Brain Controlled Human Robot Interface

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Abstract— **This Paper emphasizes on the ever increasing need of better communication medium between a human and a robot in order to control it precisely. Brain Computer Interface (BCI) is the most suitable mean of communication between them, especially for the rehabilitation of disabled people and for accomplishment of sophisticated tasks like surgery, rehabilitation and operations etc. This paper in depth reviews the state of-the-art of BCI systems for robotics which can be named as Brain Robot Interface (BRI). Various BRIs reported in the literature have been presented by categorizing them. The past, present and future of the subject area has been discussed in detail. Finally, the paper comments on contribution of BCI in the area of robotics.**

Index terms; Brain Robot Interface (BRI); Brain Computer Interface (BCI); Electroencephelogram (EEG).

I. INTRODUCTION

Robots are rapidly becoming part of our daily lives. They may be used for tasks ranging from simple human assistance to sophisticated applications. Educational sector and entertainment industry are two other areas benefitting from robotics. Ever increasing trends of robotic applications in various spheres of life has demanded requirement of precise control and choice of proper mechanism for sending commands.

Classically, muscular activities have been used to send instructions to robots through remote control or by moving a body part in a specific manner. This is not an ideal case, as in many situations the mobility of a body part may not be possible. This necessitates acquiring instructions directly from a human brain to accomplish sophisticated tasks [1]. The idea of Brain Robot Interface (BRI) basically emerged from the field of Brain Computer Interface (BCI) which permits a person to communicate directly with machines (robots) without involvement of nerve or muscular movements.

A BCI system senses the presence of particular patterns in a human brain activity by extracting neural signals [2][3][4]. It then relates the acquired pattern with the person's intention in order to formulate the control. The neural signals are recorded from scalp or from within the brain detecting the electrical activity of the neurons using electrodes. These signals afterward are translated into decision statements using different feature classification techniques that employ various signal processing methods to detect certain existing patterns inside the recorded signals. Finally a BCI system maps these patterns into meaningful control commands [4].

This paper is divided in four sections, Section-I accentuate the need of BCI in robotics and provides brief introduction to the topic. Section-II explains the working of BCI and its common types reported in literature. Section-III discusses the use of BCI in robotics and provides a detailed review of BRI systems. Finally, Section-IV comments on conclusion.

II. BRAIN COMPUTER INTERFACE (BCI)

A BCI is a system that makes use of brain pulses to identify the current state of mind of a person. BCI acquires neural signals from the brain using a mechanism. It then inspects these signals by applying different feature classification techniques and hence presence of certain neural patterns is detected in a person's brain activity. These patterns help to make decision statements related to the person's intent [3][4]. These decision statements are then translated into meaningful control commands to instigate control of a robot. Various signal processing algorithms are employed to detect these patterns. Thus signal processing is an important part of a BCI, as it is needed to take out the meaningful information from the brain signal.

Brain computer interface has two types i.e. invasive and non-invasive BCIs. Invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery while non-invasive BCIs work using technological interfaces for recording neural signals. For BRI non-invasive BCIs are most suitable. A few non-invasive BCIs are Electroencephalogram (EEG) Electromyography (EMG) and Magneto-encephalography (MEG).

A. Magnetoencephalography (MEG)

MEG as the name suggest, records magnetic fields produced by electrical currents occurring naturally in the brain to examine its activities. Sensitive magnetometers are used to extract magnetic signals from brain. MEG gives the direct access to the dynamics induced by spontaneous neural motion and location of their source in brain. Usually Super Conducting Quantum Interference Device (SQUIDS) are used as magnetometers to measure magnetic fields. SQUIDS are very sensitive and low noise sensors to detect very weak magnetic flux and convert them into voltage.

B. Electromyography (EMG)

This technique evaluates and records the electrical activity produced by skeletal muscles. When muscle cells are electrically and neurologically activated, they produce electrical potentials. An instrument named electromyograph detects these potentials and records them. Usually an EMG signal associated with muscle activity is measured near it but they can also be measured far from it as these signals are relatively high powered and propagate to a distance. EMG signals can be measured on specific positions from eye, jaw, face, tongue, and arm and leg muscles. EMG signals generated by eyes are called Electro-Oculographic (EOG) signals.

