Document Scribe: Intro to BCIs

Tracy Pham

What are Brain-Computer Interfaces (BCI)?

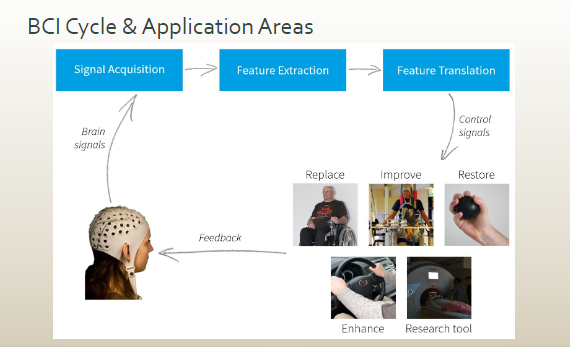
BCIs (also known as many other names such as neural interfaces or Brain-Machine Interfaces) create a link of direct communication between the human brain and an external device. As Jonathan Wolpaw defines, BCIs do this by measuring central nervous system (CNS) activity and converting it to artificial output to replace, restore, enhance, supplement, or improve the natural CNS output. One thing to note is that BCI is NOT computational neuroscience, which studies the information processing from the brain.

BCI Origins

In 1964, Grey Walter demonstrated EEG-based BCI by using delta waves to locate brain tumors. In 1969, Delgado and Fetz developed an invasive chip to stimulate the brain. In the 1970s, Jacques Vidal officially introduced the term BCI. The main motivation for developing BCIs today is to restore function is lost senses, such as prosthetic devices.

BCI Cycle & Application Areas

A general model can represent the general process of how data is collected and where it can be customized.



The user wears a headset and depending on the associated software, the raw signals are collected. Then features, or more categorizable aspects of the signals, are derived from the raw signals. These are then translated using some sort of classifying algorithm or technique of choice, depending on the application. This data becomes more meaningful and can either supply feedback to the user, help them control something actively, and so on.

BCI Cycle Description

Each general step of the cycle is essential to the system and can be broken down a little further.

- Brain Activity Recording: raw signals from a user’s brain are acquired, electroencephalography (EEG) is the most common method.

- Preprocessing: extract the data by cleaning and removing noise and artifacts from the signal

- Feature Extract: abstract more details from the signals in reference to a small group of relevant variables known as “features”

- Classification: the set of features in a specific frame of time is used as input to algorithms (called classifiers) to detect patterns and further categorize what the signals mean.

- Translation into a command: Use identified signal and associate it to a command within system

- Feedback: Provide the user with information about their brain activity

BCI Classifications

Active BCI refers translates into performing commands. Reactive BCI refers to a command derived from the user’s brain activity when given a stimulus (audio or visual). Passive BCI refers to the user’s mental state and is not voluntary. Synchronous refers to when a user only has specific times, they can interact with the BCI and asynchronous is allowed at any time. Dependent describes a system which depends on motor controls and independent is when it does not depend on it. Invasive acquires data from withing the skin, non-invasive collects data from the outside of the skin, and hybrids are a mixture of both.

Future Work

BCIs will produce an array of intuitive technology. From gaming to healthy, it is predicted that consumers will want to monitor their affective states and other mental tasks and performance measures.

Three pillars lay a foundation to the expected future of BCI:

- Excellent Science: there will be much research needed to provide evidence of feasibility and practicality, along with processing methods and further development for robustness.

- Industrial Leadership: Leaders are needed to ensure the acceptance of BCIs and further the product designs, easy and secure development, and marketability (such as plug and play style).

- Societal Challenges: Usability studies will further the evidence for use in daily live, increase in quality of life, and physiological enhancements – which all also contribute the its acceptance. An import note is also the deconstruction of “Hollywood BCI”.

Ethics

Published equipment will face many concerns involving the liability of the equipment, performance of the device, inappropriate uses of the data, health risks, and so on.

Recommendations

It is recommended that all the studies and push to integrate BCIs into society will need an interdisciplinary team with at least a programmer, a designer, and a BCI expert. Additionally, BCIs have potential to decode high-level cognitive functions such as decision making and experiments can be adjusted as needed to test hypothesis.

Types of Neuro Brain Technologies

As discussed, EEG is the most popular method because it is cheaper and efficient with high temporal resolution. But others exist which can be categorized as non-invasive (EEG, fMRI, fNIRS, MEG), semi-invasive (ECoG), and invasive (MEA, Neural Lace). Each have their own levels of spatial and temporal resolution, as well as advantages and disadvantages.

Other Brain Technologies

The flow of electrical signal can also work by sending into the hemispheres of the brain. For example, Transcranial Direct-Current Simulation (tDCS) delivers low current through electrodes on the scalp to any desired area of the brain, which has shown effectiveness for depression. Transcranial Magnetic Simulation (TMS) also stimulates the brain, but by placing a device near the head.

