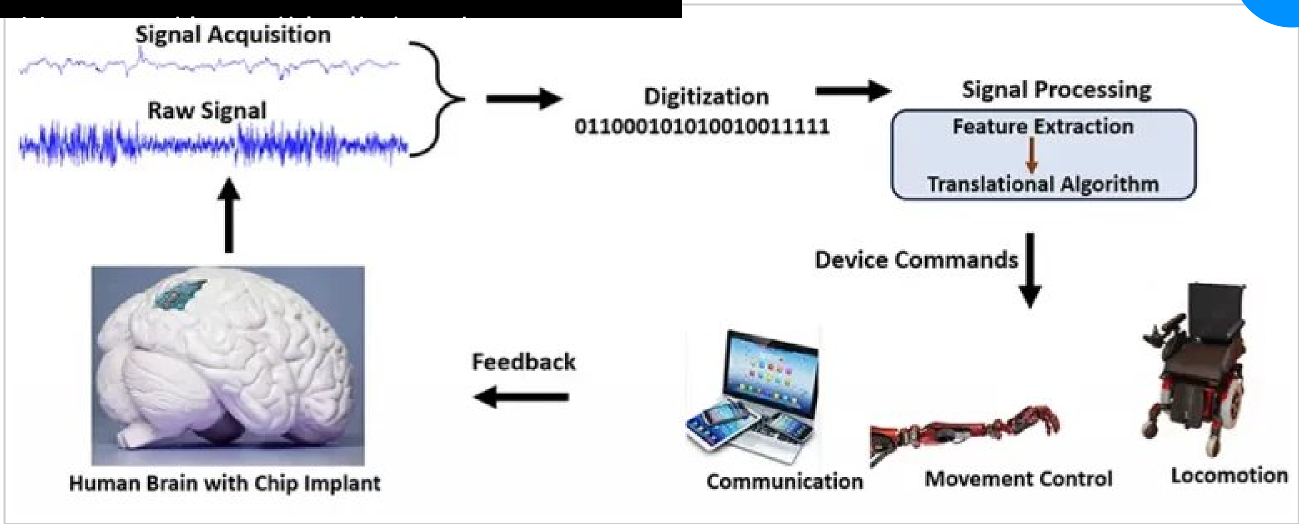
BRAIN COMPUTER INTERFACE – MEDICAL AND BEYOND

Introduction

Reading Time: 6 minutes

The burden of death and disability caused by neurological abnormalities is being recognized as a global public health issue which is set to increase during the next few decades. This is a result of aging population and lifestyle changes. Brain–computer interface (BCI), an emerging technology that facilitates communication between brain and computer, is considered as a ray of hope to tackle this menace and has attracted a great amount of interest in recent years. BCI has proven that it can restore the capabilities of brain by overcoming the neurological distortions, caused due to neurodegeneration conditions such as amyotrophic lateral sclerosis, Parkinson's disease, Alzheimer's disease, and spinal muscular atrophy, thus improving the quality of lives of people suffering from physical and mental challenges.[1][2][3]

BCI system basically comprises of four essential components such as signal acquisition, feature extraction, feature translation and device output. The primary function of BCI is to detect and quantify features of signals received from brain which are indicators of the person's intentions and later translate these features in real time into device commands that accomplish the person's



Schematic representation of Brain Computer Interface components (Source)

Signal Acquisition involves the measurement of signals from brain using a suitable sensor modality such as scalp or intracranial electrodes for electrophysiologic activity, fMRI for metabolic activity etc. The signals are amplified to levels suitable for electronic processing by appropriate filters to eliminate electrical noises or other undesirable interferences followed by digitization and transmission to an output device.

Feature Extraction involves the process of analyzing the digital signals to distinguish pertinent signal features from extraneous content and representing them in a compact form suitable for translation into output commands. These features should have strong correlations with the person's intent. Environmental artifacts and physiologic artifacts such as electromyographic signals are avoided or removed to ensure accurate measurement of the features of signals from the brain.

Feature Translation involves signal features attained during feature extraction being passed on to the feature translation algorithm, which converts the features into appropriate commands for the output device.

Device Output involves commands that are generated from the feature translation algorithm to operate the external device thus providing functions such as letter selection, cursor control, robotic arm operation, etc. Finally, the operated external device provides feedback to the person thus closing the control loop.

