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A Review Paper on Brain Computer Interface

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Abstract — **A brain–computer interface (BCI) is a proficient result in the research field of human-computer synergy, where direct articulation between brain and an external device occurs resulting in augmenting, assisting and repairing human cognitive. In our overview study past and recent research works on brain computer interface are sincerely explored as well as their productivity in the field of BCI and critical discussions about the proposed research methods for future developments are presented in this seminar. Brain–computer interfaces (BCIs) enable users to control devices with electroencephalographic (EEG) activity from the scalp or with single-neuron activity from within the brain.**

Keywords— Component; formatting; style; styling; insert (key words)

I. INTRODUCTION

For generations, humans have fantasized about the ability to communicate and interact with machines through thought alone or to create devices that can peer into person's mind and thoughts. These ideas have captured the imagination of humankind in the form of ancient myths and modern science fiction stories. However, it is only recently that advances in cognitive neuroscience and brain imaging technologies have started to provide us with the ability to interface directly with the human brain. This ability is made possible through the use of sensors that can monitor some of the physical processes that occur within the brain that correspond with certain forms of thought.

The ability to control a computer using only the power of the mind is closer than one might think. Brain-computer interfaces, where computers can read and interpret signals directly from the brain, have already achieved clinical success in allowing quadriplegics, those suffering "locked-in syndrome" or people who have had a stroke to move their own wheelchairs or even drink coffee from a cup by controlling the action of a robotic arm with their brain waves as in fig 1. In addition, direct brain implants have helped restore partial vision to people who have lost their sight.

II. HISTORY

The history of brain–computer interfaces (BCIs) starts with **Hans Berger's** discovery of the electrical activity of the human brain and the development of electroencephalography (EEG). In 1924 Berger was the first to record human brain activity by means of EEG. Berger was able to identify oscillatory activity in the brain by analyzing EEG traces. One wave he identified was the **alpha wave** (8–13 Hz), also known as Berger's wave.

Berger's first recording device was very rudimentary. He inserted silver wires under the scalps of his patients. These were later replaced by silver foils attached to the patients' head by rubber bandages. Berger connected these sensors to a Lippmann capillary electrometer, with disappointing results. More sophisticated measuring devices, such as the Siemens double-coil recording galvanometer, which displayed electric voltages as small as one ten thousandth of a volt, led to success.

Berger analyzed the interrelation of alternations in his EEG wave diagrams with brain diseases. EEGs permitted completely new possibilities for the research of human brain activities 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.

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 effector channels. Following years of animal experimentation, the first neuroprosthetic devices implanted in humans appeared in the mid-1990s.

III. ANIMAL BCI RESEARCH

Several laboratories have managed to record signals from monkey and rat cerebral cortexes 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. Other research on cats has decoded visual signals.

Fig. 1. Rats implemented with BCIs in Theodore Berger's experiments

A. Early Work

Studies that developed algorithms to reconstruct movements from motor cortex neurons, which control movement, date back to the 1970s. Work by groups led by Schmidt, Fetz and Baker in the 1970s established that monkeys could quickly learn to voluntarily control the firing rate of individual neurons in the primary motor cortex after closed-loop operant conditioning, a training method using punishment and rewards.

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.

B. Prominent Research Successes

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

In 1999, researchers led by Garrett Stanley at Harvard University decoded neuronal firings to reproduce images seen by cats. The team used an array of electrodes embedded in the thalamus (which integrates all of the brain’s sensory input) of sharp-eyed cats. Researchers targeted 177 brain cells in the thalamus lateral geniculate nucleus area, which decodes signals from the retina. The cats were shown eight short movies, and their neuron firings were recorded. Using mathematical filters, the researchers decoded the signals to generate movies of what the cats saw and were able to reconstruct recognisable scenes and moving objects.

Miguel Nicolelis has been a prominent proponent of using multiple electrodes spread over a greater area of the brain to obtain neuronal signals to drive a BCI. Such neural ensembles are said to reduce the variability in output produced by single electrodes, which could make it difficult to operate a BCI.

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.

