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Robotic Arm with Brain – Computer Interfacing

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Abstract

Brain Computer Interfaces (BCI), is a modern technology which is currently revolutionizing the field of signal processing. BCI helped in the evolution of a new world where man and computer had never been so close. Advancements in cognitive neuro-sciences facilitated us with better brain imaging techniques and thus interfaces between machines and the human brain became a reality. Electroencephalography (EEG), which is the measurement and recording of electric signals using sensors arrayed across the scalp can be used for applications like prosthetic devices, applications in warfare, gaming, virtual reality and robotics upon signal conditioning and processing.

This paper is entirely based on Brain-Computer Interface with an objective of actuating a robotic arm with the help of device commands derived from EEG signals. This system unlike any other existing technology is purely non-invasive in nature, cost effective and is one of its kinds that can serve various requirements such as prosthesis. This paper suggests a low cost system implementation that can even serve as a reliable substitute for the existing technologies of prosthesis like BIONICS.

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Keywords: *Brain – Computer Interfaces; Electroencephalography; Emotiv EPOC EEG Headset; Hyperterminal; Degrees of freedom.*

1. Introduction

Brain Signal Processing is a technology which evolved in the recent years and has lead to path breaking inventions in the field of engineering and technology. This technology ultimately reduced the distance between human brain and the computers and has led to the evolution of Brain – Computer Interfaces (BCI) [1, 2, 3].

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Brain signals are low Amplitude low frequency signals which are very sensitive to disturbances such as noises and require a very sophisticated environment for the sake of acquisition and processing. On an overview, Brain Signals are acquired, amplified and digitized to be analyzed and processed by a personal computer.

In this paper, we are suggesting the technique to design and build a fully functional robotic arm which basically acquires EEG signals from Human Brain using an EEG Headset which is then digitized, filtered and processed. The processed data from the raw EEG signals are used to operate in 3 degrees of freedom [6, 7] and an end-effector.

The entire system consists of three phases 1. Biomedical Phase, 2. Signal Conditioning and Processing Phase and 3. Hardware System Development Phase

2. Literature Review

2.1. Nature of EEG Signals

The EEG obtained from the brain scalp through a single electrode is nothing but the local field potentials (LFP) integrated over an area $10cm^2$ or more. These LFP's are spatially and temporally smoothened as well. The LFP's are generated as a result of the synaptic activities of hundreds of neurons over the integrated area in a synchronized manner and it varies considerably according to the brain activity. The depth, orientation and intrinsic symmetry of connections in the cortex are significant in it. Modern EEG acquisition techniques had even evolved to digitize these signals and make it available for digital signal processing. This is done after providing sufficient amplification to the acquired signals and bringing them up to the milli-volt level. The electrode placement plays a major role in this system arrangement. Electrodes made of conductive materials such as gold or silver chloride are generally used. Conductive gel is applied on the scalp to enhance the conductivity and to maintain an acceptable signal to noise ratio.

2.2. EEG Wave Groups

Every electrode in an EEG signal acquisition setup delivers a large quantity of data and it makes the whole process of signal acquisition complex. The data thus obtained contains a variety of components which can be further classified on the basis of different parameters such as frequency and even shape of the waveform. These components don't have an individual existence and the emanation of one component can be even superior to others depending upon the mental state of the subject.

Six types or components are particularly important and are listed in Table 1:

Table 1. EEG Wave Groups

EEG Rhythms	Frequency (Hz)
BETA	13 – 30
ALPHA	8 – 13
THETA	4 – 7
DELTA	0.5 – 4
MU	8 – 12
GAMMA	35 and Above

2.3. EEG Lead Systems

The EEG lead system defines the electrode placement standards to be implemented for the sake of EEG signal acquisition. The International 10 20 electrode placement system [5] is an internationally recognized method to describe and apply the location of scalp electrodes in the context of EEG signal acquisition. The 10 20 system was devised to ensure standardized reproducibility which enables continuous studies on the subject over time and even comparison between multiple subjects. This system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10 % or 20 % of the total front-back or right-left distance of the skull.

Each electrode placement location is identified with a combination of a letter which denotes the lobe and a number to identify the hemisphere location. The letters corresponding to various lobes such as frontal, temporal, central, parietal, and occipital are F, T, C, P and O, respectively. Biologically, the central lobe does not exist and the "C" letter is used only for identification purposes only. An electrode placed on the midline of the human brain is denoted by a letter 'z'. Even numbers (2,4,6,8) are dedicated to electrode placements on the right hemisphere and odd numbers (1,3,5,7) are dedicated to the electrode placements on the left hemisphere. In addition, A, Pg and Fp identify the earlobes, nasopharyngeal and frontal polar sites respectively.

