Brain Computing Interface - A Cutting Edge Technology

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ABSTRACT: This paper aims to provide communication capabilities to the severely disabled people who are totally paralyzed or 'locked in' by neurological neuromuscular disorders such as brain stem stroke or spinal cord injury. Many studies over the past two decades have shown that people and animals can use brain signals to convey their intent to a computer using brain-computer interfaces (BCIs). BCI systems measure specific features of brain activity and translate them into control signals driving them to an output. In this survey paper we first have the introduction, giving a brief description about the parts of the brain. Then we have the functions of the brain. Next there is the description regarding the brain related diseases. Later we cover the concept of BCI, the neuroimaging methods, the control signals used and the feature selection and extraction. We finally cover the application of BCI.

KEY WORDS: Brain-computer interfaces, artificial intelligence, electroencephalography.

INTRODUCTION

The brain is one of the most complex and magnificent organs in the human body. It serves as the centre of the nervous system in all vertebrate and most invertebrate animals. This three-pound organ is located in the head and is the seat of intelligence, interpreter of the senses, initiator of body movement, and controller of behaviour. It controls our muscle movements, the secretions of our glands, and even our breathing and internal temperature. The brain is the crown jewel of the human body. Brain has the following parts:

The brain stem: it consists of the medulla, pons and midbrain. The brain stem controls the reflexes and automatic functions (heart rate, blood pressure), limb movements and visceral functions.

The cerebellum: this integrates information from the vestibular system that indicates position and movement and uses this data to coordinate limb movements.

The hypothalamus and pituitary gland: they are responsible for visceral functions, body temperature control and behavioural responses such as feeding, drinking, aggression and pleasure.

The cerebrum: it consists of the cortex, corpus callosum and other deeper structures. It integrates info from all of the sense organs, initiates motor functions, controls emotions and holds memory and thought processes.

FUNCTIONS OF THE BRAIN

The brain is composed of two hemispheres. The left hemisphere is responsible for verbal functions while the right is responsible for spatial functions. The lobes of the brain are as follows:

Frontal Lobe - It is present on the forehead i.e. the front of the brain. It is responsible for conscious thought, behaviour, emotion, planning, personality, organizing and problem solving.

Parietal Lobe - It is present on the sides of the temporal lobes i.e. the middle-top of the brain. The left parietal lobe is for spatial language and the right parietal lobe is for spatial functions. It is responsible for integrations of sensory information from the primary sensory areas like perception, arithmetic, spelling, manipulation of objects.

Temporal Lobe - It is present on the temple region of the forehead. It is responsible for timing, attention, sense of smell, sound, processing of complex stimuli like faces and scenes, memory and understanding languages.

Occipital Lobe - It is located at the back of the head and is primarily responsible for the sense of sight.

BRAIN RELATED DISEASES

- Amyotrophic lateral sclerosis (ALS) is a progressive neurodegenerative disease that affects the nerve cells in the brain and the spinal cord. Motor neurons run from

fig: Parts of the brain

fig: Lobes of the brain
the brain to the spinal cord from where they reach the muscles throughout the body. The progressive degeneration of the motor neurons in ALS eventually leads to their death. When the motor neurons die, the ability of the brain to initiate and control muscle movement is lost. With voluntary muscle action progressively failing, patients in the later stages of the disease may face complete paralysis.

- **Alzheimer's disease** is a progressive disease that damages the nerve cells (neurons) in parts of the brain involved in memory, learning, language, and reasoning. As the disease progresses, communication among the neurons breaks down. In early stages, short-term memory begins to fail. Over the time, functions such as long-term memory, language, and judgment decline. Alzheimer's disease is the most common cause of dementia in older adults. Dementia is a loss of mental functions—such as thinking, memory, and reasoning—that is severe enough to interfere with a person's daily functioning.

