Controlling Computer Operations using Brain-Wave Computing

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Abstract:
People interact with computer using devices that have been created to serve a specific purpose. For generations, humans are fascinated about the idea of communicating with machines through devices that can peer into person's mind. Such idea motivated to the recent advancements in the field of artificial intelligence and cognitive neuroscience to provide the ability to interact with machine through brain. The proposed work is an Electroencephalography (EEG) based biomedical signal processing system to perform computer operations by manipulating the brain activity. The users have to explicitly manipulate the brain activity to produce signals that can be used to operate the computer. The brain waves are obtained with the help of scalp electrodes. EEG signals collected are then processed to interpret the command and execute the desired task. The real time implementation requires training the computer according to one's thoughts and actions through neural networks.

Keywords: *Artificial Intelligence, Cognitive Neuroscience, Electroencephalography, Biomedical signal processing, Scalp electrodes, Neural Networks.*

I. INTRODUCTION

Human-Computer Interface (HCI) allow human to work in conjunction with machine. Some of the HCI devices like EON mirror and Kinect work on the basis of gesture recognition and the most popularly used touch screen devices require tactile input. In the proposed work, brain thoughts are monitored to handle a machine making it narrower and specific to Brain-Computer Interface (BCI) from the broader Human-Computer Interaction (HCI). The researchers in BCI recognize the need for system, that makes BCI more user-friendly, real-time, manageable and more suitable for all people, expanding its region of use with clinical patients and those who are physically challenged.

The Electroencephalography (EEG) signals are generated in the brain through the voltage difference of ions moving through the neurons. EEG signals are nothing but the brain activity in the form of electro-voltaic waves. Originally, the signals were used for monitoring the brain activity of the patients. Later on, it advanced to place its footprints in BCI.

Several systems use EEG signals to identify the person, provides an aid to disabled people and there are a quantity of systems which beat the idea of the previous two, allowing gamers to use it beneficially to bag high scores according to their focusing level. Very little work has been done in this area, focusing more on medical purposes, not on overall computer operation. People wonder why to constrict the use of BCI only to particular purpose and why not for all the operations that can be done with a computer. The proposal is to insist on the use of brain thoughts as input to the Computer to operate it in a more efficient and easier manner.

The proposed system provides an alternative to other input devices, because the brain thoughts of the user are taken as input to the computer. The inputs are in form of EEG signals which are processed and then introduced to artificial neural network (ANN). ANN is a machine learning approach which replicates human brain and contains a number of artificial neurons. It increases the privacy and security of the user thus making the system more responsible to the authenticated person and resistive to the impostor.

II. EXISTING SYSTEMS

EEG signals are recommended to use by the BCI researchers to lift the ease of operating a system in various regards. Kusuma Mohanachandra and the group have used EEG signals in Brain Computer Interface as a new modality for Person Authentication and develop a screen lock application [1] that will lock and unlock the computer screen at the users will. The brain waves of the person, recorded in real time are used as password to unlock the screen. Use of EEG signals in BCI makes it more secure as nobody knows what the user is thinking of. It provides more privacy that convinces you to use it for authentication. Even though there are already graphical and click - based passwords, use of EEG in authenticating a person is a step ahead in providing security. S´ebastien Marcel created a statistical framework that has also been created based on Gaussian Mixture Models and Maximum A Posteriori model adaptation [2], successfully applied to speaker and face authentication. Using EEG signals eliminates the possibilities of occurrence of shoulder surfing and other password cracking attacks. It allows the user to be trained to work with the authentication system and then be tested for the identity. The system they implemented also improves incremental learning. But the problem is hours of training are needed for both authentications.

Katherine developed a system to identify people using EEG signals generated during their imagined speech [3]. With the help of the model, subjects are identifiable to 99.76% accuracy. But, there are chances that people can't imagine their speech with the same characteristics every time. Cheng He suggested an idea of user authentication with more accuracy and robustness [4] using EEG signals. He addressed two major problems associated with EEG biometrics. One is that the large EEG features size and the relatively limited EEG data size, make it difficult to train a robust model; the other is that the signals from EEG scalp may not be reliable in many situations.

As an attempt to make physically challenged people more independent, Jonathan and his crew used EEG signals to aid them to control their movement. A restoring function is provided to those with motor impairments providing the brain with a new, non-muscular communication and control channel [5], a direct brain–computer interface (BCI) for conveying messages and commands to the external world. Joseph developed a mobile imaging approach [6] that provides a tight coupling between human physical structure with cognitive processing and the role of supraspinal activity during control of human stance and locomotion.