C. Electroencephalogram (EEG)

In EEG, electrical signals are recorded through sensors (electrodes) attached to some specific parts of head. The electrodes attached to the scalp obtain the signals from the brain in the form of electrical pulses. These pulses are then amplified and transmitted to a computer which processes them and extracts the useful information to generate control commands for machines. However the most difficult task here is to extract the concerned information as the electrical brain activity contains the artifacts of a wide variety of phenomena and patterns of various other processes happening in the brain such as an eye blink. These artifacts make it hard to extract the required information about the person's intent [5]. Various signal processing techniques are used to acquire this information from the recorded electrical brain activity enabling people to look into ones brain. In addition to BCI it can also be used for medical checkups i.g. neurological disorders, investigate brain functions. EEG is the most common technique used in BCIs because it is easier and accurate compared to other techniques for extracting signals from brain.

III. Brain Robot Interface

A BCI used for manipulation of robots can be termed as BRI. BRI can be used to facilitate rehabilitation in many ways including control of robotic based arm, hand exoskeletons, wheel chair motion control for disabled and paralyzed people and so on. BRI can also be used in facilitating medical professionals for sophisticated tasks. It can also be efficiently used to give instructions to humanoids performing specific tasks i.g. labor, security etc. Various robots controlled with BRI strategy are reported in the literature. Here we present a detailed review of the reported BRIs.

Researchers at Univ. of Southern California presented a neural based interface for a humanoid robot [6]. Biological inspired notions are used here for the interaction between human and humanoid in the behavioral based control paradigm.

José del *et al.* [7] have demonstrated that brain signals from EEG based BCI are good enough to control a robot even though EEG was considered to be slow for controlling the rapid and complex sequences of a mechanical device. They used 8 electrodes on the scalp in the EEG based BRI for collecting signals. Two human subjects were used to control the motion of the robot at different times to experiment the motion through different rooms, corridors and doorways in an indoor environment. After these experiments it was concluded the BRI to be comparable to the manual control with a ratio of 0.74.

Cerebrovoscular brain damage produces severe motor disabilities in human. This happens when blood stops flowing in a part of the body which cannot be controlled through brain and becomes a useless part. Rehab robot assisted physical therapy integrated with BCI is the only solution to this problem. Here mechanical device will be needed for actuation of the disabled part while BCI is required to decode intentions from the brain and translate them into decision commands. Rodriguez *et al.* have presented an integrated BCI-Robotics system developed at Max Plank institute of intelligent systems [8]. They have used Barrett WAM 7 Degree of Freedom (DoF) arm using an EEG or Electrocorticography (ECoG) based BCI shared-control strategy. The robotic arm attached to the subject's impaired arm is shown in Fig. 1. In order to obtain accurate decision from EEG signals predefined trajectories are decoded to facilitate the decision.

Figure 1. Robot assisted physical therapy for stroke patients. [8]

Another BCI based robotic arm control strategy was proposed by Valbuena *et al*. In their work [9], they presented a BCI based on Steady State Visually Evoked Potentials (SSVEP). SSVEP are natural response signals produced in brain when a retina is excited by a visual stimulus of frequencies ranging from 3.5Hz to 75Hz.

The proposed BCI was integrated with a robotic arm Friend II; it translates the brain activity into the control commands to the rehab arm. More precisely BCI was responsible of navigating a menu of commands and select an action to be performed such as pouring the beverage into glass as shown in Fig. 2. The scope of this work is to disabled people less dependent on care givers

Figure 2. SSVEP based BCI control of a three dimensional robot. [9]

An EEG based working prototype for the direction control of wheelchair was developed by Kharey *et al.* [10]. To control various direction of wheelchair i.e., forward, backward, right, left and stop they used different mental tasks accordingly. Wavelet Packet Transform (WPT) extracts the features corresponding to the frequency bands. To classify the pre defined movements of wheelchair, they used Artificial Neural Network (ANN) i.g. a radial basis function network to categorize the signals. Their experiment achieved 100% accuracy and they proposed to modify the device for other purpose.

