Proceedings of International Conference on Information Technology and Computer Science
July 11-12, 2015, ISBN:9788193137307

BRAIN PAINTER: A NOVEL P300-BASED BRAIN COMPUTER INTERFACE APPLICATION FOR LOCKED-IN-SYNDROME VICTIMS

Vejey Subash Gandyer
Assistant Professor, Dept of CSE, KCG College of Technology, Chennai, India

Krishnamurthy M
Professor, Dept of CSE, KCG College of Technology, Chennai, India

Sanjeev Venkatesan
Student, Dept of CSE, KCG College of Technology, Chennai, India

ABSTRACT

It is impossible for Spinal Injury patients and Locked-In-Syndrome(LIS) victims to communicate with the outside world as all their motor and oratory skills are demolished except the movement of eyelids. Inorder to communicate with the outside world, a P300-based Brain Computer Interface Application is developed. This BCI, short for Brain Computer Interface, allows the user to draw images on the computer screen by mapping the neural signals obtained from their brain. Depending upon the thoughts of the person, various geometric shapes can be rendered on the computer screen and complicated visuals can be created by overlaying multiple geometric shapes upon each other thus resulting in a Painting drawn without using hands and just the thoughts of a person. Experiments were done using this BCI interface on Normal people and LIS people and results were tabulated. It is found that LIS victims are able to use the interface effectively to communicate with the world.

KEYWORDS *— Brain Painting, Brain Computer Interface, BCI, P300, ALS, LIS*

I. INTRODUCTION

Brain-Computer Interface (BCI) is collaboration between a brain and a device that enables signals from brain to command some external activities. The interface enables a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. Neural signals emitted from the brain can be recorded using invasive or non-invasive methods. Invasive method involves implanting electrodes directly into the gray matter of the brain by neurosurgery. It is indeed a painful and long procedure to undergo such an invasive method of acquiring brain signals and it is in any case the last resort. As these electrodes lie in the gray matter, invasive method produces highest quality of signals as it is closer to the source of signals (neurons). Non-invasive method involves placing the electrodes on the surface of scalp and measure electroencephalogram (EEG) signals. It is evident that the quality of signals acquired by a Non-invasive device is less accurate because of the fact that these signals had to penetrate the hard skull and reach the sensors placed in the scalp.

In this paper, a P300-based BCI is developed to draw images on the computer screen by mapping the neural signals obtained from the brain to geometric shapes in a canvas on the screen. Depending upon the thoughts of the person, various geometric shapes can be rendered on the computer screen and complicated visuals can be created by overlaying multiple geometric shapes upon each other. A user (either a normal person or a LIS victim) can think of a simple thing to draw in their mind. Then they have to layerize the whole picture that they thought of into layers in their mind. For example, if a user wants to draw a scenery of a sun rising behind a river and mountain, he has to layer the elements in it as Sun, Mountain, River, Boat, Fisherman. He has to order the objects in terms of the distance. First he needs to draw the object that is the farthest and work towards the closest object in the scene. This technique should be practised by the user before he attempts anything to draw on the screen. Although it takes a little practice to master, it is worth mastering this technique as it will result in a better painting as the output. The interface provided to the user for drawing the picture is shown in Fig. 5. It involves icons of various geometric shapes, sizes, eraser, colors and so on. These icons are arranged in a grid format(icons fixed in row and column fashion). And an internal algorithm will make these icons brighter and lighter in an already programmed fashion. The user is made to look at the icon for a moment(to draw sun, he has to look at the circle shape icon). The P300 interface allows the icons to blink as said already. At the instant when this circle shape icon becomes brighter, the neurons will get excited as it has seen the desired icon and it will give a big spike in the captured EEG signal. This EEG spike signal is the one that the algorithm will look for. Once this big spike event happens, the algorithm goes back 300ms (milliseconds) in the already programmed icon flasher program and finds out what icon was made brighter before 300ms. The 300ms is because of the fact that is the average time taken for a human brain to react after it is presented it with a visual stimuli of a picture or in this case a circle shape icon. It takes 300ms on average to react so that a big spike appears in the EEG signal. After a spike is detected in the signal, it is backtracked 300ms and finds the icon that was flashing 300ms before to find out what icon was the user interested in to draw on the screen. Hence the reasoning behind the "300" in P300 theory of Brain Computer Interface application development.