Other Physiological Measurements

Other methods can acquire different data form the body and can be found in hybrid BCI systems include Electrocardiography (EKG/ECG, measurement of heart rate), Electrooculography (EOG, measurement of eye movement), Electromyography (EMG, measurement of muscle movement), Electrogastrogram (EGG, measurement of stomach muscles, not to be confused with EEG), and Electrodermal Activity (EDA), Skin Conductance, and Galvanic Skin Response (GSR) which all three measure continued variation in the skin.

Hollywood BCI

A term created by the Dr. Marvin Andujar himself, and refers to the mass media effect on user perception of BCIs and devices alike. For instance, the ability to control things with your mind is seem as science fiction and in extreme cases, evil and catastrophic.

BCI Sub-Areas

The applications of BCI can be extended into more categories. Affective BCIs measure the affective state to provide feedback to the user, for example. Artistic BCI sounds as it is, it includes the use of BCIs with physical art, music, and so on. Brain-Robot Interaction include the integration of the human brain into the realm of robotics, which is where negative stigma can derive from Hollywood BCI. Hybrid BCIs use the other physiological sensors mentioned, along with brain data to unlock another array of mechanisms and applications. Brain-Computer Music Interfaces are also what they sound like: a combination of using music as a stimuli (or other uses depending on research questions) in a BCI system.

Neural Control Interfaces

Although arguable intuitive, the EEG-headset is not the primary component of a BCI, it is the control interface that actually allows the user to interact with the brain data. It relays the performance of a mental command, status and feedback, representations of the user’s brain data, and much more. It is also crucial to determining the usability of a BCI, which in a tradition study design usually looks like: a control display for the state of a controlled device, a control display for the user’s neural signals, and a display of the BCI’s control tasks.

A popular, but rather ineffective method is binary control display which moves a “cursor” on the screen to spell out words. This is achieved by a user controlling a red square on a screen.

Control Tasks

Control tasks are defined as a user actively using mental commands to change brain signals as desired. This can be done by asking a user to imagine physical movement, visualizing an object, controlling level of attention, singing, and more, WITHOUT physically moving. These tasks can be categorized as either exogenous (or evoked) which results from a user’s automatic response when focusing on a set of stimuli or endogenous (self-generated) which happens when a user invokes changes to their brain signals on purpose.

Exogenous

Exogenous, is also referred to as evoked-related potentials (ERPs) considering the external stimulus required to cause changes in the brain signals. P300 is a component of ERPs whose signals occur in the parietal region 300ms after a visual or auditory stimulus is provided. The activation of a P300 response largely depends on attention. For instance, in a P300 speller, to calibrate the system the user’s P300 response to all letters are collected. Then, to spell something letter will flash on the screen and the user will need to focus on one. The letter evoking the highest P300 response is the indicated target.

Similarly, Steady-state evoked potentials (SSVEPs) measure the visual cortex (occipital lobe) for its response to a stimulus flashing at a constant rate. For instance, if a user is looking at a word flashing at 10 Hz, the signals received from the visual cortex will also be at the speed of 10 Hz.

Endogenous

The user actively changes brain signals by performing a mental task, activating a particular part of the brain, without any stimulus. With practice, users can learn to improve and control brain signal responses. The output received from endogenous tasks consists of task-related neural activity and performance information. Additionally, Mu-Rhythm measures the amplitude of mu-band signals to control parts of a system and can be generated by actual or imagined movement.

Parts of the Brain and their Functions

Without getting into too much detail of the brain, the main regions and their functions are:

* Frontal Lobe: cognitive functions, concentration, speech, personality, and emotions
* Occipital Lobe: primarily vision
* Temporal Lobe: memory, hearing, language processing
* Parietal Lobe: Interpret language, sense of touch and pain, spatial and visual perception

How are these topics related to the real world?

BCIs provide another option. The computational power and new advantages that come with being able to utilize brain data are endless and continue to grow. Many of the slides categorized aspects of BCIs and explained the main ways brain data can be collected and processed, which parts of the brain are studied, and how we can receive AND transmit signals from the brain. Most explicitly, all the examples provided throughout the slides show all the concepts used in actual applications. The user studies provide evidence for performance enhancement, advanced technology, physical restoration, and more. There is especially a focus on restoring senses that are either lost naturally or during the course of someone’s lifetime.

Which topic is not clear to you and why?

The BCI cycle is a bit confusing because I’m not sure which parts are absolutely necessary and what more can be added and how they can be customized depending on what application (I’m not sure if you intend to go that in depth though).

Which topic area do you think we should expand on later in the semester? Why?

I would like to cover more on the real-world examples of any topics. For example, the Neuralink assignment was interesting and I’d love to hear more about what is considered cutting edge in the world today and what fields/applications exists out there.