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Brain Computer Interface

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ABSTRACT A brain-computer interface (BCI), sometimes called a direct neural interface or a brain-machine interface (BMI), is a direct communication pathway between the brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions. Research on BCIs began in the 1970s at the University of California Los Angeles (UCLA) under a grant from the National Science Foundation, followed by a contract from DARPA. The papers published after this research also mark the first appearance of the expression *brain-computer interface* in scientific literature.

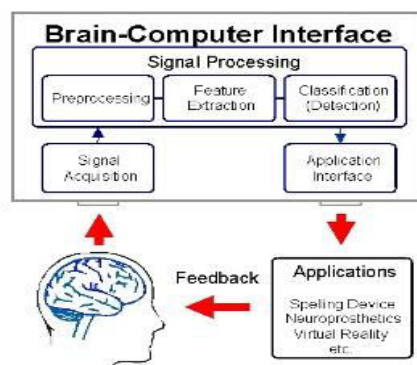
I. INTRODUCTION

The field of BCI research and development has since focused primarily on neuroprosthetics applications that aim at restoring damaged hearing, sight and movement. Thanks to the remarkable cortical plasticity of the brain, signals from implanted prostheses can, after adaptation, be handled by the brain like natural sensor or effectors channels. Following years of animal experimentation, the first neuroprosthetic devices implanted in humans appeared in the mid-nineties.

BCI versus neuroprosthetics

Neuroprosthetics is an area of neuroscience concerned with neural prostheses—using artificial devices to replace the function of impaired nervous systems and brain related problems or sensory organs. The most widely used neuroprosthetic device is the cochlear implant, which, as of 2006, has been implanted in approximately 100,000 people worldwide. There are also several neuroprosthetic devices that aim to restore vision, including retinal implants.

The differences between BCIs and neuroprosthetics are mostly in the ways the terms are used: neuroprosthetics typically connect the nervous system to a device, whereas BCIs usually connect the brain (or nervous system) with a computer system.

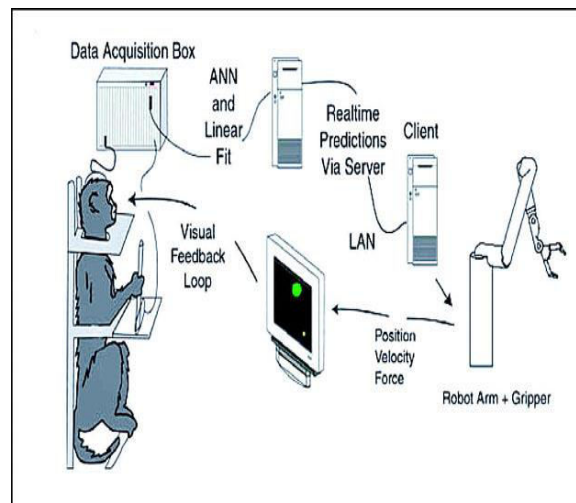


Practical neuroprosthetics can be linked to any part of the nervous system—for example, peripheral nerves—while the term "BCI" usually designates a narrower class of systems which interface with the central nervous system.

The terms are sometimes used interchangeably. Neuroprosthetics and BCIs seek to achieve the same aims, such as restoring sight, hearing, movement, ability to communicate, and even cognitive function. Both use similar experimental methods and surgical techniques.

Animal BCI research

Several laboratories have managed to record signals from monkey and rat cerebral cortices in order to operate BCIs to carry out movement. Monkeys have navigated computer cursors on screen and commanded robotic arms to perform simple tasks simply by thinking about the task and without any motor output. In May 2008 photographs that showed a monkey operating a robotic arm with its mind at the Pittsburgh University Medical Center were published in a number of well known science journals and magazines. Other research on cats has decoded visual signals.



Early work:

Monkey operating a robotic arm with brain-computer interfacing the operant conditioning studies of Fetz and colleagues first showed that monkeys could learn to control the deflection of a biofeedback meter arm with neural activity. Such work in the 1970s established that monkeys could quickly learn to voluntarily control the firing rates of individual and multiple neurons in the primary motor cortex if they were rewarded for generating appropriate patterns of neural activity.