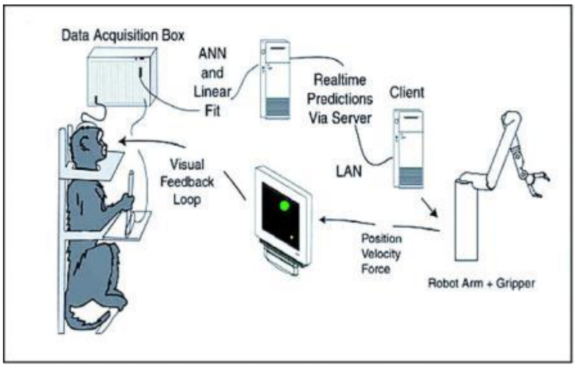

Fig. 2. BCI developed by Miguel Nicolelis and colleagues.

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.

Other labs that develop BCIs and algorithms that decode neuron signals include John Donoghue from Brown University, Andrew Schwartz from the University of Pittsburgh and Richard Andersen from Caltech. These researchers were able to produce working BCIs even though they recorded signals from far fewer neurons than Nicolelis (15–30 neurons versus 50–200 neurons).

Donoghue's group reported training rhesus monkeys to use a BCI to track visual targets on a computer screen with or without assistance of a joystick (closed-loop BCI).Schwartz's group created a BCI for three-dimensional tracking in virtual reality and also reproduced BCI control in a robotic arm. The group created headlines when they demonstrated that a monkey could feed itself pieces of zucchini using a robotic arm powered by the animal's own brain signals.

Andersen's group used recordings of premovement 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

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being developed. Such BCIs could be used to restore mobility in paralyzed limbs by electrically stimulating muscles.

IV. HUMAN BRAIN

The human brain has the same general structure as the brains of other mammals, but has a more developed cerebral cortex than any other. Size of the brain is sometimes measured by weight and sometimes by volume. An average adult have brain volume of 1130 cubic centimeter for women and 1260 cubic centimeter for men. Weight of brain in an adult is 1250 gram for female and 1360 gram for male; and for a new born baby it's just 350 gram to 400gram. Significant dynamic changes in brain structure take place through adulthood and aging, with substantial variation between individuals. In later decades, men show greater volume loss in whole brain volume and in the frontal lobes, and temporal lobes, whereas in women there is increased volume loss in the hippocampi and parietal lobes.

A. Structure of Brain

Brain consists of three main parts that are: Cerebrum, Cerebellum and brain stem attached with the spinal cord. Each part has its own functionality such as auditory, sensory, thinking etc.

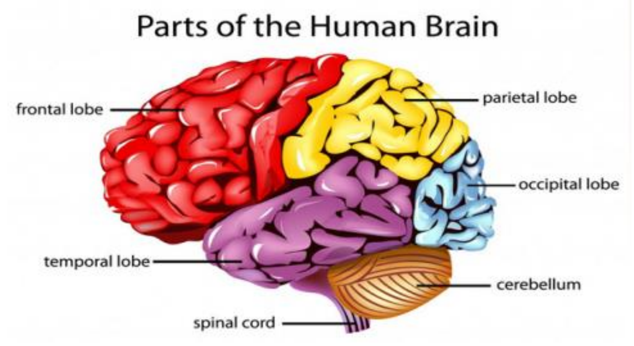

Fig. 3. Parts of the Human Brain

B. Functions of Different Parts of Human Brain

1) *The Cerebrum:*

Frontal Lobe

- Behavior
- Abstract thought processes
- Problem Solving
- Attention
- Creative Thoughts
- Some Emotions
- Intellect
- Reflection
- Judgment
- Initiative
- Coordination of movement
- Physical Reaction

Occipital Lobe

- Vision
- Reading

Parietal Lobe

- Sense of touch
- Response to internal stimuli
- Sensory Combination and Comprehension
- Some visual functions

Temporal Lobe

- Auditory Memories
- Visual Memories
- Music
- Fear
- Sense of identity

Right Hemisphere (the representational hemisphere)

- Controls the left side of the body
- Temporal and spatial relationships
- Analyzing nonverbal information
- Communicating emotions

Left Hemisphere (the categorical hemisphere)

- The left hemisphere controls the right side of the body
- Produce and understand language

