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A Technical Analysis of Brain Computer Interface and Its Real World Applications

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Abstract - A brain-computer interface (BCI), sometimes called a direct neural interface or a brain-machine interface, is a direct communication pathway between a human or animal brain and an external device. In one-way BCIs, computers either accept commands from the brain or send signals to it (for example, to restore vision) but not both. Two-way BCIs would allow brains and external devices to exchange information in both directions but have yet to be successfully implanted in animals or humans.

In this definition, the word brain means the brain or nervous system of an organic life form rather than the mind. Computer means any processing or computational device, from simple circuits to silicon chips. Research on BCIs began in the 1970s, but it wasn't until the mid-1990s that the first working experimental implants in humans appeared. Following years of animal experimentation, early working implants in humans now exist, designed to restore damaged hearing, sight and movement. With recent advances in technology and knowledge, pioneering researchers could now conceivably attempt to produce BCIs that augment human functions rather than simply restoring them, previously only a possibility in science fiction.

Index Terms- BCI, EEG, ENR, EOG

1. INTRODUCTION

Man machine interface has been one of the growing fields of research and development in recent years. Most of the effort has been dedicated to the design of user-friendly or ergonomic systems by means of innovative interfaces such as voice recognition, virtual reality. A direct brain-computer interface would add a new dimension to man-machine interaction.

A brain-computer interface, sometimes called a direct neural interface or a brain machine interface, is a direct communication pathway between a human or animal brain (or brain cell culture) and an external device. In one BCI, computers either accept commands from the brain or send signals to it but not both. Two way BCIs will allow brains and external devices to exchange information in both directions but have yet to be successfully implanted in animals or humans.

Brain-Computer interface is a staple of science fiction writing. In its earliest incarnations no mechanism was thought necessary, as the technology seemed so far-fetched that no explanation was likely. As more became known about the brain however, the possibility has become more real and the science fiction more technically sophisticated. Recently, the cyberpunk movement has adopted the idea of 'jacking in', sliding 'bio-soft' chips into slots implanted in the skull (Gibson, W.1984). Although such bio-softs are still science fiction, there have been several recent steps toward interfacing the brain and computers.

In this definition, the word brain means the brain or nervous system of an organic life form rather than the mind. Computer means any processing or computational device, from simple circuits to silicon chips (including hypothetical future technologies like quantum computing).

Research on BCIs has been going on for more than 30 years but from the mid 1990's there has been dramatic increase working experimental implants. The common thread throughout the research is the remarkable cortical-plasticity of the brain, which often adapts to BCIs treating prostheses controlled by implants and natural limbs. With recent advances in technology and knowledge, pioneering researches could now conceivably attempt to produce BCIs that augment human functions rather than simply restoring them, previously only the realm of science fiction.

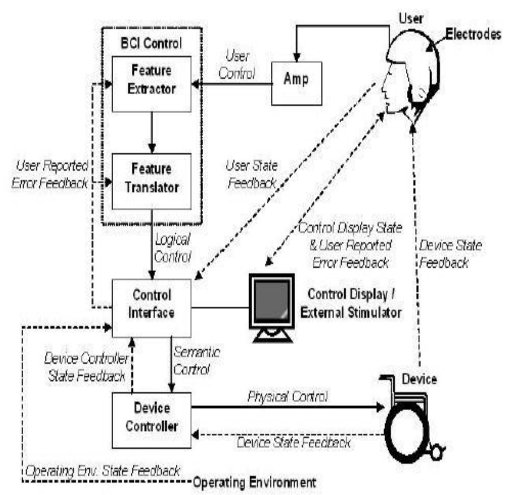


Fig 1: Schematic diagram of a BCI system

2. THE CURRENT BCI TECHNIQUES

In today's time various techniques are used for BCI interface, there implementations and result manipulation. These techniques are headed towards the development of BCI in coming era.