During late 1960s, attempts were made to control simple electrical equipment such as light bulbs using electrodes that could measure and react to signals, first from monkey brains and then from humans.[5]

First few experiments were aimed at allowing amputees to control synthetic limbs. One of the first successful demonstrations of a brain-computer interface took place in 1991 at the Wadsworth Center for Laboratories and Research, which involved usage of brain signals to move a computer cursor across a screen. Wolpaw and his colleagues showed that a cursor on a computer screen can be controlled using brain waves, in particular with the μ-rhythm (sensorimotor rhythm). [6]

In late nineties, it became possible to reproduce images seen by animals such as cats by decoding the firing patterns of neurons in their brains. Researchers from University of California used a linear decoding technique to reconstruct spatiotemporal visual inputs from ensemble responses in the lateral geniculate nucleus (LGN) of the cat, wherein, from the activity of 177 cells they reconstructed natural scenes with recognizable moving objects. [7]

Even though BCI began its journey of applications from medical field, with the advent of biocompatible sensors based on nanomaterials and artificial intelligence, it has positively impacted other several industries, including entertainment/gaming, automation, education, and neuromarketing.

Recently, researchers from The Johns Hopkins University School of Medicine in collaboration with University Medical Center Utrecht, have reported online synthesis of intelligible words using a chronically implanted brain-computer interface (BCI) in a clinical trial participant with dysarthria due to Amyotrophic Lateral Sclerosis (ALS). They have successfully demonstrated a reliable BCI that synthesizes commands freely chosen and spoken by the user from a vocabulary of 6 keywords originally designed to allow intuitive selection of items on a communication board and it was shown for the first time that a speech-impaired individual with ALS can use a chronically implanted BCI to reliably produce synthesized words that are understandable to human listeners while preserving the participants' voice profile. [8],[9]

First-in-human BCI study using a minimally invasive endovascular technique to deliver recording electrodes through the jugular vein to superior sagittal sinus

(SSS) has been reported by researchers from Australia, UK and USA in association with Synchron Australia Pty Ltd. This was based on a study to assess the safety of an endovascular BCI and feasibility of using the system to control a computer by thought. It has been concluded that endovascular access to the sensorimotor cortex is an alternative to placing BCI electrodes in or on the dura by open-brain surgery and the final safety and feasibility data from the first-in-human Stentrode with Thought-Controlled Digital Switch (SWITCH) study indicate that it is possible to record neural signals from a blood vessel. Further, the favourable safety profile could promote wider and more rapid translation of BCI to people with paralysis. [10],[11]

Stanford researchers implemented the Recurrent Neural Network (RNN) to process the Brain-Computer Interface in an attempt to synthesize speech from signals found and captured in a patient's brain. Compared to the previously existing BCI approaches that allow speech decoding, this reported method enables a person to communicate at 62 words per minute which is 3.4 times faster than the previous ones. As Artificial Intelligence (AI) is revolutionizing and stepping into every field, this new speech-to-text interface can help people to communicate effectively. [12]

Design and implementation of a real-time BCI for an electric wheelchair has been reported by researchers from University of Western Macedonia. A BCI-controlled wheelchair with Motor Imagery (MI) mental commands for turning right and left with a degree of freedom of 4 i.e., going forward, stopping, turning left and right has been presented. A Muse S headband had been employed to record the raw EEG data and Linear Discriminant Analysis (LDA) algorithm has been used to classify the mental commands. The experimentation was conducted in an office environment and the results demonstrated that the participants were able to successfully adapt and operate the BCI-controlled wheelchair with a high level of accuracy and precision. [13]

A dry electrode-based BCI for P300-based car driving, using RIDDANCE (distuRb-resIstant Dry electroDe-based brAiN Computer intErface) framework, has been demonstrated by researchers at the Department of Electrical and Information Engineering, Polytechnic of Bari. RIDDANCE analyses the data from an 8-channel dry EEG headset by g.tec. Data collection for training/testing is typically carried out in an uncontrolled environment to improve the training and the classification robustness. For this purpose, RIDDANCE embeds a user-tailored neural network (NN) topology selector that offers the most robust model in terms of average validation loss.[14]

Combining brain-computer interfaces and multiplayer video games based on code-modulated visual evoked potentials (c-VEPs) has been proposed by researchers from University of Valladolid and Biomateriales y Nanomedicina (CIBER-BBN), Madrid. The proposed application consists of a multiplayer video game controlled by a real-time BCI system processing 2 electroencephalograms (EEGs) sequentially and to detect user intention. Shifted versions of a pseudorandom binary code, following a traditional circular shifting c-VEP paradigm is used to encode the columns in which the coin can be placed. Initially each user has to perform individual tasks, and later the users are matched and the application is used in competitive mode.[15]