To develop an intelligent and intellectual BCI having the ability to catch the human intention precisely and so headed for required work in complex surroundings. Near Infrared Spectroscopy (NIRS) technique was used by Okumura and Luo to measure actions of human brain [11]. They used an interface to directly control the motion of the robot. To distinguish the activities of a human brain they performed two types of experiments, the first during subject's body motions and second during thinking job. They used tongue extension tasks and finger tapping for the experiments of body motions. While for thinking experiments puzzles and mathematical calculations were used. In body motion experiments, they got positive results and found that the left hand tapping activity is actually controlled by right side of motor cortex and vice versa. Whole scheme is given in Fig. 3.

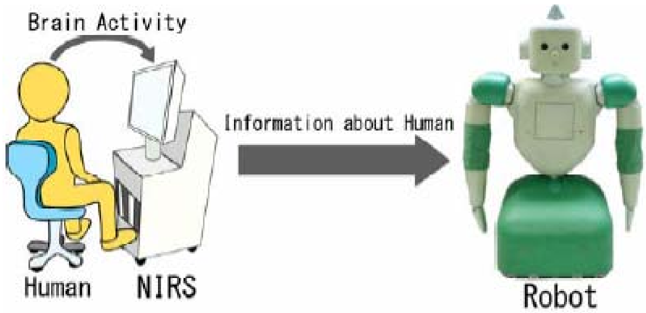

Figure 3. NIRS based BCI to control a humanoid robot. [11]

Tanaka *et al.* [12] have experimented to control a mechanical device; a wheel chair with the help of the EEG based BCI. Fig. 4 shows the position of the electrode to extract the brain signal. Band pass filter of 0.53-30Hz was used to rejects the artifacts of EMG and EOG signals. However to completely reject these artifacts, subjects were specifically requested to restrict their body movements and eyes as well. They have developed recursive training algorithms to generate recognition patterns from EEG signals. Figure 4 provides the detail of the electrode placement and rest of the BCI scheme.

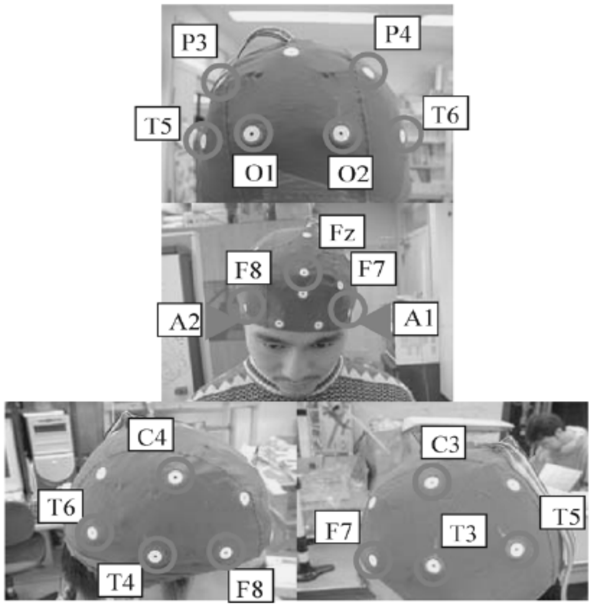

Figure 4. Wheel chair control using EEG and EOG. [12]

Marcos *et al.* [13] presented a multidisciplinary framework to write a letter on a white board through robotic arm. Figure 5 presents the graphical view of the proposed framework. Subject decides a word in mind, which is then extracted from brain through BCI. A mental speller interface is used to choose the word. Finally appropriate control commands are sent to the robotic arm, which then writes that word on white board.

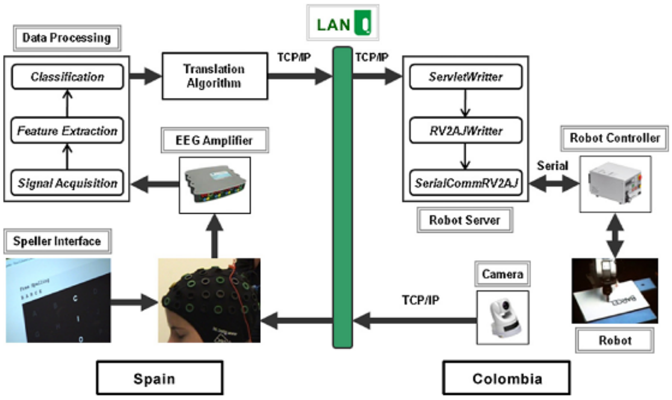

Figure 5. Daniel's framework for writing on white board using BRI. [13].

