for a range of brain-computer interface (BCI) research, most specifically in the development of BCIs for music using event-related potentials (ERPs). In the last two years, the EAVI lab has been experimenting further to apply P300 ERP detection on the Neurosky Mindset, a low-cost commercial EEG device.

Kiel Gilleade and Stephen Fairclough: Currently we use Starlab's Enobio, which offers a four-channel setup for EEG, heart rate, and

electrooculography (EOG) sensing through dry active electrodes. We are also interested in systems using higher number of dry electrodes, also in non-frontal areas, and looking forward to new technological development in the BCI field.

Sebastián Mealla (left), **Sergi Jordà and Aleksander Väljamäe**: Currently we use Starlab's Enobio for sensing EEG and heart-rate signals. We are also interested in systems using higher number of dry electrodes, also in non-frontal areas.

Chi Thanh Vi: The commercial device that we are using is an Emotiv neuroheadset. This device has 16 electrodes (14 channels and two reference electrodes). Its effective bandwidth is from 0.16Hz to 43Hz; its internal hardware sampling frequency is 1028Hz and the SDK's output frequency is 128Hz.The device can measure emotions (engagement/boredom, frustration, meditation, long/short term excitement) as well as facial movement.

Erin Solovey: In the Tufts Human-Computer Interaction Lab, we are using a functional near-infrared spectroscopy (fNIRS) device manufactured by ISS, Inc. called OxiplexTS. fNIRS is an emerging technique for brain sensing that gives us a measure of oxygenated and deoxygenated hemoglobin concentration in tissues. When applied to the forehead, this gives us a measure of brain activity in that area.

Lennart Nacke: In our lab, we are currently using the Emotiv EPOC neuroheadset. At about $1000 (including the research SDK), it is a rather cheap EEG recording device that uses 14 fixed sensor electrodes at 10-20 locations. The research SDK is needed to access the raw EEG data for each electrode and do post-processing on it. In addition to the sensor data for each electrode, the system computes affective/cognitive states such as engagement, boredom, meditation, frustration, or long- and short-term excitement. Another budget-type device we used in our lab that features a similar computation of affective states is the Neurosky Mindset, which is even cheaper at only about $200 and has free developer tools. This is an EEG headset that looks like a pair of headphones and has only three electrodes on one ear and another electrode on the forehead. Recently, we have also bought another Neurosky product, called Mindband, which features only a single electrode (and a reference for the earlobe). The latter product scores very high in ease of use (it is as easy to put on as a sports headband), but we have yet to determine whether we can actually get usable data from it.

WHAT HAVE YOU USED THE DEVICE FOR?

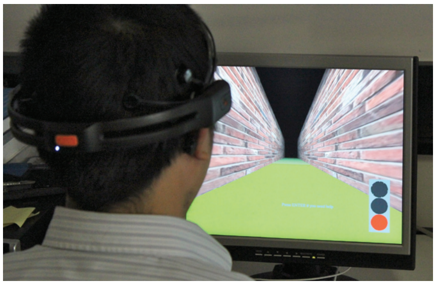
Grierson: We've taken the Event-Related Potential algorithms that we prototyped on the g.Tec mobilab and successfully deployed them on the Mindset. Following discussions with Neurosky, it was clear that they were not aware that this could be done on their hardware. It is a very positive sign for increasing the accuracy and usability of BCI technology. We've been in discussions with Neurosky about the development of our algorithms that we hope will bear fruit.

Although similar work has been done with the Emotive Epoch—and the Epoch may be slightly better in terms of its signal acquisition technology—the Neurosky Mindset has a significantly higher market penetration, is cheaper, easier to use, and is in some ways considered more durable that the Epoch. This makes it an ideal target for bringing BCI technology to the masses.

Gilleade and Fairclough: We're currently working on replicating a previous study we conducted last year with Biosemi's ActiveTwo. In this study, a 32-channel EEG setup was used to assess which positions in the 10-20 system were the most responsive to workload and motivation during a spatial rotation task. We're using the Enobio to expand this study to include more subjects using the recommended placements.

Mealla, Jordà and Väljamäe: We used Enobio in the first studies of Teclepathy, a project that explores the application of physiological computing in collaborative music performances. The project aims at studying how interactive sonification of brain and body signals, and their representation through physical objects (physiopucks) may enhance motivational and controlling aspects of music collaboration in a tabletop interface (the Reactable). Therefore, the computed magnitude spectrum of EEG frames is used to shape the spectrum of a white noise signal, offering an EEG-driven sound synthesis. On the other hand, the heart rate is used to control tempo or beats per minute (BPM) on the Reactable. In our new experiments, we want to explore the scenario where two people wearing Enobio will be performing collaborative music tasks.

Vi: We have used this device to extract the Error Related Negativity (ERN) pattern that is usually detected using expensive devices such as g.tec or Biosemi. This pattern usually appears when a user is aware of an obvious mistake or confused about their last decision in a multiple choice reaction time task. Additionally, we have found that it is possible to separate the EEG signals that contain ERN and the signals that do not on a single trial basis.