Studies that developed algorithms to reconstruct movements from motor cortex neurons, which control movement, date back to the 1970s. In the 1980s, Apostolos Georgopoulos at Johns Hopkins University found a mathematical relationship between the electrical responses of single motor-cortex neurons in rhesus macaque monkeys and the direction that monkeys moved their arms (based on a cosine function). He also found that dispersed groups of neurons in different areas of the brain collectively controlled motor commands but was only able to record the firings of neurons in one area at a time because of technical limitations imposed by his equipment.

There has been rapid development in BCIs since the mid-1990s. Several groups have been able to capture complex brain motor centre signals using recordings from neural ensembles (groups of neurons) and use these to control external devices, including research groups led by Richard Andersen, John Donoghue, Phillip Kennedy, Miguel Nicolelis, and Andrew Schwartz.

Prominent research successes:

Phillip Kennedy and colleagues built the first intracortical brain–computer interface by implanting neurotrophic-cone electrodes into monkeys.

Yang Dan and colleagues' recordings of cat vision using a BCI implanted in the lateral geniculate nucleus (top row: original image; bottom row: recording)

After conducting initial studies in rats during the 1990s, Nicolelis and his colleagues developed BCIs that decoded brain activity in owl monkeys and used the devices to reproduce monkey movements in robotic arms. Monkeys have advanced reaching and grasping abilities and good hand manipulation skills, making them ideal test subjects for this kind of work.

By 2000, the group succeeded in building a BCI that reproduced owl monkey movements while the monkey operated a joystick or reached for food. The BCI operated in real time and could also control a separate robot remotely over Internet protocol. But the monkeys could not see the arm moving and did not receive any feedback, a so-called open-loop BCI.

Later experiments by Nicolelis using rhesus monkeys succeeded in closing the feedback loop and reproduced monkey reaching and grasping movements in a robot arm. With their deeply cleft and furrowed brains, rhesus monkeys are considered to be better models for human neurophysiology than owl monkeys. The monkeys were trained to reach and grasp objects on a computer screen by manipulating a joystick while corresponding movements by a robot arm were hidden. The monkeys were later shown the robot directly and learned to control it by viewing its movements. The BCI used velocity predictions to control reaching movements and simultaneously predicted hand gripping force.

Andersen's group used recordings of pre-movement activity from the posterior parietal cortex in their BCI, including signals created when experimental animals anticipated receiving a reward

In addition to predicting kinematic and kinetic parameters of limb movements, BCIs that predict electromyographic or electrical activity of muscles are being developed. Such BCIs could be used to restore mobility in paralyzed limbs by electrically stimulating muscles.

A new 'wireless' approach uses light-gated ion channels such as Channelrhodopsin to control the activity of genetically defined subsets of neurons in vivo. In the context of a simple learning task, illumination of transfected cells in the somatosensory cortex influenced the decision making process of freely moving mice

Human BCI research

Invasive BCIs

Invasive BCI research has targeted repairing damaged sight and providing new functionality to persons with paralysis. Invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery. As they rest in the grey matter, invasive devices produce the highest quality signals of BCI devices but are prone to scar-tissue build-up, causing the signal to become weaker or even lost as the body reacts to a foreign object in the brain.

Tetraplegic Matt Nagle became the first person to control an artificial hand using a BCI in 2005 as part of the first nine-month human trial of Cyberkinetics Neurotechnology's BrainGate chip-implant. Implanted in Nagle's right precentral gyrus (area of the motor cortex for arm movement), the 96-electrode BrainGate implant allowed Nagle to control a robotic arm by thinking about moving his hand as well as a computer cursor, lights and TV. One year later, professor Jonathan Wolpaw received the prize of the Altran Foundation for Innovation to develop a Brain Computer Interface with electrodes located on the surface of the skull, instead of directly in the brain.

Partially-invasive BCIs

Partially invasive BCI devices are implanted inside the skull but rest outside the brain rather than within the grey matter. They produce better resolution signals than non-invasive BCIs where the bone tissue of the cranium deflects and deforms signals and have a lower risk of forming scar-tissue in the brain than fully-invasive BCIs.