Two anatomical landmarks act as the reference to the whole electrode placement system. The nasion is the point just above the bridge of the nose and inion, which is the lowest point of the skull from the back of the head. The 10 20 electrode placement system is represented in Fig. 1.

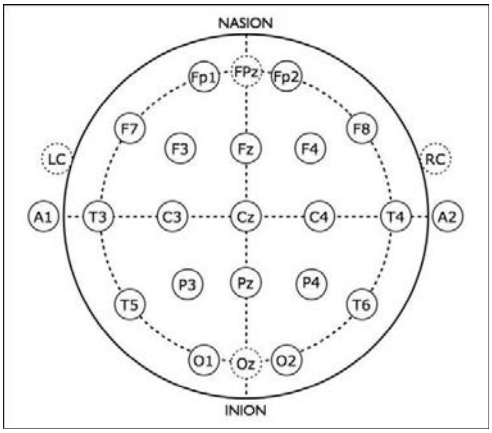

Fig. 1. EEG Lead System

2.4. Robotic Arm with Brain-Computer Interfacing : A look back

- *1870* : Motor Cortex was discovered. Scientists apply electricity to the motor cortex of a dog which results in the movement of its limbs.
- *1969* : First Brain-Machine Interface was invented in University of Washington. Monkeys were taught to move a dial using nerve impulses recorded from their brains
- *1982* : The idea of thought-controlled robot raised from the discovery that electrical firing in the motor cortex can predict which way a monkey's limb is moving
- *1998* : A single electrode was implanted to the brain of a paralyzed man who is unable to speak. The implant helped him move a cursor to select messages from a computer menu.
- *2014* : Two ports were screwed to the brain of a paralyzed lady through which researchers can insert cables that connect with two thumbtack-size implants in her brain's motor cortex. The signal thus obtained from the motor cortex is plugged into a robotic arm that she controls with her mind.

3. System Design

3.1. Robotic Arm

A Robotic Arm is a very versatile robot which can be used for a variety of applications. A robotic arm is probably the most mathematically complex robot that could be built. The design of a robotic arm depends on a number of parameters among which Degree of Freedom (DOF) being the most basic one. Each degree of freedom is a joint on the arm, a point upon which it can bend or rotate or translate. The number of DOF will be equal to the number of actuators on the robot arm.

The Denvit-Hartenberg (DH) [7] convention is the accepted method of drawing robot arms in Free Body Diagram (FBD's). Rotation and translation are the two motion that a joint can perform. The connection between two actuators is named as a link. Hence, considering all the 3 axes, the maximum number of DOF that a joint can exhibit is six. The action of end effectors is not considered as a DOF. A robotic arm with 3 DOF can be represented as a FBD as in Fig. 2.

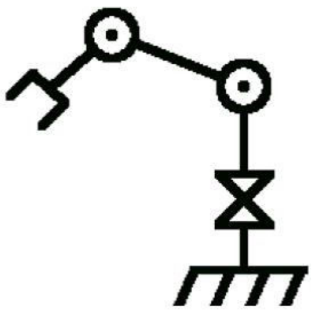

Fig. 2. Free Body Diagram

3.1.1. Force Calculation of Joints

When it comes to design of a robotic arm, the force exerted at each joints have to be calculated for the sake of motor selection. The motor should be selected in such a way that it can not only support the weight of the robot arm, but also what the robot arm will carry [13].

The first step is to label your FBD, with the robot arm stretched out to its maximum length.

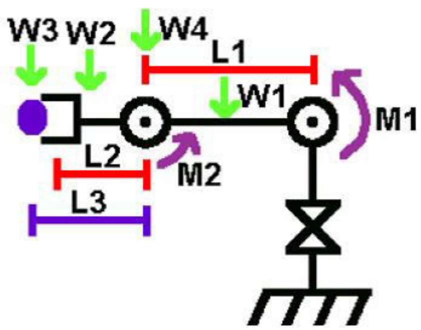

Fig. 3. Robotic Arm Design – Calculation of moments

The parameters involved are:

- Weight of each linkage
- Weight of each joint
- Weight of object to lift
- Length of each Linkage

The Moment arm is calculated multiplying the downward force with the linkage length. This must be done for each lifting actuator. The centre of mass of each linkage is assumed to be $\frac{length}{2}$. (Refer Fig. 3)

Torque about Joint 1 :

$$M1 = \frac{L1}{2} \times W1 + L1 \times W4 + \left(L1 + \frac{L2}{2}\right) W2 + (L1 + L3) W3 \quad (1)$$