The rest of the paper is organized into five sections starting with previous research work that has happened over a span of time by Brain Scientists around the world. Followed by a section on the hardware that is used for the experiments. A section on System Architecture talks about the detailed architecture of the Brain Painting BCI system. The next section on Experiments & Results brings out the various experimental results that are done on both normal and LIS patients. Conclusion and Future Work is given in last section. Acknowledgement is at the end for supporting this project. The references that made this paper possible comes last.

Fig. 1 Neurosky Mindwave Mobile EEG Headset

II. PREVIOUS WORK

Brain-Computer Interface is science for connecting the brain & the computer has been primarily developed to help in the field of neuroprosthetics. Earlier days of BCI involved in using Invasive BCIs and later on Non-Invasive BCIs were developed. Invasive BCIs include an array of tiny electrodes directly placed on the neural region. Non-Invasive BCIs include EEG headsets, fMRI[5]. In addition, partial BCIs like ECoG do exists. P300 (P3) is a technique used for decision making by harvesting the Event Related Potential (ERP) from the brain signals[4][7]. There are two types of P3a & P3b. P3a is recorded on the scalp with latency around 250-280 ms, whereas P3b is recorded near the ear-references with a latency around 300 ms, although it varies from 250-500 ms. P300 has been used in various fields to control an environment using decision at intermittent points, one such is Brain Painting. Brain Painting is the art of producing paintings without any muscular movement. Brain painting was co-developed by Andrea Kübler [4] from the University of Würzburg (Germany) and Adi Hoesle. They used P300 for decision making at various stages of painting.

III. HARDWARE REQUIREMENTS

NeuroSky MindWave Headset

NeuroSky MindWave Headset as shown in Fig 1 is a low cost EEG device with a biosensor to collect EEG signals from the surface of scalp and send them to a paired computer or any other mobile device over bluetooth technology.

Emotiv EPOC Headset

Emotiv EPOC Headset is a little steep in terms of costing as shown in Fig 2. It is also an EEG device with 14 biosensors that collects EEG signals from the surface of scalp and sends them to a paired device. It is a high resolution, multi-channel, portable system that is designed for practical research applications.

Fig. 2 Emotiv Epoc EEG Headset

IV. SYSTEM ARCHITECTURE

The system architecture includes various modules like Mindwave Communicator, EEG to Browser interface, Signal Filter, Signal Analyzer, Brain Painter P300 interface. The EEG to Browser interface depends on NeuroSky MindWave Communicator and EEG - Browser Interface as shown in Fig 4. The raw data(EEG signals) from the device is received in JSON format and used as per the need. The EEG Signals are acquired, analyzed by the proprietary classification algorithms (both Neurosky and Emotiv) to classify the user's thoughts and render the objects in the painting canvas accordingly. Additionally, an Action-Signal Model Library is created as shown in Fig 3. This ASML, for short, contains all the actions that a user is thinking and the corresponding signal generated in the EEG device for that particular thought. Brainicons, termed by us for Icons used in this application using P300 theory, are used for feature selection, Signal filtering, extracting features from the EEG signals.

The flow diagram as shown in Fig 4 explains how the user is involved in a BCI setup and how he interacts with the Brain Painter application. The user mounts the given EEG headset (either a Neurosky or an Emotiv) and sends a cue to the system and then the system activates the browser interface. Now the browser interface listens for Raw EEG signals that maps to various predefined brain states that in turn corresponds to objects like circle, rectangle, square and various colors.