Electrocorticography (ECoG) measures the electrical activity of the brain taken from beneath the skull in a similar way to non-invasive electroencephalography (see below), but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater. ECoG technologies were first trialed in humans in 2004 by Eric Leuthardt and Daniel Moran from Washington University in St Louis. In a later trial, the researchers enabled a teenage boy to play Space Invaders using his ECoG implant. This research indicates that control is rapid, requires minimal training, and may be an ideal tradeoff with regards to signal fidelity and level of invasiveness.

Light Reactive Imaging BCI devices are still in the realm of theory. These would involve implanting a laser inside the skull. The laser would be trained on a single neuron and the neuron's reflectance measured by a separate sensor. When the neuron fires, the laser light pattern and wavelengths it reflects would change slightly. This would allow researchers to monitor single neurons but require less contact with tissue and reduce the risk of scar-tissue build-up.

This signal can be either subdural or epidural, but is not taken from within the brain parenchyma itself. It has not been studied extensively until recently due to the limited access of subjects. Currently, the only manner to acquire the signal for study is through the use of patients requiring invasive monitoring for localization and resection of an epileptogenic focus.

Non-invasive BCIs

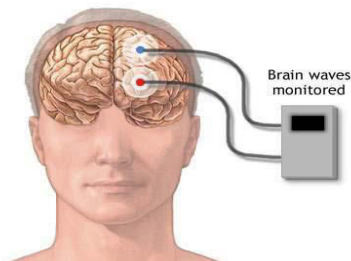
As well as invasive experiments, there have also been experiments in humans using non-invasive neuroimaging technologies as interfaces. Signals recorded in this way have been used to power muscle implants and restore partial movement in an experimental volunteer. Although they are easy to wear, non-invasive implants produce poor signal resolution because the skull dampens signals, dispersing and blurring the electromagnetic waves created by the neurons. Although the waves can still be detected it is more difficult to determine the area of the brain that created them or the actions of individual neurons.

EEG

Recordings of brainwaves produced by an electroencephalogram

Electroencephalography (EEG) is the most studied potential non-invasive interface, mainly due to its fine temporal resolution, ease of use, portability and low set-up cost. But as well as the technology's susceptibility to noise, another substantial barrier to using EEG as a brain-computer interface is the extensive training required before users can work the technology. The experiment saw ten patients trained to move a computer cursor by controlling their brainwaves. The process was slow, requiring more than an hour for patients to write 100 characters with the cursor, while training often took many months.

A further parameter is the method of feedback used and this is shown in studies of P300 signals. Patterns of P300 waves are generated involuntarily (stimulus-feedback) when people see something they recognize and may allow BCIs to decode categories of thoughts without training patients first. By contrast, the biofeedback methods described above require learning to control brainwaves so the resulting brain activity can be detected.



Lawrence Farwell and Emanuel Donchin developed an EEG-based brain-computer interface in the 1980s. Their "mental prosthesis" used the P300 brainwave response to allow subjects, including one paralyzed Locked-In syndrome patient, to communicate words, letters, and simple commands to a computer and thereby to speak through a speech synthesizer driven by the computer. A number of similar devices have been developed since then. In 2000, for example, research by Jessica Bayliss at the University of Rochester showed that volunteers wearing virtual reality helmets could control elements in a virtual world using their P300 EEG readings, including turning lights on and off and bringing a mock-up car to a stop