2.1 P300 Detection:

Farwell [Farwell & Donchin 1988] of the Department of Psychology and Cognitive Psychophysiology Laboratory at the University of Illinois at Urbana- Champaign IL, describes a technique for detecting the P300 component of a subject's event-related brain potential (ERP) and using it to select from an array of 36 screen positions. The P300 component is a positive-going ERP in the EEG with a latency of about 300ms following the onset of a rarely-occurring stimulus the subject has been instructed to detect. The EEG was recorded using electrodes placed at the Pz (parietal) site (10/20 International System), limited with band-pass filters to .02-35Hz and digitized at 50Hz. Electro-oculogram (EOG) data was also recorded from each subject via electrodes placed above and below the right eye.

The "odd-ball" paradigm was used to elicit the P300, where a number of stimuli are presented to the experimental subject who is required to pay attention to a particular, rarely-occurring stimulus and respond to it in some non-motor way, such as by counting occurrences. Detecting the P300 responsereliably requires averaging the EEG response over many presentations of the stimuli. The purpose of the current experiment was to discover the minimum number of presentations at two different inter-stimulus intervals (ISI) required for detecting the P300 response. The experiment presented a 36- position array of letters, plus common typing characters and controls (e.g. space, backspace), made to flash in a random sequence first by rows and then columns. Each trial consisted of a complete set of six column or row flashes. Trials contaminated with muscular or EOG response were rejected and additional trials presented until data were collected from a block of 30 good trials, during which subjects were to fixate on a particular position, and count the number of times it flashed while a control message was elsewhere on the screen. After each block the fixated letter (one of B-R-A-I-N) was added to the screen so that subjects were conscious of slowly spelling out the word "BRAIN" through a succession of five blocks. A set of five blocks was run at each ISI -- 125ms and 500ms. The two presentation rates were chosen to bracket a range of communication rates from a low of 30 averaged trials at 500ms ISI (93.6 seconds of presentation per character) to a high of one trial at 125ms (1.245 seconds of presentation per character), an effective communication rate range of .01 to .8 characters-per- second, respectively.

The authors used four techniques to analyze the data for reliable P300 response detection stepwise discriminate analysis (SWDA), peak picking, area, and covariance, and identified SWDA as leading to the greatest accuracy at thefastest presentation rate. Results indicated that a character chosen from among 36 items can be detected with 95% accuracy within 26 seconds.

2.2 EEG mu-rhythm Conditioning:

Three papers using this technique were reviewed including Wolpaw [Wolpaw et al 1991], McFarland [McFarland et al 1993], and colleagues at the Wadsworth Center for Laboratories and Research, Albany, NY, and Pfurtscheller [Pfurtscheller et al 1993] and colleagues at the Ludwig Boltzmann Institute of Medical Informatics and Neuroinformatics, Department of Medical Informatics, Institute of Biomedical Engineering, University of Technology Graz, Austria. All three papers describe subjects' abilities to move a cursor toward a target on a computer screen by manipulating their mu-rhythm, a detectable pattern in a great majority of individuals in the EEG 8-12Hz frequency range, centered about 9.1Hz. Work is based on earlier research efforts by Kuhlman [Kuhlman 1978b] who described the mu-rhythm in normal and epileptic subjects.

Wolpaw describes detecting subjects' mu-rhythm amplitude, defined as the square-root of the spectral EEG power at 9Hz, using two scalp- mounted electrodes located near location C3 in the International 10/20 System and a digital signal processing board analyzing continuous EEG in 333ms segments, and using it to drive a cursor up or down on a screen toward a target placed randomly at the top or bottom. An experiment operator preset the size of the ranges and number of cursor movement steps assigned to each range for each subject during testing prior to each experimental run.