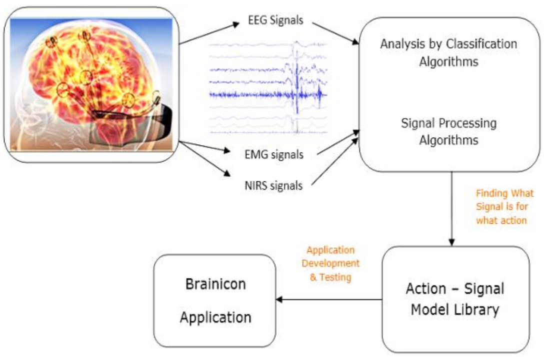


Fig. 3 System Architecture of Brain Painter

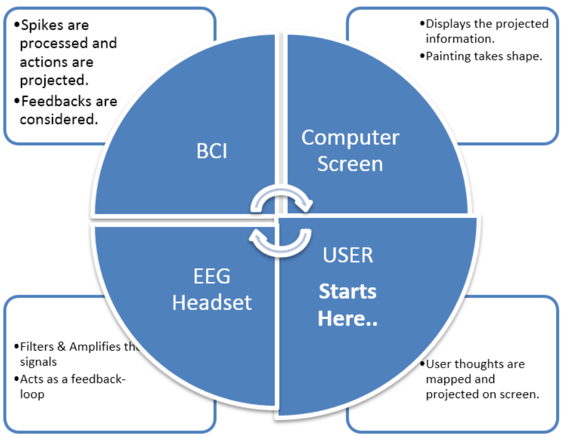


Fig. 4 Flow Diagram of P300 in Brain Painter

Whenever the brain state of the subject matches the predefined brain state and if the user had selected that object using P300 panel, then the corresponding object is displayed in the browser interface canvas. In addition, the system continuously filters the raw EEG output that is sampled accordingly. The feedback loop improves the recognition of the specific subject's brain state using a Neural Network.

A. *Mindwave Communicator*

This module as shown in Fig 5 implements the bridge between the Mindwave device and the EEG-Browser Interface. It establishes connection with Mindwave device over the ThinkGear Connector socket protocol. Once the connection is established, it transfers the EEG data to the EEG-Browser Interface module. As per the ThinkGear socket protocol, this module sends an authorization request to the MindWave Device with an app key and app name. The MindWave device then returns a registration acknowledgement message. Mindwave communicator then sends a configuration message to the MindWave device and tells the device to send the data in JSON format. Once done, JSON data starts flowing to the EEG-Browser interface, which are then parsed and made usable.

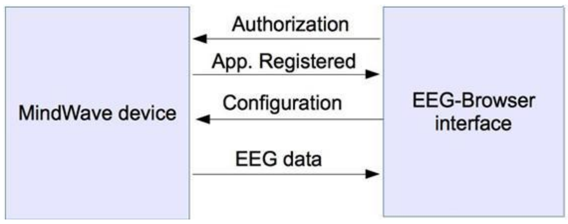


Fig. 5 Mindwave Communicator

EEG to Browser Interface

This module performs the translation of EEG data to distinguishable commands by analyzing the EEG data patterns. This module is implemented inside a server with a port at the other end of Mindwave communicator

Sample EEG data:

"eegPower":{"delta":8600,"theta":6480,"lowAlpha":6903,"highAlpha":8865,"lowBeta":4306,"highBeta":4413,"lowGamma":1588,"highGamma":2340}

Here, the meditation value in the above data is very high. Delta wave ranges from 0.1 to 3 Hz. Theta wave ranges from 4 to 7 Hz. Alpha wave ranges from 8 to 15 Hz. This module creates a message "scroll down" and send it to the web socket client. The user interface looks like the one shown as in Fig 7, it has different cells or icons that blinks at a particular moment of time.

The P300 principle, discussed above in the Introduction section, used to select a particular icon by the user. When the user thinks of an icon that he is interested in, and when that icon is made brighter by the Icon Flasher program, a spike is generated after 300ms and that is captured by the EEG headset. Then the algorithm backtracks in time to -300ms and finds the icon that was blinking that time. Once this is found, the icon that is selected by the user will be drawn on the canvas. The icon that the user is interested can be any geometric shape icons like circle, square, rectangle or it can be any color icon or it can be an eraser tool to erase the previous drawn shape or color.

Visualization Tool

This module is built by setting up a simple server to serve HTTP requests between data & the HTML page. It basically has all the data set values and the data set is collected and stored as neuro.json. In fig 3.5, these are RAW EEG values representing the state of the mind at those instances. In the html file, the neuro.json should be loaded and scatter plot should be generated in accordance to the values in the dataset. The margins must be automatically adjusted to fit in all the values.