- **Paralysis or Strokes** occur when blood vessels carrying oxygen and other nutrients to the brain become blocked or suddenly burst. It is the inability of a muscle or group of muscles to move voluntarily. Muscles are controlled by messages sent from the brain that trigger movement. When the part of the brain is damaged after a stroke, messages between the brain and muscles are not transferred effectively. Paralysis or weakness can affect any part of the body.

- **Parkinson’s disease** is the most common among the major movement disorders: a category of conditions in which a malfunction in the nervous system affects communication between the brain and the muscles. The symptoms include tremor, stiffness, difficulty in moving, and problems with walking and balance. Parkinson's disease may be difficult to diagnose in the early stages, because the symptoms begin gradually and progress over time. There isn’t a cure for Parkinson's, but treatments exist to help control symptoms.

- **Cerebral palsy** is a term which encompasses a set of neurological conditions that cause physical disability in human development - they affect the brain and nervous system. The word cerebral refers to the area in the brain that is affected, while palsy means complete or partial muscle paralysis, frequently accompanied by loss of sensation and uncontrollable body movements or tremors.

**BRAIN COMPUTING INTERFACE**

A brain computer interface (BCI), also known as a brain machine interface (BMI), is a hardware and software communications system that enables humans to interact with their surroundings, without the involvement of peripheral nerves and muscles, by using control signals generated from electroencephalographic activity.

A BCI is an artificial intelligence system that can recognize a certain set of patterns in brain signals following five consecutive stages: signal acquisition, pre-processing or signal enhancement, feature extraction, classification, and the control interface. The signal acquisition stage captures the brain signals and may also perform noise reduction and artefact processing. The pre-processing stage prepares the signals in a suitable form for further processing. The feature extraction stage identifies discriminative information in the brain signals that have been recorded. Once measured, the signal is mapped onto a vector containing effective and discriminate features from the observed signals. The extraction of this interesting information is a very challenging task. Brain signals are mixed with other signals coming from a finite set of brain activities that overlap in both time and space. The classification stage classifies the signals taking the feature vectors into account. Finally, the control interface stage translates the classified signals into meaningful commands for any connected device, such as a wheelchair or a computer.

**NEUROIMAGING**

BCIs rely on a recording stage that measures brain activity and translates the information into tractable electrical signals. Two types of brain activities may be monitored: (i) electrophysiological and (ii) hemodynamic.

Electrophysiological activity is generated by electrochemical transmitters exchanging information between the neurons. The hemodynamic response is a process in which the blood releases glucose to active neurons at a greater rate than in the area of inactive neurons. The neuroimaging methods are:

- **ELECTROENCEPHALOGRAPHY (EEG)** - EEG measures electric brain activity caused by the flow of electric currents during synaptic excitations of the dendrites in the neurons and is extremely sensitive to the effects of secondary currents. EEG signals are easily recorded in a non-invasive manner through electrodes placed on the scalp, for this reason it is by far the most widespread recording modality.

- **MAGNETOENCEPHALOGRAPHY (MEG)** - MEG is a non-invasive imaging technique that registers the brain’s magnetic activity by means of magnetic induction.

- **ELECTROCORTICOGRAPHY (ECOG)** - ECoG is a technique that measures electrical activity in the cerebral cortex by means of electrodes placed directly on the surface of the brain. Therefore ECoG is an invasive recording modality which requires a craniotomy to implant an electrode grid.

- **INTRACORTICAL NEURON RECORDING** - Intracortical neuron recording is a neuroimaging technique that measures electrical activity
inside the gray matter of the brain. It is an invasive recording modality that needs to implant microelectrode arrays inside the cortex to capture spike signals and local field potentials from neurons.

**CONTROL SIGNAL TYPES IN BCI**

Brain signals involve numerous simultaneous phenomena related to cognitive tasks. The physiological phenomena of some brain signals have been decoded in such way that people may learn to modulate them at will, to enable the BCI systems to interpret their intentions. The control signals are:

**VISUAL EVOKED POTENTIALS** - They are brain activity modulations that occur in the visual cortex after receiving a visual stimulus. These modulations are relatively easy to detect since the amplitude of VEPs increases enormously as the stimulus is moved closer to the central visual field. They may be classified according to 3 different criteria:

- **The morphology of the optical stimuli** - VEPs may be caused by using flash stimulation or using graphic patterns such as checkerboard lattice, gate, and random-dot map.