Apart from the above works, researcher I-Jan Wang developed a wearable, wireless EEG- based headset [7] to win the shot in gaming, monitoring the focusing level of the user using the EEG signals. Chin-Teng Lin eliminated the use of conduction gel required by the use of foam based dry electrodes [8] instead of ordinary wet- scalp sensors that is used normally, to reduce the skin-electrode contact impedance. Qiang Wang has proposed Neuro-feedback games [9] and design algorithms to implement the 2D and 3D concentration games. Neuro-feedback games are assessed by the healing effect of ADHD (Attention Deficit Hyperactivity Disorder) with significant EEG distortion.

From a thorough investigation on BCI researches, the following limitations are spotted out in the current BCI systems. The BCI systems which are in use today are developed in such a way that they can serve only a specific purpose. Because of the fact that only an intended purpose can be served with the help of existing system, the role of devices that are used for interacting with computer cannot be avoided completely. EEG headset is needed in addition to already connected traditional interacting devices. The user may find it difficult to deal with multiple interacting devices simultaneously. There are possibilities that the user may get bored by performing the same kind of action all the time.

III. PROPOSED SYSTEM

The system proposed will create a new generation in BCI which eliminates the need for any assisting devices to operate a computer. Using this system, computer can be operated with the help of our thoughts. All the system needs as input is the user's brain waves which are the results of some brain activity i.e. thoughts. The brain waves of the user are collected in the form of Electroencephalography (EEG) signals that can be processed further in MATLAB. The EEG signal of the user is used as input to computer; it lifts the privacy of the user to a superior level.

The pattern of collected signal is to be analyzed and the features are to be extracted. Before feature extraction, the collected signal must be amplified so that it would be easier to extract features without any error or loss of information. After the signal strength is boosted up, the artifacts in the signal must be detected and removed.

The refined EEG signal is then processed to extract features which help to identify the command of the user. For the identification of the command, one must classify the signal to its corresponding output. The most important step is to create a model of the neural system of the user's brain. The neural network must undergo training in order to understand the user's thoughts and other brain activities. With the help of back propagation algorithm [11] the training of neural networks is done. Once the command is interpreted from the signal, the logic corresponding to implement the command is executed to perform the intended task. The real- time implementation is entirely based on how the training is done and how quick the system can identify the command that is needed to be executed.

1.1. Advantages of Proposed System

Many physically challenged people have a necessity to use computers every day. It is obvious that these people will face difficulty in interacting with the computer. The system proposed helps the physically challenged people to work with computer in a much easier way. The system has been designed to reduce the fatigue of normal computer users while having to deal with various external devices attached to the computer, in order to operate it. The idea used in the proposed system enhances the resistivity of the system to inexperienced users and reduces the operational difficulty faced by the computer users. Hereby, with the use of proposed system, we can provide an alternative approach to handle a computer in the absence of traditional devices like mouse, keyboard.

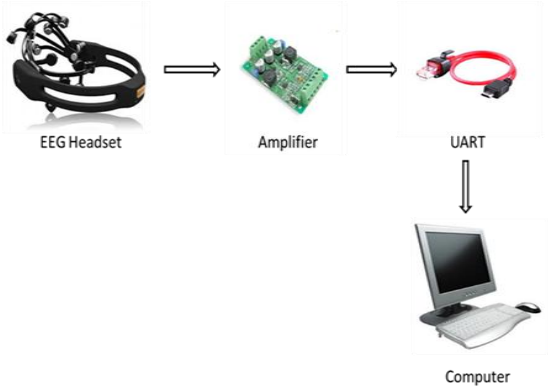

Figure 1. General Architecture

IV. SYSTEM IMPLEMENTATION

The proposed system consists of four different parts that are needed to be implemented. Figure 2 shows what are process are needed to be implemented for our system to work.

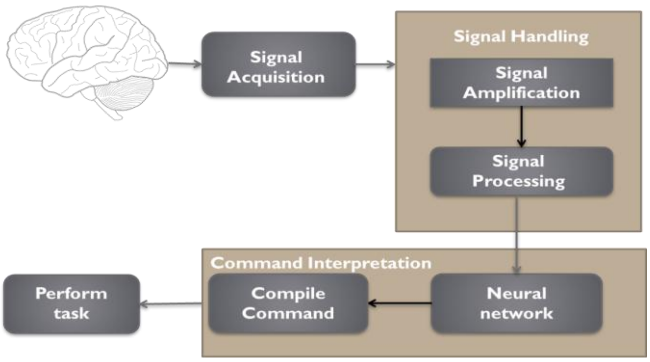

Figure 2. System Architecture

1.2. Signal Acquisition

Signal acquisition involves collecting the electroencephalography signals generated in the human brain. EEG signals are generated due to the electrical activity on the brain scalp. Under the human scalp, there is a flow of ions through the neuron network that occurs due to user's thoughts and actions. The voltage fluctuations due to the ionic current in the neural network of human brain are recorded as EEG signal. EEG signals can be recorded in two ways: one is through surgical procedure and other is done by scalp electrodes. The most preferred is the second method in which an EEG headset is used to gather brain waves of the user. EEG signals are nothing but voltage fluctuations that occur due to brain activity.