A group of researchers in [14] proposed a new system based on visual P300 oddball paradigm. They summarize and compare the approaches of neuro-mechanisms in this paper and showed their relevance with the real world. They use Fisher criteria for temporal features and for selection of EEG channels. Since signal-to-noise ratio in BCI is very low so they used common spatial patterns spatial filter as it enhances P300 classification rates. For organization of input features, projection of the filtered data was required instead of the variance of the projections. The result of this paper was reached offline so made more research to bring it online.

In thinking experiments they cannot reach to any finite conclusion. They highlighted that if experimental setup is better and more different types of experiments on different subject are done, then better result can be expected.

A research group of University of North Florida [15] have used visual matrix (shown in Fig. 6) to control robotic arm manipulator specifically for rehabilitation purpose. This flashing visual matrix consists of a set of symbols. Subjects were asked to select a set of symbols from the set and resulting brain signals were recorded through BCI and were then mapped into control commands for three dimensional motion of the manipulator. This work is envisioned to provide autonomy to the disabled people and long term solution of their disability.

Perrin *et al.* [16] worked on semi-autonomous navigation strategy given in Fig. 7 to minimize the involvement of user. The robot does not need the attention of user for every job it has performed but instead robot proposes movements based on information taken from environment. User just has to monitor the actions of robot and reject if he/she disagrees with the robot activity. So user was supposed to do the function of monitoring.

At first the robot extracted features in unknown surroundings but then recognized places of interest e.g. crossing. Based on this topology, robot proposed actions and user just monitored them. They demonstrated the effectiveness of the strategy in simulations as well as on real robot.

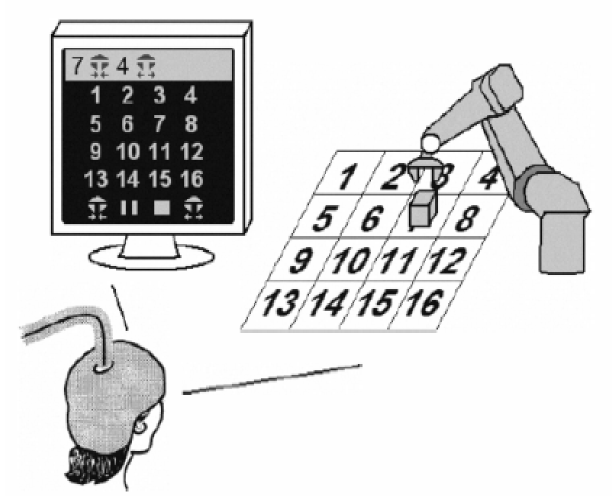

Figure 6. Visual Matrix based BCI to control a manipulator. [15]

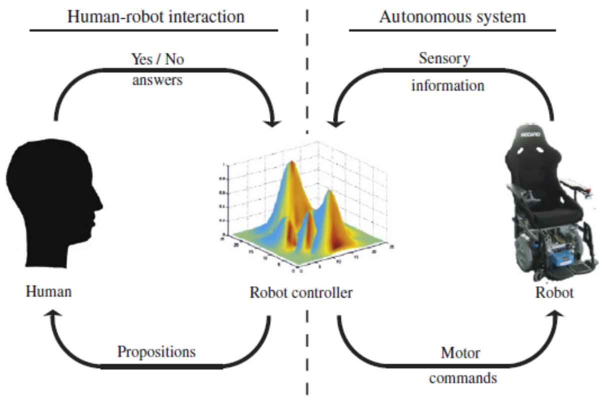

Figure 7. Semi-autonomous robot navigation strategy. [16]

A semi-autonomous robotic personal assistant for handicapped people was proposed by Knoblauch *et al.* [17]. They employed a hybrid BCI to communicate state-of-the-art humanoid robot (Fig. 8). EEG based BCI extracts and processes the cortical signals and converts them into meaningful commands. It uses P300 and Event Related De-synchronization (ERD) to translate these signals into control commands. In their experiment, all participants were able to control the robot successfully to accomplish a shopping task.

