Control of Pathfinder Robot Movement Using Combination of Brain Rhythmic Waves and Evoked Potential Features in Virtual Environment

Saeid Ghazanfari
Department of Bio Medical Engineering
Science and Research Branch, Islamic Azad University
Tehran, Iran
Saeid.bme@gmail.com

S. Mohammad P. Firoozabadi
Department of Medical Physics
Tarbiat Modares University
Tehran, Iran
pourmir@modares.ac.ir

Ali Motie Nasrabadi
Department of Biomedical Engineering
Shahed University
Tehran, Iran
nasrabadi@shahed.ac.ir

Abstract—**this paper investigates the safe movement of pathfinder robot in a Virtual Environment (VE) comprising fixed and moving obstacles only by using electroencephalogram (EEG) signal. In the proposed system, users can choose the movement destination using P300 evoked potential and also change the velocity to react to the moving obstacles in the real time. The experimental results of system evaluation on four healthy male persons illustrate its ability to move different objects by handicap users.**

Keywords-virtual reality; alpha wave; P300; pathfinder robot

I. Introduction

In the evolution of robotic it has always been tried to improve robot intelligence to the level close to human intelligence. Along with all the failures in this field, the robot control was signified by using human intelligence again. Especially in the cases that an individual needs to communicate to the object which should be able to perform her/his intended commands by using her/his intelligence because of being handicap or having disability in doing some actions. Thus a branch of science called Human Machine Interface (HMI) was created. In this field human as the main framework of control is trying to communicate with a machine which is able to fulfill affairs that an individual unable to do alone. Some simple types of HMIs can be pointed out such as keyboard, mouse, and joystick and touch systems which are using to control some devices. . In the next level, there are the interfaces which are able to generate some commands by processing sounds or images and individual's facial modes [1-3]. In the more advanced stage, we can mention wearable electromechanical trackers which are using strain gage and optical sensors for gesture recognition [4] as well as gaze tracker based systems which track person's attention focus and desire command from her/his eye gaze [5]. The more sophisticated HMIs are Electromyogram (EMG)-based interfaces which are using healthy muscular signal to improve the person's physical abilities or replace the disable muscles [6]. One of wearable types of these interfaces is Exoskeleton that by using neuromuscular signals enhances muscle performance via mechanical arms [7]. The common mechanism of all these interfaces is based on movement of a part of body. In some disease such as brain stem stork, cerebral palsy, multiple sclerosis, amyotrophic lateral sclerosis and muscular dystrophy, the person's body is deprived of mobility in various organs and the patient faces disorder and extended or even complete paralysis of the neuromuscular system. Hence using Brain Machine and Computer Interface (BMI and BCI) systems becomes important. These types of interfaces produce a communication channel between the user and a machine or the computer for real time or on line control by using brain signals. There are various approaches in using brain signals based on types of brain signal record. Different kinds of brain signal record can categorize to three groups; invasive, partially invasive and non-invasive [8]. We can suggest neural records of cortex includes electrocorticogram (ECoG), field potential (FP) and single unit (SU) records as invasive record methods [9], [10] and methods of EEG, MEG, NIRS, FMIR and PET as non-invasive records [8]. The more invasive methods, FP and SU, are very rarely applied in humans but ECoG method is used for neuroprosthetic interface more extended in humans [8-11]. Among non-invasive methods EEG is applied widely in humans and has specially drawn attention of researchers. Generally electrophysiological resources of EEG are applied in BCI systems are consist of following cases; alpha, beta, gamma and Mu rhythms, movement related potentials, P300, visual evoked potentials (VEPs), steady state VEPs (SSVEPs), slow cortical potentials (SCPs) and response to mental tasks [12]. Delta, theta, alpha, beta and gamma waves are called rhythmic waves and N100, P100, N200, P200, P300 and N400 templates are enumerated as event related potentials (ERPs) [13]. These potentials are typically generated in response to peripheral or external stimulation and are quite small (1-30 μV) relative to the background EEG activity [14].