2.3 VEP Detection

This technique was reviewed by Sutter [Sutter 1992] at the Smith-Kettlewell Eye Research Institute in San Francisco CA, and Cilliers [Cilliers & VanDerKouwe1993] and colleague at the Department of Electrical and Electronic Engineering, University of Pretoria, South Africa. Sutter describes presenting a 64-position block on a computer screen and detecting which block the subject looks at, while Cillier's work uses a series of four lights. In each case, several simultaneously presented stimuli are made to change rapidly in some controlled way(intensity ,pattern, color- shift) and the subject has scalp electrodes placed over the visual cortex (back of the head) in a position to detect changes in the evoked potential (VEP) at that location. Sutter used a lengthy binary sequence to switch 64 screen positions between red and green, and in other trials to reverse a checkerboard pattern. Each screen position was shifted 20ms in the binary control sequence relative to its neighbors, and the entire sequence was auto correlated with the VEP in overlapping increments(the VEP response components last about 80ms) beginning 20ms apart, with the resultant vector stored in a 64-position array of registers. When a coefficient remains greater than all the others and above a threshold value for a certain amount of time, the corresponding stimulus is considered to have been selected. The 64 positions represent the letters of the alphabet and commonly used words in the English language. The subject can fixate on any word or letter. Whenever the subject fixates on a letter, the commonly used words change to words beginning with that letter, for quick selection of an entire word. Sutter suggests a need to optimize both electrode placement and stimulation mode for each individual subject for good target discrimination. Seventy.

2.4 EEG Pattern Mapping:

Several experimenters describe techniques for classifying, detecting and mapping EEG patterns. Pfurtscheller's technique used a neural net featuring learning-vector quantization (LVQ) to map EEG patterns during the 1-

second interval before a signal the experimental subject was instructed to wait for. Hiraiwa [Hiraiwa et al 1993] used a back-propagation artificial neural network to study readiness potentials (RP's) -- patterns in the EEG immediately prior to the subject's uttering one of five different Japanese syllables or moving a joystick in one of four different directions. Twelve channels of EEG data taken from scalp-mounted electrodes at locations Fp1, Fp2,Fz, C3, C4, Pz, F5, F6, F7, F8, O1 and O2 (International 10/20 system) were used to train and then test two neural networks optimized for averaged data and for single- trial, real-time analysis, respectively. High recognition rates were obtained for the averaged data. Single trial RP recognition, though less reliable, showed considerable promise in the experimenters' view. Keirn and Aunon [Keirn&Aunon 1990] recorded EEG data from scalp-mounted electrodes at locations P3, P4, C3, C4, O1 and O2 (International 10/20 System) during accomplishment of 5 different tasks during which subjects had their eyes open or closed, for 10 alternative responses. The tasks included:

3. Relaxing and trying to think of nothing,
4. A non-trivial multiplication problem,
5. A 30-second study of a drawing of a 3- dimensional object after which subjects were to visualize the object being rotated about an axis,
6. Mental composition of a letter to a friend,
7. Visualize numbers being written on a blackboard sequentially, with the previous number being erased before the next was written.

Feature vectors were constructed from the EEG patterns based on the Wiener- Khinchine method and classified using a Bayes quadratic classifier.

2.5 Detecting lateral hemisphere differences:

Drake 1993] studied induced lateral differences in relative brain hemisphere activation after subjects heard arguments through left, right or both earphones which they either strongly agreed with or strongly disagreed with, as determined by prior interviews. Subjects exhibited greater discounting of arguments they disagreed with during left hemisphere activation as measured by ratings of truth. Results supported previous work indicating asymmetries in lateral activation potential during processing persuasive arguments, however the study did not include measuring directly either activation levels or potentials in the cortex.

3. BCI Applications

After we go through the various techniques of BCI the first question that comes to our mind is, what does BCI do to us and what are its applications. So BCI in today's time turns useful to us in many ways. Whether it be any medical field or a field leading to enhancement of human environment. Some of the BCI applications are discussed below.

