Brain-Computer Interface Technologies for Neurological Diseases

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Abstract. A Brain-Computer Interface (BCI) is a device that monitors central nervous system (CNS) activity and transforms it into artificial output that can be used to replace, improve, supplement, or restore the natural CNS output. Brain-Computer Interface (BCI) technologies for neurological diseases are vital for the well-being of related patients. This paper presents 4 forms of BCI technologies used for neurological diseases: EEG-based BCI for the treatment of Attention Deficit Hyperactivity Disorder (ADHD), Neural Cursor and BCI Spellers for ALS patients, Seizure Prediction BCI for those with epilepsy, and Motor Imagery BCI (MI-BCI) for the treatment of upper-limb strokes. The development and applications of the aforementioned BCI technologies are covered in detail. This literature review's objective is to examine the key characteristics of BCI technologies used to make the life quality of neurological disease sufferers better. The author aims to assist concerned researchers and individuals with the gathered information and help future researchers to learn better from previous studies.

Keywords: BCI, ADHD, ALS, Epilepsy, Upper-limb stroke.

1. Introduction

A BCI system measures the brain activities, processes these activities, and converts them into an output. BCI is at the leading edge of medical research, applications of BCI make it possible for human brains to communicate unseamed with a machine and are therefore seen to be appropriate instruments to treat neurological disorders.

Data gathering, preprocessing, feature extraction, and translation methods are all included in a general BCI system [1]. First, brain signals like an electroencephalogram (EEG) are captured by either invasive or non-invasive sensors. Second, the BCI system pre-processes the data. Then, the BCI system conducts machine learning by extracting features from the data and inputting them into translation algorithms. Last, the computer output device commands the mechanical device, such as a robotic arm, to provide influence to the user or the environment.

EEG-based BCI is a vital tool to rehabilitate ADHD patients. ADHD is a major neurological disease among young people. The behavioral disorders caused by ADHD include inattentiveness, hyperactivity, and impulsivity. The traditional treatment of ADHD is mainly medication. However, it leads to multiple negative effects in children. The treatment can harm children’s cardiovascular systems, their height, and their somatic complaints [2]. The P300 potential is utilized by an EEG-based BCI system in several virtual reality (VR) feedback games to enhance the participants' attention [3].

The development of Neural Cursor and BCI Spellers is beneficial for ALS patients. ALS disrupts neurological networks, affecting the communication between the brain and the other organs in the body. It mostly affects the motor control of the muscles. Similar to Locked-in Syndrome (LIS), the voluntary muscles, including the tongue muscle, gradually become out of control in ALS. Without the ability to speak and use sign language, ALS patients are increasingly difficult to communicate with [4]. Neural Cursor and BCI Spellers are alternative ways of communication to help ALS patients regain social abilities.

Epilepsy in medicinally headstrong patients can be controlled by seizure expectation-used BCI. Epilepsy is a prolonged neural disorder with spontaneous seizures as its feature. One percent of the world's population is affected, while seizures were not recorded in roughly 30% of patients with epilepsy. But because the epileptic location of the patient can be diagnosed and treated only by electrodes placed strategically, rather than being surgically removed, BCI can be used to predict seizures of epilepsy patients [5].

MI-BCI is useful for upper-limb stroke rehabilitation. Often accompanied by death or disability, stroke is one of the most harmful neurological disorders for human beings [6]. Because of the brain damage, a large number of stroke survivors remain permanently disabled. Most rehabilitation nowadays relies on patients' physical practice (PP). According to former research, people with upper-limb stroke can conduct actual movements with the help of MI-BCI, some of them even possess the same level of control over non-invasive, EEG-based MI-BCI as healthy individuals [7].

2. Related works

2.1. EEG-based BCI for ADHD rehabilitation

To help ADHD sufferers, researchers employed BCI to provide feedback from the recorded EEG. In a series of feedback exercises, the P300 potential, a positively significant potential in the recorded EEG data, is used to improve participant attention. Around 300 milliseconds following a cognitive event, the P300 potential peaks. As a result, it is possible to determine whether a subject is paying attention based on the appearance of the P300 potential [3].

Event-related (de)synchronization (ERD/ERS) is the foundation of the experimental approach to BCI treatment [3]. Alpha signals range from 7.5Hz to 12Hz, Theta signals from 3.5Hz to 7.5Hz, Delta signals from 0.5Hz to 3.5Hz, and theta signals from 3.5Hz to 7.5Hz, Beta signals range from 12Hz to 30Hz, and Gamma signals range from 31Hz and above in frequency [1].

