ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 8, Special Issue 1, August 2021

Rehabilitation of Post-Stroke Patients Using Virtual Reality and Brain-Computer Interface

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Abstract

Upper Limb Rehabilitation of Post-stroke Patients can be made possible with the help of the Brain-Computer Interface (BCI) framework which combines the BCI and Virtual Reality (VR) technologies. The idea behind this framework is that Virtual Reality feedback is shown to the patients to experience a great activation of the brain regions thus can be helpful in the repair of brain cells involved with the performing of upper limb motor tasks. The brain activity is recorded using an electroencephalograph (EEG). This framework also uses an Adaptive Neuro-Fuzzy Inference System classifier also called ANFIS classifier to differentiate between a motor task and rest condition of the upper limb of the patient. During the First step, a classification is made between the motor task and rest condition. During the second step, a classification is made between flexion and the rest conditions. To support the working of this system around eight healthy subjects were participated in the sessions. Experimental procedures were conducted and the best result of these experiments was shown to be around 99.3% and 88.9%. This method can be directly implemented in the treatments of patients having partial palsy or total palsy due to stroke and also can be implemented in those patients having any neurological diseases or brain injury.

Key Words: Brain-Computer Interface (BCI), Virtual Reality (VR), Adaptive Neuro-Fuzzy Inference System Classifier (ANFIS), Electroencephalograph (EEG)

1. Introduction

Stroke is a chronic disease that is caused when the blood supply to the brain is interrupted, this prevents the brain tissue from getting oxygen and nutrients. This may cause partial or total palsy of the patient. There are around 15 million people was suffering due to stroke per year and around 6 million people were dying because of that. For motor recovery of the patients, physical therapy is needed so that they can recover

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the movement of their paralyzed body parts. This kind of rehabilitation technique would take a long time because of the lack of interest from the patient's side and the conflicts between human and technological resources. Here introduces the usage of Brain-Computer Interfaces (BCI) to perform motor imagery training. This helps in the arm and hand motor rehabilitation for post-stroke patients.

Brain-Computer Interfaces can be effectively used in many application areas such as motor rehabilitation, mental state monitoring, motor substitution, and entertainment. When it comes to motor rehabilitation of the patient's Brain-Computer Interfaces stimulate the neuroplasticity phenomena in post-stroke patients. So, this must detect the neural damage of depth of the patient to design.

Depending upon the chosen limb for motor recovery of the patients, an appropriate BCI protocol can be chosen. BCI is used as a training tool to recover the hand motor functions in post-stroke patients. The initial studies test whether applying Brain-Computer Interface on the stroke patients can be found suited features in signals from the unaffected hemisphere. This signal processing identifies brain activity patterns while performing the task. A study is conducted which involves a large number of patients developing the Brain-Computer Interface training based on kinesthetic motor imagery (MI) along with robotic therapy. This has observed improvements in motor function compared to baseline.

2. Concepts Used

The main technologies behind the rehabilitation system were Brain-Computer Interface (BCI) along with Virtual Reality (VR). Also uses an Adaptive Neuro-Fuzzy Inference System (ANFIS) classifier to distinguish between the motor task and rest conditions.

2.1 Brain-Computer Interface (BMI)

Brain-Computer Interface is a direct communication pathway in between a wired brain and an external device usually a computer or robotic arm. Presently two types of BCI applications post-stroke rehabilitation have been investigated. These strategies were mainly focusing on neuroplasticity and its modulation. The first approach uses Brain-Computer Interface for training patients which helps to recreate regular brain responses associated with motor activity. This is based on the hypothesis of more brain responses produced by the regular brain function usually improve motor control. Experiments were conducted in animals and humans showed changes in brain activity. The second approach uses BCI to operate devices, these devices are used to assist movements. Hence with the help of these devices brain activity of patients can be improved as well as measured.

2.2 Virtual Reality (VR)

Virtual Reality (VR) means the utilization of computer technology to make a simulated environment. Virtual Reality places the participants inside an experience. Users were able to involve and also interact with the 3D worlds using virtual reality. By simulating as many senses as possible, the computer is transformed into an entry to the artificial world. VR in BCI provides feedback to interact in real-time.