Researchers from University of Western Macedonia in collaboration with University of Ioannina have reported a 3D non-invasive BCI game that uses a Muse 2 EEG headband to acquire electroencephalogram (EEG) data and OpenViBE platform for processing the signals and classifying them into three different mental states i.e., left and right motor imagery and eye blink. The game is developed to assess user adjustment and improvement in BCI environment after training, wherein the classification algorithm used is Multi-Layer Perceptron (MLP), with an accuracy of 96.94%. 33 subjects had participated in the experiment and successfully controlled an avatar using mental commands to collect coins.[16]

University of Technology Sydney researchers have developed three-dimensional micropatterned sensors based on a subnanometer-thick epitaxial graphene for detecting the EEG signal from the challenging occipital region of the scalp, wherein, the patterned epitaxial graphene sensors showed efficient on-skin contact with low impedance and achieved comparable signal-to-noise ratios against wet sensors. Also, upon using these sensors, they have demonstrated hands-free communication with a quadruped robot through brain activity.[17]

Several start-ups are actively engaged in research in this area**.**

Inner Cosmos, a neurotechnology company that develops BCI, unveiled smallest neurostimulation device designed to treat depression.[18],[19]

Synchron manufactures and markets medical devices that can be delivered to the brain with a catheter to record neuron signals which in turn might be used to control prosthetics.[20],[21]

Precision Neuroscience is working to help patients with paralysis operate digital devices by decoding their neural signals.[22]

Blackrock Neurotech has developed intracortical electrode, the NeuroPort Electrode. Its primary focus is on providing new possibilities for people with paralysis and neurological disorders.[23]

Neuralink Corp. has developed implantable brain-computer interface chips that are designed to control a computer or mobile device. The U.S. Food and Drug Administration (FDA) approved Neuralink's request to conduct its first human clinical study. The approval was a critical milestone for the startup, which had only conducted research on animals.[24],[25]

ONWARD Medical N.V. has developed spinal cord stimulation therapies for people with spinal cord injury (SCI) in order to restore movement and function. Recently, it announced the development of a human implant ARC^IM Stimulator (Attachment, regulation, and competency – Implantable) utilized to restore arm, hand, and finger function after SCI.[26]

Some recent patent publications in this area are listed below:

WO2023038829A1 filed by **Neuralink Corp.,** relates to a biological BCI comprising genetically modified cells engrafted onto an adult mammal above cortical layer, forming an artificial cortical layer termed layer zero (L0). L0 goes through a developmental process, post engraftment, characterized by synchronous waves of activity that gradually recede to resemble spontaneous cortical activity. Synaptic connections necessary for bidirectional communication with the brain were formed after Axons and dendrites from L0 non-destructively infiltrated the host cortex.

US11612808B2 assigned to **Hi LLC** relates to an illustrative system including a

BCI system configured to be worn by a user and to output brain activity data while the user parallelly plays an electronic game and a computing device configured to obtain the brain activity data and modify an attribute of the electronic game.

US20220061728A1 filed by **Brain Scientific Inc.,** relates to a system for brain signal measurement and analysis using graphene-based electrodes. The proposed system is minimally invasive with small size electrodes and a stamp-size electronic processor with wireless communication and a remote computing device, enabling brain signal collection outside of clinical settings. The electrodes and electronic processor are both imprinted onto the subject's scalp using three-dimensional printers with small size electronics and post usage, the electrodes and electronic processor may be washed off or removed without injuries to the subject.

US20200085375A1 filed by **Neuralink Corp.,** relates to biocompatible multi-electrode devices capable of being implanted in sensitive tissue. The disclosed arrays, which include linear arrays, multi-thread arrays, tree-like electrode arrays etc., can be implanted in living biological tissue with a single needle insertion.

CN114376580A filed by **Shanghai Institute of Microsystem and Information Technology of CAS**, relates to a flexible nerve electrode, applicable for brain computer interface, comprising a silicon substrate with a sacrificial layer, forming polyimide layers and detection electrode arrays onto the sacrificial layer. The proposed nerve electrode could reduce the damage to the brain after the nerve electrode is implanted into the brain, and further improve the feasibility and the reliability of the long-term in-vivo implantation of the nerve electrode.

Brain Computer Interface technology certainly has great potential to revolutionize the wellbeing of humans by providing amicable solutions to neurological disorders which currently have limited curative methods. Furthermore, it is also expected to impact the gaming and vehicular driving sector. With the advent of innovative soft electronics in conjunction with developments in the fields of artificial intelligence and neuroscience, the field of BCI is bound to grow tremendously in the near future. However, there are certain hinderances in achieving large scale commercialization. While cybersecurity is a touchstone for many businesses and individuals, neural security may become the same for BCI technology. Strong international ethical guidelines related to accessibility, assessibility, and manipulation of human neural systems, need to be framed to address the serious concerns pertaining to the privacy of human neural activity.

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AUTHORS

Dr. Sivaprasad

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