Corpus Callosum

- Communication between the left and right hemisphere

2) *The Cerebellum*:

- Balance, Posture
- Cardiac, respiratory, and vasomotor centers

3) *The Brain Stem*:

- Motor and sensory pathway to body and face
- Vital centers: cardiac, respiratory, and vasomotor

V. ARCHITECTURE OF BCI

The architecture of Brain Computer Interface consists of mainly 3 parts:

i. Signal Acquisition, i.e., Input
ii. Signal Processing
iii. Elector Device, i.e., Output

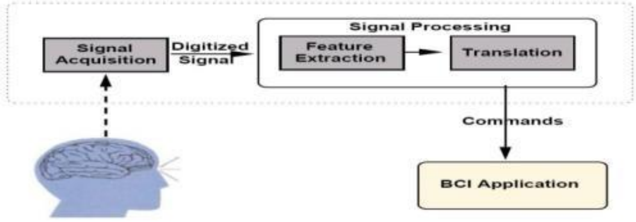

Fig. 4. Simple Architecture of Brain Computer Interface.

1) *Signal Acquisition*: the EEG signals are obtained from the brain through invasive or non-invasive methods (for example, electrodes). After, the signal is amplified and sampled.
2) *Signal Pre-Processing*: once the signals are acquired, it is necessary to clean them.
3) *Signal Classification*: once the signals are cleaned, they will be processed and classified to find out which kind of mental task the subject is performing.

4) *Computer Interaction*: once the signals are classified, they will be used by an appropriate algorithm for the development of a certain application.

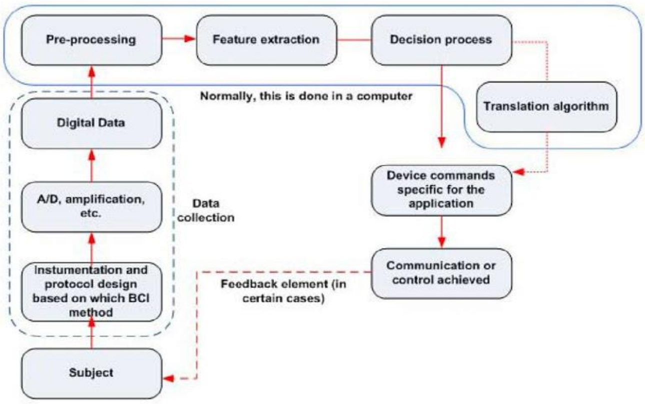

Fig. 5. Flow chart showing data flows as per architecture of BCI.

A. BCI2000 (An Existing Application)

BCI2000 is an existing application to play games on emulator devices or on mobile devices such as mobile phones or Wireless PDAs using brain computer interface technology.

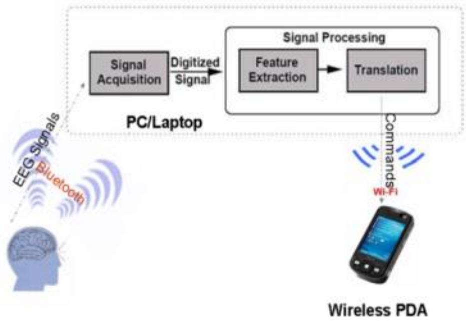

Fig. 6. An Existing Application BCI2000

VI. WORKING PRINCIPLE

Main principle behind this interface is the bioelectrical activity of nerves and muscles. It is now well established that the human body, which is composed of living tissues, can be considered as a power station generating multiple electrical signals with two internal sources, namely muscles and nerves.

We know that brain is the most important part of human body. It controls all the emotions and functions of the human body. The brain is composed of millions of neurons. These neurons work together in complex logic and produce thought and signals that control our bodies. When the neuron fires, or activates, there is a voltage change across the cell, (~100mv) which can be read through a variety of devices. When we want to make a voluntary action, the command generates from the frontal lobe. Signals are generated on the surface of the brain. These electric signals are different in magnitude and frequency.