Solovey: We have taken steps toward building an adaptive user interfaces using fNIRS. To classify cognitive states from fNIRS data alone, we developed noise reduction and machine learning classification algorithms. These have been developed to work in real time, as data is collected, in order to adapt the system in real time. In addition, we have conducted studies to determine the feasibility of recognizing various cognitive states with the fNIRS device. From these studies, we have shown the viability of distinguishing various cognitive workload levels, game difficulty levels, specific cognitive resources (i.e. verbal working memory), and cognitive multitasking states.

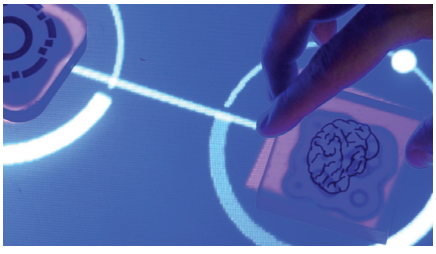
Nacke: We have used both devices and their demo applications to collect interaction data with children participating in a science camp during the summer. We have also investigated how to augment game control using both devices for additional BCI control. Recently we have been working on integrating the BCI sensors together with other physiological data for evaluating video games.

WHAT ARE YOU HOPING TO DO WITH THE SENSORS?

Grierson: We aim to collaborate with game companies that have an interest in BCI to develop a range of audiovisual interaction approaches and apply them to commercial games and interaction products. As one part of this, we aim to market a product using the Mindset. The project has firm agreements with a UK game company that has an ongoing relationship with Neurosky and a track record for producing BCI games.

Gilleade and Fairclough: We intend to use Enobio as part of a multi-modal wireless sensor platform, which will monitor the level of interest in museum visitors as they explore the exhibits. This platform is part of ARtSense, an EU project that is working on creating an adaptive augmented reality museum experience using physiological input.

Mealla, Jordà and Väljamäe: With Enobio we want to explore the affordances of non-invasive physiology sensing devices to assist collaborative music creation, particularly in multimodal interfaces. Given the nature of music performance, ergonomics, portability and detection of artifacts due to muscular movement are critical aspects when integrating physiology sensors into multimodal music systems. We believe that devices tackling these issues will allow musicians to display implicit, physiology-based cues (as relaxation and emotional states) through multisensory strategies (sonification, visualization and tangible feedback). Such paradigm may have a strong effect on the dynamics of collaboration during music performances.



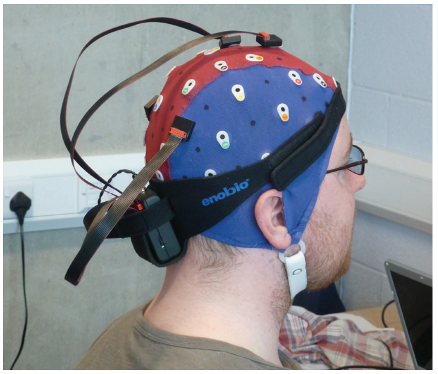
Vi: We aim to apply the results from the neuroscience community to benefit the HCI community by using low-cost EEG devices. For example, we expect that by detecting ERN patterns, a system can give users opportunities to correct incorrect before committing. Another example is the Neurophone, which used P300 waves to dial a phone number by "thoughts."

Solovey: We hope to build adaptive user interfaces that better support the user by recognizing aspects of the user's cognitive state in real time. This could be useful in high-workload scenarios or when a user is multitasking. We have begun investigating the potential in situations such as human-robot team tasks, video games, usability studies, and visual analytic tasks.

Nacke: We are currently preparing a number of studies that are investigating the impact of game violence on children. We are planning to supplement psychological questionnaires and interviews with the data we can gather from the budget-type EEG devices. While we are using both the affective and cognitive states provided by the software and the EEG signals post-processed with our own filtering and transformations, we hope to be able to find meaningful correlations between the EEG signals, cognitive states, and other data that we are recording.

TELL US ABOUT YOUR EXPERIENCE WITH THE SENSOR SETUP

Grierson: Although the Neurosky is by no means a perfect EEG device, we've been surprised at its quality with respect to the acquisition of raw EEG data for processing and, through some novel approaches, have been able to get very meaningful information from the device. Most importantly, the type of information we can get reflects cognition in a way dissimilar to all other commercial EEG BCIs, and even many BCI research projects. Further to this, we feel that our approach opens doors to those interested in studying cognitive activity cheaply across a wide range of subjects. Event-related potentials (ERPs) are exciting to us—more so than Steady State Visually Evoked Potentials (SSVEP) and spontaneous potentials—because ERPS reflect cognition.