- **The frequency of visual stimulations** - VEPs can also be classified as transient VEPs (TVEPs) and as steady-state VEPs (SSVEPs). TVEPs occur when the frequency of visual stimulation is below 6 Hz, while SSVEPs occur in reaction to stimuli of a higher frequency. SSVEP further classifies into: Time modulated VEP(t-VEP), Frequency modulated VEP(f-VEP), Pseudorandom code modulated VEP(c-VEP).

- **Field stimulation** - VEPs can be divided into whole field VEPs, half field VEPs, and part field VEPs depending on the area of on-screen stimulus.

**SLOW CORTICAL POTENTIALS** - They are slow voltage shifts in the EEG that last for a few seconds. They belong to the part of the EEG signals below 1Hz. They are also associated with changes in the level of cortical activity, whereas positive SCPs coincide with decreased activity in individual cells. These brain signals can be self-regulated by both healthy users and paralyzed patients to control external devices by means of a BCI. SCP shifts can be used to move a cursor and select the targets presented on a computer screen. Although most thought-translation devices show continuous feedback, it is possible to train SCP self-modulation in the absence of continuous feedback.

**P300 EVOKED POTENTIALS** - They are positive peaks in the EEG due to infrequent auditory, visual, or somatosensory stimuli. The use of P300-based BCIs does not require training. However, the performance may be reduced because the user gets used to the infrequent stimulus & consequently the P300 amplitude is decreased. A typical application of a BCI based on visual P300 evoked potentials comprises a matrix of letters, numbers or other symbols or commands. P300-based BCIs provide a very low rate of information transmission because the classifier based on an average is too simple, and the accuracy of P300 potential detection is too low.

**SENSORIMOTOR RHYTHMS (Mu & Beta)** - Sensorimotor rhythms comprise of mu and beta rhythms, which are oscillations in the brain activity localized in the mu band (7–13 Hz), also known as the Rolandic band, and beta band (13–30 Hz), respectively. The amplitude of the sensorimotor rhythms varies when cerebral activity is related to any motor task although actual movement is not required to modulate the amplitude of sensorimotor rhythms.
FEATURE EXTRACTION AND SELECTION

Different thinking abilities result in different patterns of brain signals. BCI is seen as a pattern recognition system that classifies each pattern into a class according to its features. BCI extracts some features from brain signals that reflect similarities to a certain class as well as differences from the rest of the classes. Some of the different methods used are:

PCA (Principal Component Analysis) - Linear transformation, set of possibly correlated observations is transformed into a set of uncorrelated variables, optimal representation of data in terms of minimal mean-square-error.

ICA (Independent Component Analysis) - Splits a set of mixed signals into its sources, mutual statistical independence of underlying sources is assumed and may corrupt the power spectrum.

CSP (Common Spatial Pattern) - Good result for synchronous BCIs and is less effective for asynchronous BCIs. Its performance is affected by the spatial resolution.

APPLICATIONS

One of the most exciting areas of BCI research is the development of devices that can be controlled by thoughts. A more difficult task is interpreting the brain signals for movement in someone who can’t physically move their own arm. With a task like that, the subject must "train" to use the device. The most common and oldest way to use a BCI is a cochlear implant. Motor restoration may alleviate their psychological and social suffering. One of the main goals of BCI-based applications is to achieve maximum independence for the patient, despite any motor disability. Until now, research into BCI technology has usually focused on assistive applications, such as spelling devices, wheelchair control or neuroprostheses rather than applications with entertainment purposes. However, interest in entertainment applications has arisen over the recent years due to the significant advances in this technology.

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