According to former studies, ADHD patients show extra low frequency (Theta and Alpha) activities and less amount of high frequency (Beta) activities [8]. The BCI treatment aims to increase the proportion of higher frequency signals. [3].

The feedback games were created to test sustained visual attention and visual discrimination, two skills that are difficult for kids with ADHD. They were based on the theories mentioned above. One kind of feedback game requires the young patients to search for a certain object among others, for example, a letter or an animal [3]. In another kind of game, the speed of the character controlled by the patient is related to his/her attention, so patients need to concentrate to finish the game [9]. Attention training using EEG-based BCI showed reduced children's ADHD symptomatology [1].

2.2. Neural Cursor and BCI Spellers for ALS patients

One of the most frequent causes of LIS, in which people are unable of making the majority of voluntary movements, such as limb, face, and speaking movements, is ALS [10]. Communication is a crucial BCI application because it is a priority for ALS patients.

Kennedy and colleagues first implanted an electrode into an individual with ALS [10]. To record the patient's action potentials for several months, the electrode caused myelinated fibers to develop onto its recording tip. The outcome demonstrated that the patient was able to switch brain signals on and off [11].

The patient was able to control the neurotrophic electrode's constant signals during a second session, which allowed him to move a cursor across a computer screen. The firing rate was inversely proportional to the speed of the cursor movement.

The first instance of trustworthy multi-dimensional cursor control via motor cortex neurons was documented in 2006 [10]. To give individuals with tetraplegia a neural cursor, researchers developed a decoder. The brain cursor allowed a tetraplegic patient to read fictitious emails and control television while still being able to speak. According to the findings, paralyzed people might gain independence via brain control-based neuromotor prostheses (NMPs), such as artificial hands or arms.

More than 10 words per minute can now be typed thanks to the usage of customized keyboards that can control the cursor's direction. Intracortical recording may provide LIS and ALS patients with the basis to immediately communicate with others through these and other modest efforts, it is hoped [10].

BCI spellers have been developed at a fast speed in recent years. The basic types of BCI spellers include matrix speller-based P300 spellers, other P300 interfaces (Chroma Speller, T9, Checkerboard Paradigm, Geospell, Gaze-Independent Block Speller (GIBS), Lateral Single Character Speller (LSC), Hex-O-Spell as ERP, and Rapid Serial Visual Presentation (RSVP)), SSVEP Spellers (Bremen Speller, Multi-Phase SSVEP Spellers, Multi-Target One-Phase SSVEP Spellers, RC SSVEP Speller, FlashTypeTM, and DTU BCI Speller), and MI Interfaces (Hex-O-Spell, Oct-O-Spell, and other MI Spellers). Hybrid spellers like SSVEP plus P300 and MI plus P300 were also created, combining the advantages of different systems [4]. Various kinds of spellers give patients multiple choices, and allow them to choose based on personal situations.

2.3. Seizure Prediction BCI for epilepsy patients

With the use of cloud computing and deep learning to help handle huge data of scalp EEG and electrocorticographic (ECoG), researchers built a BCI seizure forecasting as well as a localization algorithm [5].

The identification of the epileptic preictal state from long-duration intracranial electroencephalographic (iEEG) recordings in dogs has been managed using the support vector machine (SVM) technique. In the study, transportable intracranial EEG monitoring devices were implanted into the hemispheres of eight dogs with naturally occurring epilepsy. The results demonstrated that while algorithms are subject-specific, they significantly outperform a time-matched Poisson random predictor in terms of prediction performance.

Studies have then focused on local processing and storage, without using big data processing [5]. As of 2011, Chaovalitwongse and colleagues proposed two time series classification techniques, the Support Function Machine (MFS) and the Network Support Vector Machine (NSVM) to determine whether someone is epileptic based on EEG signals.

Recent studies developed seizure prediction BCI via EEG big data and the Internet of things. To meet the requirement for safe storage and high computational resources, researchers developed new BCI systems based on cloud computation. Machine learning was used to reduce calculation time and electricity consumption, while still predicting seizures accurately [5].

2.4. MI-BCI for upper-limb stroke rehabilitation

For patients with upper-limb stroke who are not candidates for physical practice (PP), BCI therapy eliminates the need for any residual movements.