In the early 90s Babak Taheri, at UC DAVIS demonstrated the first single and also multichannel dry active electrode arrays using micro-machining. The single channel dry EEG electrode construction and results were published in 1994. The advantages of such electrodes are: (1) no electrolyte used, (2) no skin preparation, (3) significantly reduced sensor size, and (4) compatibility with EEG monitoring systems. The active electrode array is an integrated system made of an array of capacitive sensors with local integrated circuitry housed in a package with batteries to power the circuitry. This level of integration was required to achieve the functional performance obtained by the electrode. The electrode was tested on an electrical test bench and on human subjects in four modalities of EEG activity, namely: (1) spontaneous EEG, (2) sensory event-related potentials, (3) brain stem potentials, and (4) cognitive event-related potentials. The performance of the dry electrode compared favorably with that of the standard wet Ag/AgCl electrodes in terms of skin preparation, no gel requirements (dry), and higher signal-to-noise ratio. In 1999, researchers at Case Western Reserve University led by Hunter Peckham, used 64-electrode EEG skullcap to return limited hand movements to quadriplegic Jim Jatich. As Jatich concentrated on simple but opposite concepts like up and down, his beta-rhythm EEG output was analysed using software to identify patterns in the noise. A basic pattern was identified and used to control a switch: Above average activity was set to on, below average off. As well as enabling Jatich to control a computer cursor the signals were also used to drive the nerve controllers embedded in his hands, restoring some movement.

Electronic neural networks have been deployed which shift the learning phase from the user to the computer. Experiments by scientists at the Fraunhofer Society in 2004 using neural networks led to noticeable improvements within 30 minutes of training

MEG and MRI

ATR Labs' reconstruction of human vision using fMRI (top row: original image; bottom row: reconstruction from mean of combined readings)

Magneto encephalography (MEG) and functional magnetic resonance imaging (fMRI) have both been used successfully as non-invasive BCIs. In a widely reported experiment, fMRI allowed two users being scanned to play Pong in real-time by altering their haemodynamic response or brain blood flow through biofeedback techniques.

fMRI measurements of haemodynamic responses in real time have also been used to control robot arms with a seven second delay between thought and movement. More recently, research developed in the Advanced Telecommunications Research (ATR) Computational Neuroscience Laboratories in Kyoto, Japan allowed the scientists to reconstruct images directly from the brain and display them on a computer. The article announcing these achievements was the cover story of the journal *Neuron* of 10 December 2008. While the early results are limited to black and white images of 10x10 squares (pixels), according to the researchers further development of the technology may make it possible to achieve color images, and even view or record dreams.



Commercialization and companies

John Donoghue and fellow researchers founded Cyberkinetics. The company markets its electrode arrays under the BrainGate product name and has set the development of practical BCIs for humans as its major goal. The BrainGate is based on the Utah Array developed by Dick Normann.

Although 16 paying patients were treated using William Dobbelle's vision BCI, new implants ceased within a year of Dobbelle's death in 2004. A company controlled by Dobbelle, Avery Biomedical Devices, and Stony Brook University are continuing development of the implant, which has not yet received Food and Drug Administration approval in the United States for human implantation.

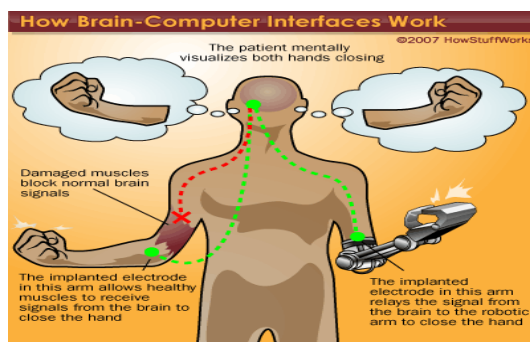
A Spanish company, Starlab, has entered this market in 2009 with a wireless 4-channel system called Enobio. Designed for research purposes the system provides a platform for application development

There are three main consumer-devices commercial-competitors in this area (launch date mentioned in brackets) which have launched such devices primarily for gaming- and PC-users:

World first: Neurochip developed by Caltech researchers Jerome Pine and Michael Maher

Ethical considerations

There has not been a vigorous debate about the ethical implications of BCIs, even though there are several commercially available systems such as brain pacemakers used to treat neurological conditions, and could theoretically be used to modify other behaviors like the neurosky.



II. CONCLUSION

As we can see there are many applications of Brain Computer Interface. It can be very helpful for people with moving disabilities as human-machine interface. But it can also be used for control of human body muscles. To bring this in reality it has to be developed more adaptable BCI system and foremost avoid all risks..

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