2.3 Adaptive Neuro-Fuzzy Inference System Classifier (ANFIS)

An Adaptive Neuro-Fuzzy Inference System Classifier is a kind of artificial neural network. This technology was developed within the early 1990s. This technology combines the neural network and fuzzy logic principles and can show them in a single framework. Its inference system is corresponding to a set of fuzzy if-then rules. The ANFIS classifier was considered to be a universal estimator.

3. Working

During the study participants were involved in magnetoencephalography (MEG) experiments, they were asked to control their sensorimotor rhythms (SMR) during the motor imagery tasks of the stroke-affected hand to perform a mechanical orthosis that causes flexion or extension of their hands. The magnetoencephalography analysis selects those features which distinguish the MI tasks from the rest condition independently of their location in the brain.

In MI-based BCI, feedback plays an important role in the training of patients. This is made possible by using observations of signals in the screen, movements of the mechanisms, using robots, or 3D graphs in Virtual Reality (VR).

Mirror therapy (MT) is the reflection of the movement of the limb which is unaffected and is superimposed on the paralyzed limb. Applying VR to stimulate Mirror Therapy increases the brain activity of patients in the sensorimotor cortex in response to the simulated movement.

The Machine learning algorithms can simultaneously lean and model the uncertainty on brain signals are an important component for reliable BCI control. The type-2 fuzzy sets are associated with ANFIS classifier for a BCI application where the classification is carried out by a combination of binary classifiers using type-2 fuzzy sets to calculate the output. The ANFIS time-series predictor and multiresolution fractal vectors were used to extract the features in motor imagery classification.

MI-based Brain-Computer Interface and Virtual Reality feedback are used as the major technologies in this work, which increases the activation of the brain region to contribute to the upper limb rehabilitation of post-stroke patients, Brain activity is recorded using electroencephalograph (EEG) electrodes. At last, the ANFIS classifier is used to evaluate the performance of the VR-BCI system.

4. Experimental Procedure

The experimental procedure is conducted on eight healthy subjects. The average age of the participants was about 25 years. The participants were read and signed an ethical consent about the experiment and were informed about the test.

Electroencephalograph (EEG) data were recorded using a 16-channel amplifier and 16 active electrodes. These electrodes were uniformly distributed around the motor cortex over the scalp of the participants. The data was bandpass filtered from 0.1 to 30 Hz notch filter was applied and the sampling frequency used was 256Hz.

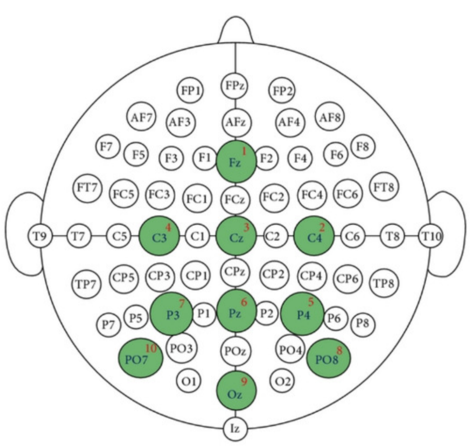

Figure 1: EEG Electrodes positions over the motor cortex

Visual feedback to the users is provided with the help of a virtual arm also called an avatar. The virtual arm is build using three software's such as Make human, Blender, and Unity. Make human is used to obtaining the shape and characteristics of a human arm. Blender is used to perform the animation. Finally, Unity is used to obtain the final interactive application and for communication. The virtual arm performs three positions called flexion, extension, and rest. A User Datagram Protocol (UDP) is used to accomplish a connection between the Simulink and Unity.