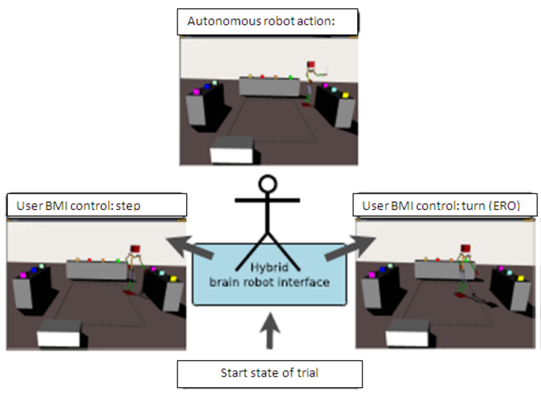

Figure 8. A hybrid brain interface for a humanoid robot asisstant. [17]

Palankar *et al.* [18] controlled a 9-DoF wheelchair which having on built robotic arm. In this wheelchair 7-DoF were used to control robotic arm while the remaining 2-DoF controlled power wheelchair mobility in a single control mechanism. They used P300 BCI and BCI2000 to control Wheelchair Mounted Robotic Arm (WMRA). Electrode cap was used to control the WMRA by analyzing and recording the brain activity. Using visual matrix containing the alphabetic array or symbols (according to the WMRA motion), the user chooses an element in the matrix and then BCI2000 system identifies that the element chosen is communicated to WMRA controller, shown in Fig. 9.

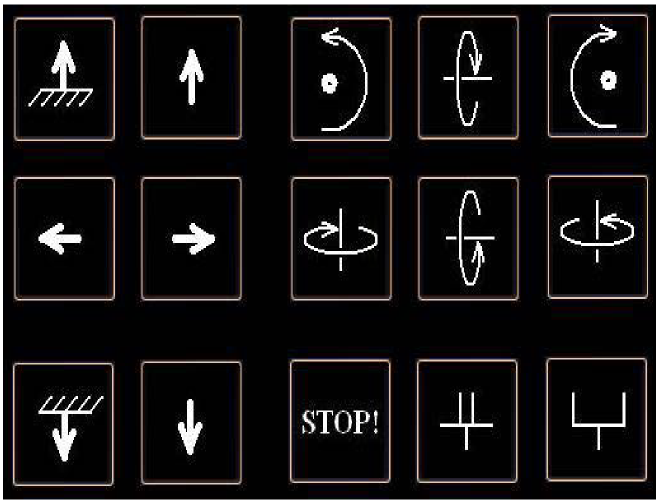

Figure 9. Wheelchair Mounted Robotic Arm (WMRA) control display. [18]

The future prospect of BRI is potentially very encouraging in facilitating medical professionals for sophisticated tasks like rehabilitation, surgeries and operations. Similarly tele-surgeries and distant control of robots using internet or other communication medium is an exciting prospect of BRI in future. BRI can also be used to beneficiate agricultural fields. Next generation humanoid robots will be instructed directly through brain to be used for labor and assistance at homes and factories. Military is another very important domain of brain controlled robots where they can be used for battling, transporting or any other dedicated application in future. Another exciting application is BRI based gaming platforms. Thus the future of BRI seems very promising not only because it is hot topic today but also because the applications of BRI are predicted almost everywhere in a technological world of tomorrow.

IV. Conclusion

BCI has given a new birth to ever-progressing field of robotics. A substantial amount of work has been done in this field and a few important brain controlled robots are reported in this paper. Since the dawn of robotics, the most important problem for the scientists and engineers have been how to communicate to pursue control over robots. In the past they used remote control strategy to send instructions to robots. Moreover they are also using predefined human muscle movements to send instructions to robots. But these conventional methods have limitations at some point especially in the case of rehabilitation as discussed earlier in this paper. Thus the natural control would be to control the rehabilitation instrument through brain using BCI. BCI is gaining lot of popularity in the world of robotics because of its applicability in almost every situation for the sake of communication between a human and a robot. This paper provides a detailed review on the work which has been done in the field of BRI so far. Our analysis of reported BCI systems are potentially useful to access impact of control based on neural signals and can serve as guide for researchers working in this area.

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