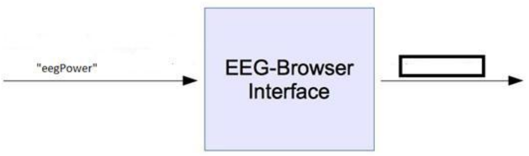


Fig. 6 System Architecture of Brain Painter

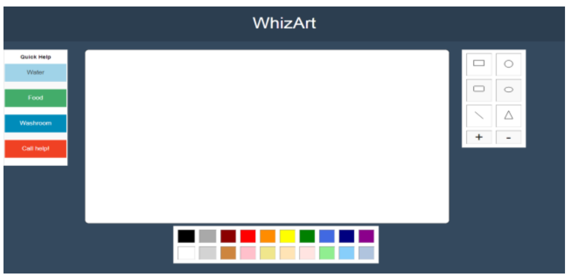


Fig. 7 Brain Painter Interface

Visualization Tool

A visualization tool is built by setting up a simple server to serve HTTP requests between data & the HTML page.

python –m SimpleHTTPServer 8000

It basically has all the dataset values as the data set is collected and stored as neuro.json, these are RAW EEG values representing the state of the mind at those instances. In the html file, the neuro.json is loaded and scatter plot is generated in accordance to the values in the dataset. The margins are automatically adjusted to fit in all the values. Thus this step is useful in visualizing data and finding a spike pattern that is happening because of the user seeing his desired icon blinking after 300ms.

V. **EXPERIMENTS & RESULTS**

The experiments are carried out with the following specifications and the results are tabulated and analyzed in this section. The EEG headsets used for these experiments are Neurosky Mindwave Mobile and Emotiv Epoc Headsets. The users of this BCI application are both Normal persons and LIS victims.

For conducting this experiment, the Brain Painter BCI application is presented to the user as in Fig 7 after a computer chosen picture is shown to the user. The pictures are chosen at random and presented to the user just before he is shown the Brain Painter canvas to draw.


```
{ eSense: { attention: 0, meditation: 0 },
  eegPower:
   { delta: 247592,
     theta: 273215,
     lowAlpha: 39974,
     highAlpha: 10668,
     lowBeta: 20901,
     highBeta: 235447,
     lowGamma: 4456,
     highGamma: 1914 },
  poorSignalLevel: 29 }
```


Fig. 8 Raw EEG data in JSON format from EEG device

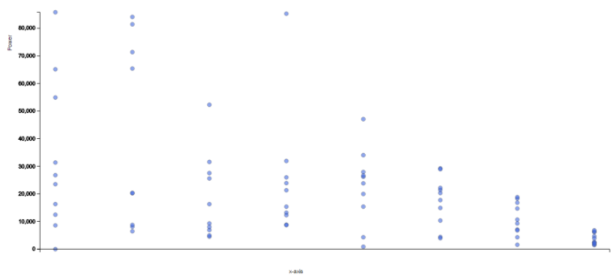


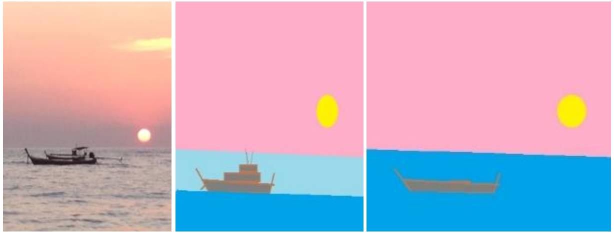
Fig. 9 Visualization Tool used for finding spikes

Once the user is presented with a random picture, he is asked to draw the picture using this Brain Painter application using both EEG headsets. The user is asked to draw the shown picture as close as possible to the real shown picture. The idea is to evaluate how this Brain Painter application is effective in terms of re-creating the shown picture to the user. The comparison between the chosen picture and the drawn picture using both Neurosky and Emotiv among Normal vs LIS patients is shown in Fig 10.