3.1 The Mental Typewriter:

On March 14, 2006 Scientists demonstrated a brain-computer interface that translates brain signals into computer control signals this week at CeBIT in Berlin. The initial project demonstrates how a paralyzed patient could communicate by using a mental typewriter alone – without touching the keyboard. In the case of serious accident or illness, a patient's limbs can be paralyzed, severely restricting communication with the outside world. The interface is already showing how it can help these patients to write texts and thus communicate with their environment. There's also a PONG game (computer tennis) used to demonstrate how the interface can be used. Brain Pong involves two BBCI users playing a game of tele-tennis in which the "rackets" are controlled by imagining movements and predictably the general media has focused the majority of its attention on computer gaming applications but BCCI could equally be used in safety technologies (e.g. in automobiles for monitoring cognitive driver stress), in controlling prostheses, wheelchairs, instruments and even machinery. On the first day of the 2006 CeBIT Computer Fair, Fraunhofer FIRST and the Berlin Charité demonstrated how the mental typewriter could be used for this purpose. On the other days of the CeBIT Fair, a simulated test setup using a shop-window dummy will be on display.

3.2 BCI offers paralyzed patients improved quality of life:

Tubingen, Germany. A brain– computer interface installed early enough in patients with neuron-destroying diseases can enable them to be taught to communicate through an electronic device and slow destruction of the nervous system.

Fundamental theories regarding consciousness, emotion and quality of life in sufferers of paralysis from Amyotrophic Lateral Sclerosis (ALS, also known as 'Lou Gerhig's disease') are being challenged based on new research on brain-computer interaction. ALS is a progressive disease that destroys neurons affecting movement.

The study appears in the latest issue of Psychophysiology. The article reviews the usefulness of currently available brain- computer –interfaces (BCI), which use brain activity to communicate through external devices, such as computers.

The research focuses on a condition called the completely locked-in state (CLIS, a total lack of muscle control). In a CLIS situation, intentional thoughts and imagery can rarely be acted upon physically and, therefore, are rarely followed by a stimulus. The researchsuggests that as the disease progresses and the probability for an external event to function as a link between response and consequence becomes progressively smaller it may eventually vanish altogether.

Researchers have found that by implementing a brain-computer interface before the completely locked-in state occurs; a patient can be taught to communicate through an electronic device with great regularity. The continued interaction between thought, response and consequence is believed to slow the destruction of the nervous system.

3.3 Adaptive BCI for Augmented Cognition and Action:
The goal of this project is to demonstrate improved human/computer performance for specific tasks through detection of task-relevant cognitive events with real-time EEG (Fig. 1). For example, in tasks for which there is a direct tradeoff between reaction time and error rate, (such as typing or visual search) it may be beneficial to correct a user's errors without interrupting the pace of the primary task. Such a user interface is possible through the direct detection of EEG signatures associated with the perception of a error, often referred to as Error Related Negativity. In general such signatures may be used to dynamically adjust the behavior of human-computer interfaces and information displays. This project advances signal analysis techniques for high density EEG to detect discrete events associated with cognitive processing. Corresponding real-time adaptive interfaces with sub-second latency are being designed to evaluate this concept of an adaptive brain-computer interface in three specific applications:

(1) Error and conflict perception:
Error related negativity (ERN) in EEG has been linked to perceived response errors and conflicts in decision-making. In this project we have developed single trial ERN detection to predict task-related errors. The system can be used as an automated real-time decision checker for time-sensitive control tasks. In the first phase of this project we demonstrated improved human/computer performance at a rapid forced choice discrimination task with an average 23% reduction of human errors (results on one subject are shown in Fig. 2).

(2) Working memory encoding.
Transient modulation of oscillations in the theta (4-8 Hz) and gamma (20-30 Hz) bands, recorded using EEG and magneto encephalography (MEG), have been implicated in the encoding and retrieval of semantic information in working memory. In this project we will exploit these neural correlates of semantic processing to detect problems with semantic information processing. This memory gauge could be used to detect memory recall deficits, and repeat or enhance the presented information and thus better prime memory recall.