Torque about Joint 2:

$$M2 = \frac{L2}{2} \times W2 + L3 \times W3 \quad (2)$$

3.1.2. Design Layout

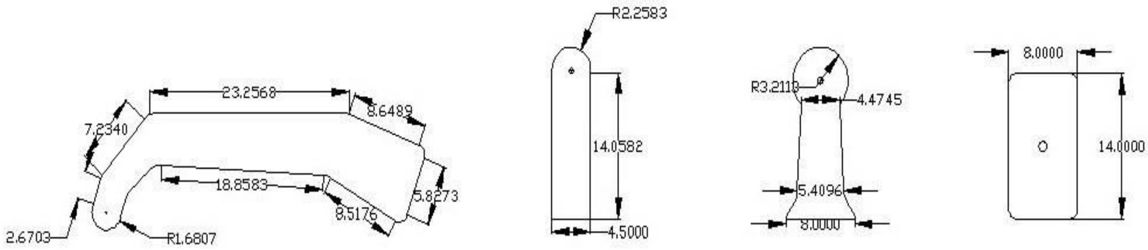

Fig. 4. Design Layout

4. System Implementation

The system consists of the following stages in system implementation as shown in the block diagram (Fig. 5.)

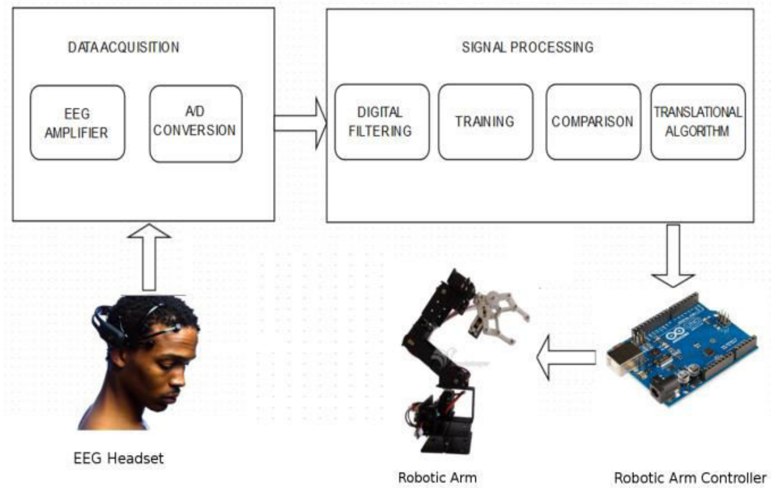

Fig. 5. Block Diagram for System Implementation

4.1. Signal Acquisition

In the signal acquisition part of BCI operation, the chosen input is:

i. Acquired by the recording electrodes

ii. Amplified
iii. Digitized

Data acquisition is achieved by using EEG device. EEG data is obtained from the Emotiv Epoc Headset, which reads brain activity via the scalp of your head and translates it into various actions. This 14-channel hardware is used to acquire signals from various electrodes placed on the human scalp at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8 and AF4 positions, according to the international 10-20 system. Odd numbers of electrodes are reserved for left hemisphere of the brain; even numbers of electrodes are reserved for right hemisphere of the brain. Two referencing electrodes CMS (on the left side) and DRL (on the right side) are used for reduction of noise in signal.

Headset Features [10]:

The EMOTIV EPOC Headset has 14 biopotential sensors with gold plated connectors which offer optimal positioning for accurate spatial resolution. In addition, gyroscope generates optimal positional information. High performance wireless gives users total range of motion. The dongle is USB compatible and requires no custom drivers. The headset is powered by rechargeable lithium battery. The Emotiv Epoc headset has an inbuilt EEG amplifier and an analog-to-digital converter. Dry electrodes are used to tap the electrical signals from brain. The headset has a digital fifth order Sinc filter for filtering. The digitized data obtained from the brain is received to a computer system via Bluetooth in 2.4 GHz band. The EPOC uses sequential sampling method for sampling. Sequential sampling is different from single, double or multiple sampling. The EEG output will be in the range of 0.2 to 45 Hz.

4.2. Digital Filtering

The EMOTIV EPOC headset itself contains notch filters of frequency 50Hz and 60Hz to reject the power supply frequency. These notch filters removes the noise if any caused by the power supply frequencies 50 Hz and 60 Hz. Power supply usually causes serious disfiguration to the EEG signal acquired which is overcome by these notch filters.