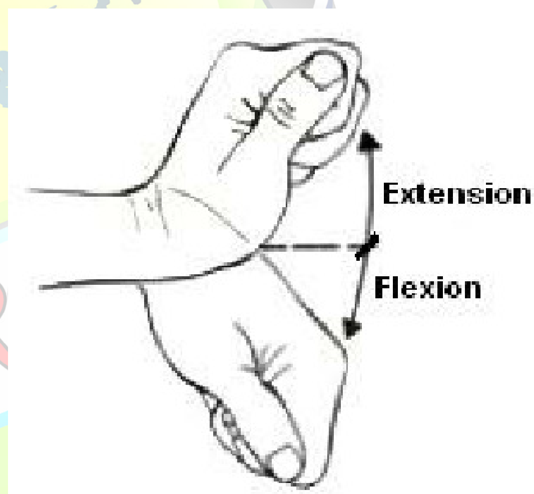

Figure 2: Flexion and Extension

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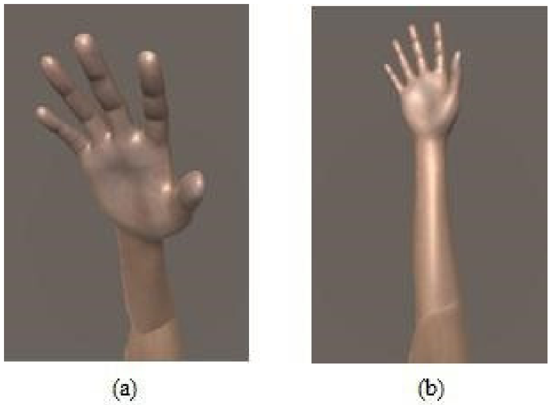

Figure 3: Virtual arm showing positions(a) Flexion (b) Extension.

During the training stage, the participants were seated in a chair in front of the computer screen with both arms were resting on their lap. Participants were asked to stay relaxed and limit their eye movements during the experiment. Initially, a black screen was shown for 2 seconds. Immediately after that, a cross is displayed for 1 second, which indicates that the motor imagery task was about to begin. From 3 to 9 seconds, an image was presented on the screen. The image shows an arm with an arrow pointing inside or outside indicates flexion or extension. Each of the runs is consists of 20 trials and a total of 5 runs were recorded, that is 100 trials in total. After each run is conducted, a 30 seconds break is provided.

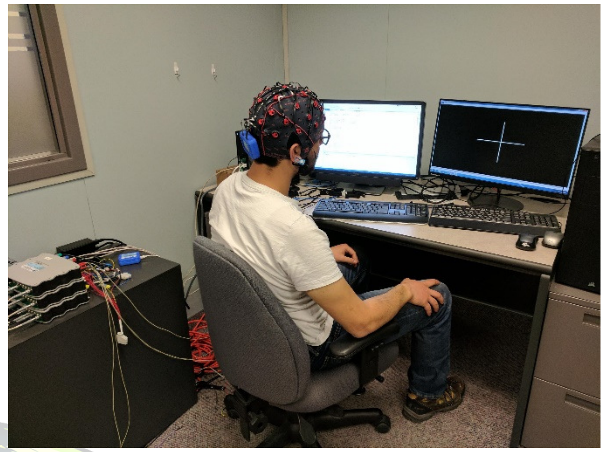

Figure 4: The participant in the study

An online test is used to evaluate the efficiency and accuracy of the algorithm. The participant is asked to seat in the chair in front of the computer screen. The user is provided with visual feedback from the system. Initially, a blank screen was displayed for 2 seconds. After that, a message was shown to the participant which indicates the movement the participant needs to imagine, usually either flexion or extension. After 3 seconds the message is disappeared. From the 5^{th} to 13^{th} seconds, the user had to imagine the movement which is presented by the message. During this time, the algorithm computes the EEG data recorded. At the time 13^{th} second, the virtual arm performs the movement thought by the participant based on the output of the classifier. If the classification was successful, the virtual arm performs the required movement, otherwise, it didn't move and stays in the same position. Finally, the trial is started again and again.

5. Conclusions

The rehabilitation of post-stroke patients using the VR-BCI framework is proposed in this system. This combines the Brain-Computer Interface and Virtual Reality technologies to increase the activation of certain brain regions which involves the movement of the upper limb. The system is being tested against healthy subjects, which results in accuracy greater than 77%, and the best case out of it is about 99.3% during the training stage, and 89% in the online tests. Based on these results it is visible that the system can be directly applied in the treatments of patients having post-stroke difficulties or brain injury.

This study depicts that the adaptive and fuzzy capabilities which are provided by algorithms like ANFIS can be effective to distinguish between the motor imagery tasks and rest conditions in the Virtual Reality – Brain-Computer Interface environment. Spatial ability tests and anxiety tests will be taken in the participants to evaluate their susceptibility to different types of VR-BCI in the future. Also, we can extend this work to other sophisticated Neuro-fuzzy algorithms as well as different motor imagery tasks using immersive Virtual Reality.

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