The user has to place the headset on the scalps in order to record the EEG signals. EEG headsets are designed by integrating 16 highly sensitive sensors in such a way that it senses the voltage fluctuations in the human scalp. The electrodes in the headset are to be placed in the standard positions [10] as prescribed by International 10-20 system. International 10-20 system is the internationally accepted idea of location specification of the electrodes to obtain the EEG signals generated in the human brain. The "10" and "20" refer to the fact that the actual distance between the electrodes placed on the scalp are 10% or 20% of the total front-back or left-right distance of the skull. Before placing the sensors on the scalp, it is advised to apply conductive gel in order to reduce the electrode-scalp impedance.

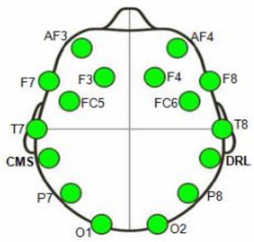

Figure 3. Standard location of sensors as per International 10-20 system

EEG signals have Gamma, Alpha, Beta, Theta and Delta wave patterns. Alpha waves are generated when the user is in a state of physical and mental relaxation and completely aware of what is happening around. Beta waves are emitted when the person feels agitated, stressed or afraid whereas theta waves get emitted during reduced consciousness of the subject. And delta waves are generated during deep sleep or unconsciousness. Alpha waves are used to implement the proposed system. During the recording of the signals, sometimes the amplitude of the signal reaches an observable length. The observable peak is called as Event Related Potential (ERP). The ERP defines that an event has occurred in brain or a thought has been generated in the brain. The most used is the P300, where the EEG signal peak reaches after 300 milliseconds after the event has occurred.

1.3. Signal Handling

The signal acquired from brain is very weak (about 30 – 100 µV). Hence it is necessary to amplify this signal before processing. Signals from the EEG headset are amplified using EEG amplifier kit. Amplifying is just boosting up the strength of the signal. Amplifiers are used to amplify the signals i.e. to improve the strength of the signal and can reduce the noise present in the signal. EEG 100C amplifier is an Electroencephalogram amplifier that amplifies bio-electric potentials associated with neural activity of the brain. The output delivered by the amplifier can be switched between normal EEG output and Alpha wave detection. The amplifier used to amplify EEG signals is voltage amplifier since these signals are the measured in voltage potentials. Voltage amplifiers are commonly available type of amplifier which amplifies input voltage to a larger output voltage. The input impedance of amplifier is high whereas the output impedance is low. The amplified signal must be given to the computer through an UART (Universal Asynchronous Receiver/Transmitter).

The EEG data is usually mixed with huge amounts of useless data produced by physiological artifacts that masks the EEG signals. Artifacts are signals that are recorded by an EEG headset, but are not of cerebral origin i.e. those are not generated due to brain activity. In most cases, the amplitude of artifacts is more than the amplitude of EEG signals. Hence, there are chances that artifacts can suppress significant features from EEG. Artifacts may be physiological (generated from the person) or non-physiological (generated from the environment or equipment). Common artifacts may include power-line artifact, eye blinking, eye movement, respiratory artifact, electrode popping, sweat artifact or due to breakage of electrode. AAR (Automatic Artifact Removal) [12] automatically removes artifacts from EEG data based on blind source separation and other various algorithms. The AAR toolbox is implemented as an EEGLAB plug-in in MATLAB and was used to process our EEG data subset on two stages: Electrooculography (EOG) removal using the Blind Source Separation (BSS) algorithm then Electromyography (EMG) removal using the same algorithm.

After artifact detection and removal, the signal is processed by Fast Fourier Transform (FFT). FFT is used to eliminate all the unnecessary altering signals in the brain wave i.e. EEG signal. The FFT is applied to the signal and its amplitude is used for further process.

$$DFT(FFT):$$

$$X(k) = \sum_{n=0}^{N-1} x(n) \cdot e^{-j\left(\frac{2\pi}{N}\right)nk} \quad (k = 0,1,\ldots,N-1)$$

$$IDFT(IFFT):$$

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) \cdot e^{j\left(\frac{2\pi}{N}\right)nk} \quad (n = 0,1,\ldots,N-1)$$

Figure 4. FFT and its inverse

where x(n) is the input signal values and e is an exponential constant. The above method helps to retain the range of the signal, now we need to normalize it. A simple sampling theorem has been used to normalize the signal. Based on the information needed to be retained and those afforded to be lost, sampling frequency must be chosen.

$$\mathbf{f_s >= 2\ f_m}$$

where f_s – Sampling frequency and f_m- frequency of the modulating signal. It is recommended to set the sampling frequency equal to Nyquist rate. Nyquist rate is the minimum frequency at which the signal is to be sampled to avoid any loss of information.

$$\mathbf{f_s = 2\ f_m}$$

After sampling, the samples are to be quantized i.e. the samples are rounded-off to the nearest amplitude value.