(3) Rapid visual recognition:
We are exploring the signals elicited by visual target detection, which were recently observed in rapid sequential visual presentation (RSVP) experiments. We have demonstrated that the detection of these signals on a single trial basis can be used to replace the slow manual response of a human operator, thereby significantly increasing the throughput of image search tasks (Fig 3). This paradigm has the potential to improve the performance of Image Analysts who need to routinely survey large volumes of aerial imagery within short periods of time. In addition, the approach looks to measure the "bottleneck" between constant delay perceptual processing and more variable delay cognitive processing. Thus the detected signatures can be used to "gauge" if cognitive systems are capable/ incapable of assimilating perceptual input for fast decision making.

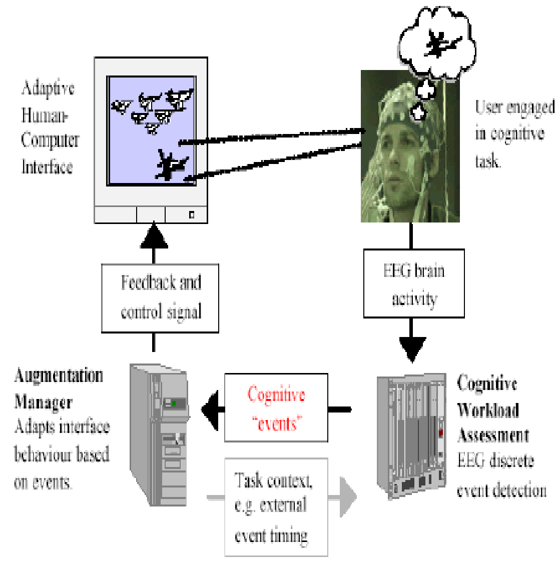
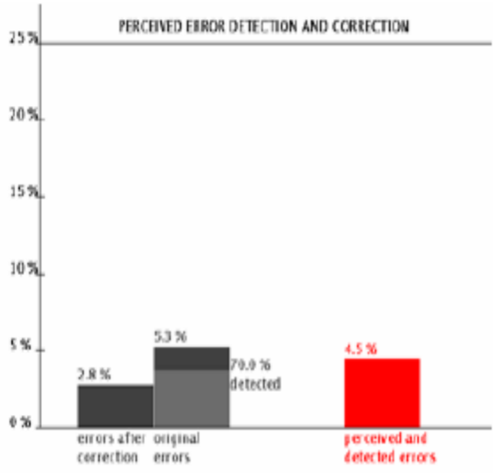
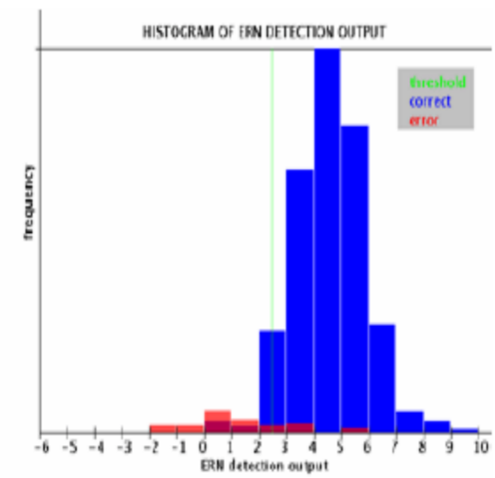
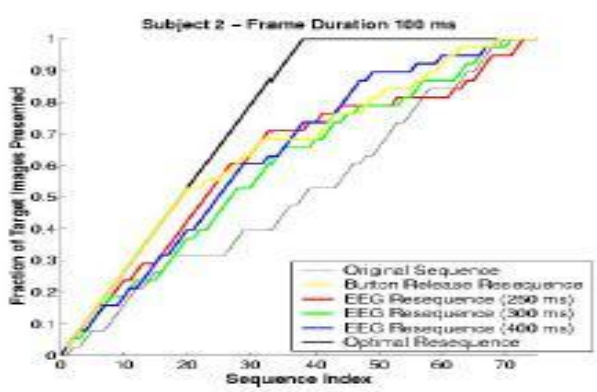


Fig.2 Real-time brain computer interface system for augmented cognition and action.