By monitoring and analyzing these signals we can understand the working of brain. When we imagine ourselves doing something, small signals generate from different areas of the brain. These signals are not large enough to travel down the spine and cause actual movement. These small signals are, however, measurable. A neuron depolarizes to generate an impulse; this action causes small changes in the electric field around the neuron. These changes are measured as 0 (no impulse) or 1 (impulse generated) by the electrodes. We can control the brain functions by artificially producing these signals and sending them to respective parts. This is through stimulation of that part of the brain, which is responsible for a particular function using implanted electrodes.

VII. ADVANTAGES AND DISADVANTAGES

Every Application has its merits as well as demerits as no application has the perfectness in every manner. So Brain Computer Interface being a great upgrading technique in direct communication between man and machine do have some demerits as well.

A. Advantages

Eventually, this technology could:

- Allow paralyzed people to control prosthetic limbs with their mind.
- Help people with inabilities to control wheel chair or other devices with their brain activity.
- Develop better sensing system.
- Transmit visual images to the mind of a blind person, allowing them to see.
- Transmit auditory data to the mind of a deaf person, allowing them to hear.
- Allow gamers to control video games with their minds.
- Allow a mute person to have their thoughts displayed and spoken by a computer.
- BCIs are linguistic independent and can be use anywhere across the world.

This has provided new are for scientists and researchers across the world.

B. Disadvantages

- The brain is incredibly complex.
- The signals are weak and are prone to interference.
- Surgery to brain might be risky and cause brain death.
- There are chemical reactions involved in brain which BCI devices can not pick up.
- The equipment is less than portable.
- Research is still in beginning stages.
- The current technology is crude.
- Ethical issues may prevent its development.
- Electrodes outside skull can detect very few signals from the brain.
- Electrodes placed inside the skull create scar tissues in the brain.

VIII. COMPARISON WITH OTHER TECHNOLOGIES

Technologies that can be compared with the development of Brain Computer Interface are:

A. Human Machine Interaction

Human interact with computer in many ways, and the interface between humans and the computer they use is crucial to facilitating this interaction. Desktop applications, internet browsers, handheld computers, and computer kiosks make use of the prevalent Graphical User Interfaces (GUI) of today. Voice User Interface (VUI) are used for speech recognition and synthesizing systems, and the emerging multi-modal and gestalt User Interface (gUI) allow humans to engage with embodied character agents in a way that cannot be achieved with other interface paradigms.

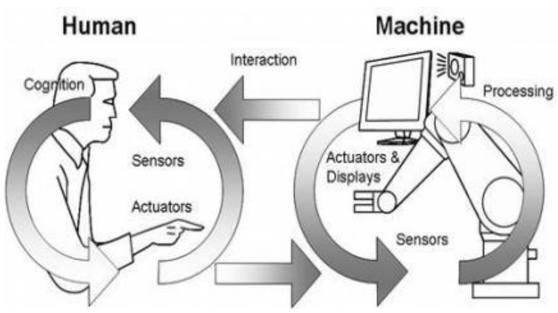

Fig. 7. Human Machine Interaction

Comparison of HMI with BCI: When we are working with HMI, we have to do much more efforts while providing inputs to the machine be it a computer or another king of machine. Machine can work if and only if we provide some inputs or we switch that ON. Whereas, in BCI we need not to do that much effort as computer is directly interacted with human mind. As and when a person works with BCI and have electrodes attached with his mind, he just has to think about the working and the work will process in accordance with his thinking. A disabled person cannot interact properly with machine in HMI whereas BCI was mainly initiated for disabled persons only, machine help disabled person in moving, talking, seeing…

B. Robotics

Robotics is the branch of mechanical engineering, electrical engineering and computer science that deals with design, construction, operation, and application of robots, as well as computer systems for their control, sensory feedback, and information processing. These technologies deal with automated machines that can take the place of human in dangerous environments or manufacturing processes, or resemble humans in appearance, behavior, and/or cognition. Many of today's robots are inspired by nature contributing to the field of bio-inspired robotics.

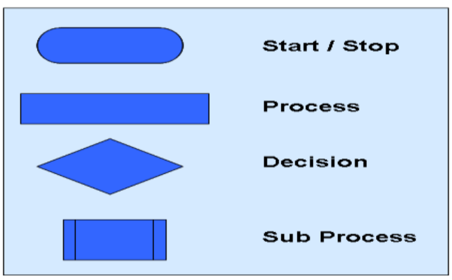

Fig. 8. Flow chart of Robotics

Comparison of Robotics with BCI: Robots are preprogrammed for particular task, they will process the task step by step for which they are preprogrammed. Robots have no decision making capabilities as they don't have their own mind to think according to the situation. Both of these conditions can be seen feasible with BCI as it is directly interacted with human mind.