1.4. Command Interpretation

Interpretation of commands in the system is done by the neural network, which is a type of signal classifier. The neural network is specified by the neuron model, architecture, and learning algorithm. The network must be trained and should be able to behave correctly on new instances of learning tasks. A neuron is a basic information processing unit. The architecture is linked with the learning algorithm used for training the system.

Multilayer perceptron is the type of neural network consists of an input layer, possibly a number of hidden layer, and one output layer. The output of each node in one layer connects to the input of the next layer, but not within the same layer.

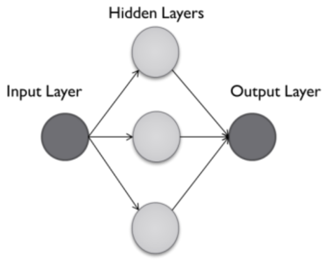

Figure 5. Neural network

Neurons are also referred to as nodes, and the lines between the nodes are called synapses. The inspiration comes from the human brain but it is a simplified version. Each neuron consists of weights, adder functions that adds all the weights and activation function which is used to limiting amplitude of the output. The boundless strength with neural networks is that they are flexible, if given the right setup.

Neural networks needs to be trained before it can be used. In case of supervised learning, training sets with sample input and the resultant output are given to the network, and then an algorithm alter the weights of the synapses so that it can map valid input to correct output. A very common algorithm for this is the back-propagation algorithm.

1.4.1. Back- propagation Algorithm

The training is done using back- propagation algorithm. The algorithm searches for the weight and this can be found with the help of error value during training set. The weight is defined as the strength of connection between two nodes. If the error value is minimum compared to the previous values, then that corresponding weight value is found. Training sets are given to the algorithm which defines what user want the network to do and changes on network's weights so that, when training is finished, it will give you the required output for a particular input. Back propagation networks are ideal for simple Pattern Recognition and Mapping Tasks.

The training begins with the network, first initialised by setting up all its weights to be small random numbers say between –1 and +1. Next, the input pattern is applied and the output calculated (this is called the forward pass). The calculation gives an output which is completely different to what user wants (Target), since all the weights are random. Then calculate the Error of each neuron, which is essentially: Target – Actual Output (i.e. What user wants – What user actually got). The error value is then used mathematically to change the weights in such a way that the error gets smaller. In other words, the Output of each neuron will get closer to its Target (this part is called the reverse pass). The process is repeated again and again until the error is minimal. The pseudo code for the algorithm is given below:

```
Initialize the weights;
while stopping criterion has reached do
for all example e training set do
        O = actual, output (network, e); //propagate forward
        T = wanted output for e
        Calculate error (T - O) at each neuron in the output layer
Compute Mean Squared Error value; //propagate backward
Compute updateweight for all weights
Update all the weights in the network such that
        Sum-squared value of error is minimized
end for
end while
```

The Mean Squared Error (MSE) value is calculated and forms the performance index. This value reflects the effectiveness of the training done so far. The stopping criterion could either be when the MSE has reached an acceptable limit, or when the number of training cycles is attained. Once the correct signal is identified, the logic representing the particular command for that signal has to be identified. The command intended to perform is opening a notepad. During training, first as a baseline the user is asked to be in a meditated and relaxed state. For execution of the command, the user is asked to solve a math question and accordingly the training is done and that action is entitled to that operation to open the notepad. Now to test whether the system works, the user is made to solve a math question. Then after recording and processing of the EEG signal, enters to the neural network where the command is identified. The logic that perfectly matches with the command has to be compiled and the intended task will be performed.

V. Conclusion

The evolution of BCI has brought up a revolution in the current technical era. The system proposed has a necessity to provide initial training to the system. Because, the system have to identify which action equals to the desired command. Commands are completely action specific i.e. the imagination of a particular action by the user. In future, the system must be modified in such a way that it can respond to the user commands automatically eliminating the need to train the systems regarding the command specification. People may have like thoughts but not completely same thoughts. Hence, using thoughts of a person for intermingling with a computer can augment the security. Also, the uniqueness of thoughts among a vast population of people would boost up privacy of the user. The biggest challenge in the proposed work is not just the implementation of the system but the training of the neural network. The system is perfect for handicapped people who find difficulties in using the system. Brain- wave computing will indeed be a new alternative for manual work needed to control the system.

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