In Figure 10, the first column is the Ground truth (shown picture to the user), the second column shows the output drawn by normal people and the last column is the Brain Painter Output (drawn by the user) using Neurosky EEG headset by a LIS patient.

Graphs for showing accuracy between normal and LIS victims with both Emotiv and Neurosky headsets are shown in Fig 11. These graphs show how much LIS victims are deviating from the actual picture that they wanted to draw on the Brain Painter canvas given to them during experiments.

Ground Truth	Normal Patients	LIS Patients



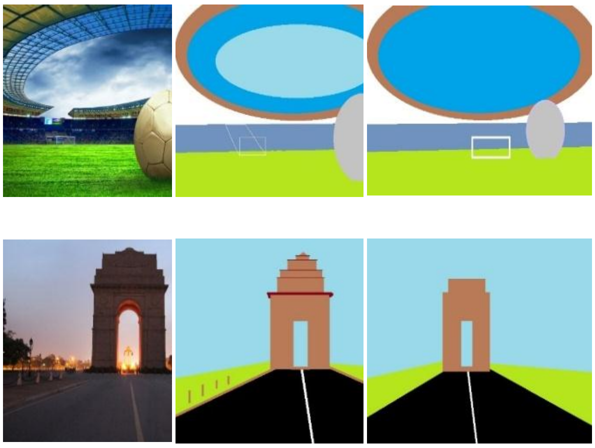


Fig. 10 Brain Painter Output
First Column – Images shown to draw
Second Column – Brain Painter Output drawn by Normal people
Third Column – Brain Painter Output drawn by LIS patients

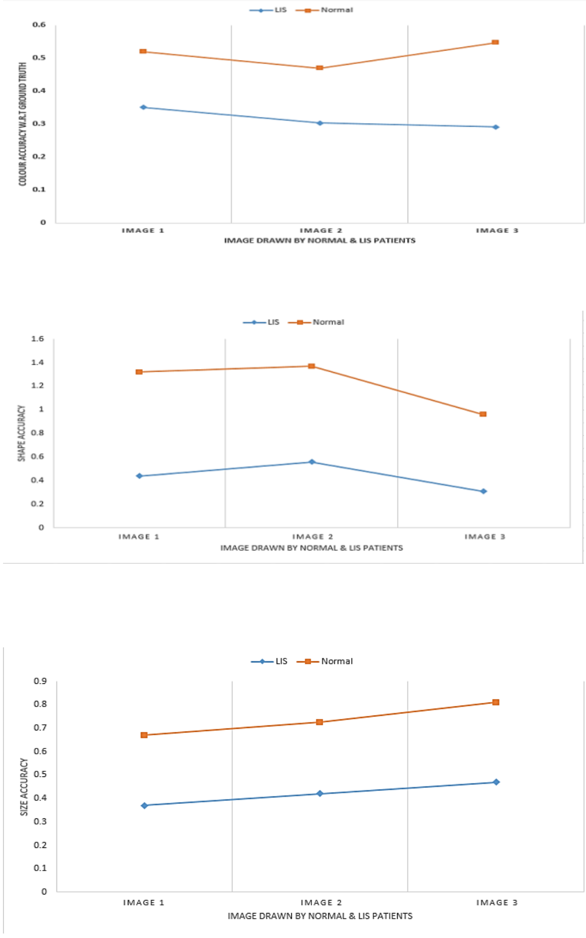


Fig. 11 Accuracy Graphs of LIS vs Normal people across images

1. Color Accuracy 2. Shape Accuracy 3. Size Accuracy

VI. CONCLUSION & FUTURE WORK

A Brain Computer Interface application in the name of Brain Painter is thus created and tested with a sample population of Normal people and LIS victims. From the experiments done and from the tabulated results, it is evident that LIS victims can communicate with the outside world only with just their thoughts. And they can communicate with some effectiveness shown through accuracy graphs. It is also found that Emotiv headsets are better in terms of accuracy than Neurosky headsets. A BCI system that paint pictures with improvement in terms of accuracy and ease of use for end-users are to be taken care of in the future.

ACKNOWLEDGMENT

The authors thank the "Tamil Nadu State Council of Science & Technology" (TNSCST), India for providing the necessary funds to carry out this project.

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