Gilleade and Fairclough: We originally purchased Enobio to perform quicker and/or less formal studies (e.g. out of the lab) after reducing the channel setup using a high-grade acquisition device. Enobio is ideally suited for this because (a) the wireless sensor provides full access to the raw data, (b) the electrodes can be freely placed anywhere across the scalp, and (c) four-channel devices are less imposing than our traditional equipment.

The original system came with flat electrodes, which would have difficulty picking up signals through hair and were generally placed on the forehead. This is less than ideal because you maximize your chances of picking up muscle activity and eye movements. We purchased a second generation electrode design in order to penetrate hair. However, the electrodes require gel and a traditional EEG electrode cap if the researcher wants to be confident about placement.

At LJMU we work with a range of wireless physiological sensors, the most useful being those that provide the raw data. The more processed the data is, the more likely the researcher will have to validate the measure before they can use it in a study. The most common issue we've had to deal with is how to handle radio transmission failures during real-time monitoring. The nature of these types of artifacts varies between manufacturers, which makes it difficult to know how to compensate.

Mealla, Jordà and Väljamäe: According to our experience, Enobio is a good candidate for out of the lab studies. It offers a fast non-invasive setup (short preparation, application and stabilization times), which is appreciated when working with professional musicians.

Also, three different biopotentials (EEG, ECG and EOG) can be wirelessly acquired using a single device, with direct access to the raw data over TCP/IP. On the other hand, it is restricted to frontal areas of the scalp, thus limiting the usage of known BCI paradigms for our application, e.g. brain rhythms synchronization across different brain areas. Also, muscular artifacts are commonly noticed in long-term monitoring, especially in the case of heart rate sensing, as the electrode placement is limited to the wrist.

Vi: Emotiv provides more flexibility for researchers because of its number of electrodes. This allows researchers access to different parts of human brain; [researchers] have more data to run analysis (e.g. Independent Component Analysis). On the other hand, Emotiv requires more setup time as it requires a saline solution to be put onto the electrodes before use.

Solovey: fNIRS can open new doors for HCI research since it is safe, non-invasive, and portable, yet still provides cognitive state information. If used with care, this additional information can lead to interfaces that adapt appropriately to changes in the user's cognitive state. Since this input has unique characteristics that set it apart from most standard input techniques, we have been exploring the effective use of the device in human-computer interaction.

Nacke: Both of these devices, from Emotiv and Neurosky, work really well out of the box and are definitely a great step forward for BCI. However, some minor problems persist. One of the obvious questions is the computation or the algorithms behind the affective or cognitive states that both headsets present. How is attention, meditation, or engagement calculated? And are the terms used an oversimplification of what is really going on computationally? We were not yet able to find this out. Another potential problem lies in the use of Bluetooth as a communication protocol. Depending on how well the driver works and which other Bluetooth devices are used simultaneously, this could be problematic in some computer setups. However, recently we found it to work rather well with a Windows 7 setup. We have also had some great experience reports of researchers using budget BCI headsets with good accuracy at our CHI 2011 workshop on "Brain and Body Interfaces." I do think there is very interesting potential for these budget BCI headsets in HCI research.

CONCLUSION

It wasn't long ago that observing the brain required the education and equipment of a neuroscience department, which constrained research almost exclusively to top research universities and laboratories. However, modern commercial brain sensors focus on accessibility for the researcher and the user. The advancement of brain-sensing equipment and signal analysis has enabled us to study the brain in natural settings—playing a game, using the office computer, or composing music. It's a new and emerging field, filled with validation studies and experiments that are foundational but also may occasionally seem divorced from real-world experiences.

This research is asking questions and seeking answers that are crucial to the future of BCI. What do easy-to-setup sensors sacrifice over traditional EEG systems? Can we measure interesting brain states while users interact with complex systems and environments? How can we create a computer that is attentive, and responds to the user's cognitive state?

We are building a future where brain sensing isn't simply in the laboratory, but also in the living room. Someday, we may be able to capture the "aha!" moment during a fit of creativity, or construct applications that understand when we are overloaded with information, or interact with music and visual environments in innovative and exciting ways. With commercial brain sensing technology continuing to push the barrier of convenience and accessibility, someday, there might just be an SDK for the brain.

ACRONYMS

BCI Brain-Computer Interface: A class of technologies that allow direct interaction between a human brain and an external interface, unmediated by the subject's consciousness.

EEG Electroencephalography: A form of BCI that works non-invasively by measuring electrical activity along the human scalp.

EM Electron Microscope: A technology that uses a beam of electrons to illuminate and magnify a subject with far greater resolution than normal optical microscopes.

fMRI Functional Magnetic Resonance Imaging: A non-invasive form of BCI that measures the change in blood flow in regions of a subject's brain and/or spinal cord.

HCI Human-Computer Interaction: The study of how human beings interact with computers, for example for the purposes of research into the efficacy of subliminal computing.

UCD User-Centered Design: A modern interface design principle that emphasizes the primary role of the user in driving design decisions such as visibility and legibility of the product.