IX. Rapid Development

BCI is a developing technology, having a number of applications developing. 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 is in any medical field or in a field leading to enhancement of human environment. Some of the BCI applications are discussed below.

1) Adaptive BCI for Augmented Cognition and Action
2) BCI offers paralyzed patients improved quality of life
3) The Mental Typewriter

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
2) Working memory encoding**.**
3) Rapid visual recognition

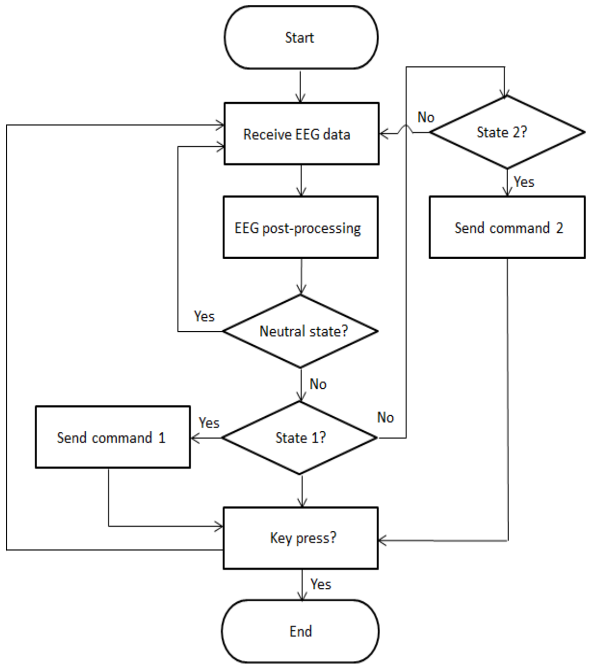

Fig. 9. Example of Mental Typewriter

X. CONCLUSION

Research and development in Brain Computer Interfaces has exploded in the last ten years, both in the technologies available and the number of organizations involved in the field. BCIs have now evolved beyond laboratory experimental systems and some are now offered as commercial products. No longer, the realm of science fiction, BCIs are becoming a viable and effective alternative for assistive technology and a plethora of mainstream applications. New paradigms of interaction open even more possibilities for BCI and create new fields of study, such as neural imaging for computational user experience.

XI. FUTURE WORK

In the BCI research world, that has more practical purposes, the early work will be revised and improved to get a new result.

A. Thought-Communication Device

A new thought-communication device might soon help severely disabled people get their independence by allowing them to steer a wheelchair with their mind. Mind-machine interfaces will be available in the near future, and several methods hold promise for implanting information. Linking people via chip implants to super intelligent machines seems to a natural progression –creating in effect, super humans. These cyborgs will be one step ahead of humans. And just as humans have always valued themselves above other forms of life, it is likely that cyborgs look down on humans who have yet to evolve.

B. Virtual Reality

The early work, in BCI virtual environments, in controlling a virtual apartment and a virtual simulator can be extended. Using some enhancement, the person with inabilities can "walk" through the virtual world by imagining the foot movement, and can "touch" things in the virtual world by imagining reaching and hand movement.

C. Communication

Communication systems that do not depend on the brain's normal output pathways of peripheral nerves and muscles. In these systems, users explicitly manipulate their brain activity instead of using motor movements to produce signals that can be used to control computers or communication devices. The impact of this work is extremely high, especially to those who suffer from devastating neuromuscular injuries and neurodegenerative diseases such as amyotrophic lateral sclerosis, which eventually strips individuals of voluntary muscular activity while leaving cognitive function intact.

Will people want to have their heads opened and wired? Technology moves in light speed now. In that accelerated future, today's hot neural interface could become tomorrow's neuro trash. Will you need to learn any math if you can call up a computer merely by your thoughts? Thought communication will place telephones firmly in the history books.

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