4.3. Training Comparison

The system is trained based on the signals acquired from the EEG Headset. The EEG signals corresponding to the various thoughts for movements is recorded and analyzed in the EMOTIV CONTROL PANEL. The EMOTIV CONTROL PANEL is the one integrated tool for monitoring the EEG signals obtained from the EEG Headset. EMOTIV CONTROL PANEL enables identification and isolation of various features from the EEG signals. The gestures are extraction and the result thereby obtained is the collective data from all the 14 channels of the EEG EPOC HEADSET. EMOTIV CONTROL PANEL helps identification and isolation of various expressive, affective and cognitive features along with the signals from the inbuilt accelerometer in the EMOTIV EPOC HEADSET.

Training Neutral: The Neutral action refers to the user’s idle state of mind; which is not associated with any of the selected Cognitive actions. Typically this means engaging in idle mental activities like just relaxing. However, to minimize false-positive Cognitive action results, it may also be helpful to emulate other mental states and facial expressions those are highly unlikely to be encountered in the application context and environment in which you will be using Cognitive. Neutral training must precede the training of any other actions.

The neutral training is used as a benchmark for rest of the features to be trained. Any number of features can be trained on the system during its training phase. Whenever the system turns to operate in the execution mode, the signal acquired from the EEG Headset will be compared with the trained features and thus the feature will be identified.

The comparison is achieved by cross correlating [8, 9] the signal acquired from the EEG headset with the training dataset. The cross correlation operation is given by:

$$(f * g)[n] = \sum_{-\infty}^{\infty} f^*[m]\, g[m+n] \tag{3}$$

4.4. Translational Algorithm

The translational algorithm is the one integral part of the whole system which generates device commands from the processed EEG signals. Commands thus generated by the translational algorithm help carrying out the user's intent. EMOKEY is the software that enables execution of the translational algorithm. Rules will be defined for different features that have been extracted in the EMOTIV CONTROL PANEL. The system will behave according to these rules in a virtual environment. A finite number of conditions can be assigned for each rule specifying a feature. The condition specifies situations at which a trigger has to be applied. A trigger in EMOKEY is passed to the target application in the form of a keystroke. A rule in an EMOKEY assigns a character value to the extracted feature.

EmoKey emulates a Windows-compatible keyboard and sends keyboard input to the Windows operating systems input queue. The application with the input focus will receive the emulated keystrokes. In practice, this often means that EmoKey is run in the background.

The Keys dialog allows the user to specify a desired as well as a customized keystroke behavior. The customizable options include: Holding a key pressed for the duration of the rule activation period. Hot keys or special keyboard keys: any combination of modifier keys and another keystroke.

We can also fix a threshold for generating and triggering a keystroke. The threshold fixed for each rule in the EMOKEY will be based on the cross correlation value obtained while the comparing is carried out.

Each keystroke generated and triggered after identification of the feature will then be transferred to the HYPERTERMINAL which is the target application where the virtual environment device commands are transferred to real life system.

4.5. Robotic Arm Control

The output from the signal processing and the translational algorithm stage is in virtual reality of robotic arm, a real life system with the help of interfacing software called HYPERTERMINAL. Hyper terminal interacts with ARDUINO UNO R3 [12] which is the Robotic arm controller via serial port where the characters are converted into blocks of four bits in parallel for transmission.

The HYPERTERMINAL identifies the robotic arm controller as a COM port. The baud rate can be fixed in the hyperterminal itself once the device has been identified as a COM port. The ARDUINO development board can be programmed in such a way that whenever a particular keystroke has been received in the serial data pin then the Controller should actuate that particular joint of the robotic arm so that the user's intent is accomplished.

5. Finished Model

Fig. 6. The designed robotic arm

6. Conclusion

The Robotic Arm with Brain-Computer Interfacing has been developed and was tested to actuate all the joints in all possible directions for which it was designed to move. The objective of this project was to develop a prosthetic limb for amputees that can help them work very similar to any common man where the arm can be actuated by device commands derived from brain signals. Amputees who suffer from lost appendages and whose brain function properly can make use of this system. By suitably extracting and processing their brain waves the prosthetic arm can be designed to move in all possible directions according to their wish. Thus apart from the engineering point of view, this project also has a wide range of socioeconomic applications.

As the applications of BCI go unbounded, the applications of this system and the scope for its improvement also go unbounded. If we are able to generate more device commands, this can be implemented with more degrees of freedom that can ultimately imitate an actual human arm. The same technology can be extended to develop a brain controlled robotic leg which can also serve as a prosthetic appendage for physically challenged. More efficient signal processing algorithms can build a system which is less vulnerable to noise. Such an algorithm can also minimize the ambiguity in feature extraction and execution of device commands.

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