The information delivery to the human is adapted to a user's cognitive processing based on cognitive events detected in real-time high-density EEG. Applications include automatic correction of perceived errors, prediction of memory performance, and rapid visual search. In the experimental system a pipelined modular processing architecture is used to collect EEG data, increase the signal-to-noise ratio (SNR), and generate a control signal that is fed back to the subject via a display. As an example consider the task of fast image search. A rapid sequence of images is presented on the display. The subject views the images with the goal of detecting a target image. The EEG signal from the high-density sensor net is sampled and processed in real-time using algorithms for artifact removal, and noise reduction. The signal is analyzed in real-time to identify the cognitive activity associated with visual target detection. The augmentation manager records the images associated with recognition events. Fig.3: Reduction of error by correcting a subjects response based on single trial detection of perceived reaction errors using Error Related Negativity. First two bars show reduction of error rate by a factor of 2 for one of 7 subjects. The number of perceived and detected errors (right) could be understood as an "gauge" that measures perceived task difficulty over an extended period of time. Increase in target image throughput detected EEG signatures compared to the ert responses (button release). Note that detected EEG signature results in a er e fraction of the targets to be placed in front of the image stack, thus improving the search efficiency.







4. FUTURE OF THE BCI

The first research into this field an in the 1970's but wasn't used with mans in any practical sense until the mid1970's. The interface implants that now exist are designed to restore a particular function of the human brain that is not working as it should. This restoration may include the facilities of hearing, sight or movement; however this scope could increase in the future. With recent discoveries made and no doubt future discoveries to be made soon, brain-computer interfaces could potentially be designed to improve our natural human functions as well as restoring them. This will certainly make for lots of interesting ethical discussions and dilemmas in the near future.

Research working with brain-computer interfaces in humans can be invasive, semi-invasive or non invasive in nature. Invasive interfaces are implanted directly into the brain of a person and are generally used to repair damaged facilities of sight or to provide extra functionality to a paralysis patient. As well as these functions, brain-computer interface implants have also been used to allow someone to control an artificial robotic hand and even to move a computer cursor. Semi or partially-invasive interfaces are put inside the head but not within the actual brain of the patient. Non-invasive brain-computer interfaces record brain signals through a neuro-imaging procedure.

Electroencephalography (EEG) is the most well known non-invasive interface which has been used as everything from a way of giving limited hand movement back to quadriplegic patients to acting as an interface for people to express musical ideas. Indeed the future of brain-computer interfaces will not only lie with the helping of the sick and disabled, but will equally be used to provide all people with a powerful way of doing anything on a computer at all. One good example of this is the software product mind ball which allows a user to control the movement of a virtual ball by learning to manipulate the EEG content coming from their brains. This trains the user to be focused and relaxed and may even have some future uses in the fields of meditation and education. This way of training someone to use a computer is totally unspecific to culture as it works with very basic functions of brain control.

Brain-computer interfaces are still in their infancy as research continues into both brain functioning and the ways to map it effectively to electronic data. Ethical considerations will no doubt have an impact on the future of this field, as will cultural considerations and questions regarding the way language is controlled in the brain. Today its main use is in helping those with disabilities to function more fully, and through this we will hopefully learn more about how to use our brain as an effective interface for the future. You may be using a keyboard and a mouse right now to access your computer, but there are many other interface options and methodologies out there being worked on. Lots of people are doing research into the field of brain- computer interfaces that work by directly linking together an external device with a human or animal brain. A brain-computer interface (BCI) can theoretically work through either a one way or a two way process, but two way interfaces have not yet been successfully implemented.

5. CONCLUSION

Brain Computer Interface (BCI) systems will allow communication through direct thought processing. From applications in medical world, military, telepathy, cell culture, etc., this technology has also promising to be a spear head in game theory and entertainment industry. After all, what else besides wishful thinking would make people believe that it will soon be possible to "read

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thoughts”?

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