Ka Kai et al. described two methods for employing BCI for neurorehabilitation (2015). One uses MI detection to initiate feedback, while the other detects MI and provides MI and PP using a robot. The results showed that motor function had significantly improved.

In a subsequent investigation, researchers used a special BCI that links in time the brain signals produced when a stroke patient tries to perform a movement to induce neuroplasticity. The BCI was also advantageous for healthy participants: exposure to the BCI was followed by neuroplastic alterations accompanied by appreciable improvements in function as measured by clinical measures.

In a recent study, MI-BCI was used to deliver visual feedback to treat stroke-related upper-limb paralysis. The MI-BCI assisted stroke survivors in maintaining short-term Fugl-Meyer motor assessment (FMA) improvement in the upper extremities. Thought weariness during therapy may develop, according to an examination of the relative beta potency of the EEG [7].

3. Discussion

Research had predicted that mainstream adoption of BCI would occur soon [1]. The subjects of BCI technology are expanding from locked-in patients to individuals with less severe neurological disorders. Even healthy people need to use BCI to improve cognitive abilities like memory, attention, communication, or to entertain themselves. To assist the growing BCI user community, a more detailed instructing system needs to be built. Considering a big amount of BCI users have disabilities on different levels, the instruction, either printed or electronic, should be simple enough for nursing assistants to understand. The after-service is also important: BCI companies should train staff to answer phone calls and emails from buyers, to solve their problems precisely.

Some neurological disorders the author didn't mention in this article, are also possible to be treated by BCI. Studies have shown that when employing mental activity to manipulate commands in BCI devices, dyslexics and non-dyslexics produce different brain activities. Thus, dyslexia can be identified at an early age, allowing youngsters to learn the fundamentals and prevent harm to their self-esteem and confidence. BCI EEG neuro-feedback training can then help the patient's spelling issue.

Another neurological condition that appears to be treatable by BCI is anxiety. Reviewers looked at the relationship between discomfort scale scores and EEG signals and found that there was a significant difference between the two levels of tension in the fear-induced frontal EEG asymmetry. Higher levels of tension in the subjects result in more EEG asymmetry. This finding has implications for the treatment of anxiety using BCI and EEG.

Unsolved issues preventing BCI's widespread application. Some neurological diseases' progression is accompanied by neurophysiological and cognitive changes, which must be taken into consideration during BCI designing. Take goal-directed thinking in ALS for instance, the hypothesis on its existence is often considered binary – either the patients hold the capacity for goal-directed thinking, or they do not. However, it is much more likely that ALS patients switch in and out of consciousness in a status that is out of the brain's control. If this hypothesis is true, the BCI treatment for ALS can be much more challenging.

Another issue is how recently BCI innovation has occurred. Because brain impulses vary, BCI devices should only be used by professionals and have limitations including weak BCI signals, slow information transfer rates, and significant mistake rates [1]. Both a person's bodily motions, such as eye blinks and muscle contractions, as well as their mental or emotional states, such as frustration, depression, weariness, diversions, intentions, and wants, have an impact on BCI signals.

4. Conclusion

This paper mainly focused on the applications and development of BCI technologies for various neurological disorders. EEG-based BCI is used to develop feedback games to enhance the visual attention and visual discrimination of ADHD patients. For ALS patients, researchers developed neurotrophic electrode-based neural cursors and various BCI spellers to help those with locked-in syndrome to communicate with others. Seizure prediction BCI has advanced significantly as a result of big data, cloud computing, and deep learning, moving from local processing and storage systems to cloud-based BCI systems and even integrating with the Internet of Things. MI-BCI provided a novel choice for upper-limb stroke patients, it can provide visual feedback for users, but still has the drawback of presenting mental fatigue.

BCI is a promising technology for dealing with neurological diseases, however, both technological and ethical challenges exist in the popularization of BCI. Speed and accuracy are the main concerns of technological challenges. The ethical challenges include privity issues, consent of locked-in patients, individual agency, and other social problems like inequity. These issues need to be discussed in detail before the large-scale promotion of BCI technologies.

Finally, the author predicts that BCI technology will soon be widely used to treat neurological illnesses. A sizable portion of the global population is impacted by the treatment of neurological illnesses. By assisting in easing the severity of the disorders, the ground-breaking BCI technologies will have a substantial impact on a large number of neurological patients and their families.

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