In our proposed prototype alpha wave and visual evoked potential P300 are used. P300 is nonobligatory response to stimuli, and vary in amplitude, latency, and scalp distribution. This wave represents cognitive functions involved in orientation of attention, contextual updating, response modulation and resolution, and consist of two main overlapped subcomponents P3a and P3b. P3b is elicited by infrequent and rare events, but unlike P3a, it is task relevant or involves a decision to evoke this component while P3a is an involuntary shift of attention that appears to a fundamental biological mechanism for survival [14]. Almost many works are done in the field of movement control using EEG. In 2004, it had been tried to control direction of movement of mobile robot by using EEG record of 8 electrodes that movement command had been produced by using combination of 3 mental states and 4 conceptual states from environment by several sensors. The relatively high error rate, high rejection rate and long training process are drawbacks of this work [15]. In another attempt in 2005, Tanaka et al. controlled movement of electrical wheelchair (EW) by using EEG record of 13 electrodes [16]. They used two mental states 'left thinking' and 'right thinking' for determination of movement direction. The disadvantages of their work are low recognition rate and high time longitudes of training and valid distinguish of user's intended direction. In 2007, Martinez et al., by using visual stimulation and SSVEP record from five points of scalp, succeeded to extract 4 movement directions and completely online control of a virtual automobile in 2D virtual environment with high accuracy [17]. In another example in 2009, a mobile robot was able to change its motion direction online by alpha wave due to opening and closing user's eyes [18]. It can be numerated user's continuity of mental activity any time for reaching to movement destination as a drawback of these systems. This defect was solved in P300 based systems. In these systems, user is able to select the destination which is going to move to there in a visual stimulation. In one of the simplest P300 based systems [19], user can select 5 options 'right', 'left', 'front', 'back' and 'stop' instead of determining movement destination by using her/his potential P300. In 2009, Rebsamen et al. could move an EW for reaching to different destinations in a building by recording signal from 15 channels and using a graphical unit interface (GUI) for visual stimulation. The only user's task was to select a path among a path list that depart from the current location to the location which was proposed on the GUI and the task of conveying user from origin to destination is mission of path guidance system which is carried out by processing of complex sensors [20]. However the mentioned system doesn't present a solution for passing through mobile obstacles of environment. In the same year Iturrate et al. introduce a P300-based system which transported an EW to the user's intended points in its surrounding environment with high accuracy by using 10 electrode signals and automated navigation system [21]. Some of the unique properties of this system are no-collision to the mobile obstacles and reconstruction of real environment in the virtual environment by using sensor-based online map for suitable visual stimulation that enable user to select the point of environment is going to move to it only by concentrating in the start of movement path. The avoiding collision to mobile hindrance is performed via a complex navigation system composed of the local planner and the laser sensors which is generally very complicated in the hardware and software approach which results in the high cost implementation. The propose of current study is setting up a P300 wave based system that reacts to the mobile obstacle by using alpha wave and without applying any complex hardware and sensors in order to benefit from substantial properties of these both waves without aggrandizing any extra hardware to the EEG based system.

II. System Structure

The prototype includes two parts of working with P300 evoked potential and 8-11 Hz rhythmic wave. In order to obtain high accuracy and low amount training process, evoked potential classification is used to choose one of thirteen points in the three dimensional (3D) space of VE and for the sake of high speed occurrence (unlike P300 which occurs with 300 ms delay) and relative low accuracy, alpha waves are utilized to change the velocity for expediting the system reaction to dynamic environment. To perform all BCI system algorithms, total process divides to two parallel massive ones running in two separate computers. The first computer (Com1) is related to VE, graphical process of 3D space and codes are responsible for movement control; and EEG signal processing i.e. recording, pre-processing and etc. performs in the second computer (Com2)(Com1 is a Laptop and Com2 is a Personal Computer (PC)). In this system, four main electrodes are used to signal recording in the mono polar state. EEG signal is recorded corresponding to a visual stimulation trial and then passed through a band pass filter in order to eliminate power line noise and other common artifacts. The filtered signals of four channels are segmented relevant to visual stimulation rate and pre-processing is executed in each channel separately. The processed segments of each channel are concatenate to compose feature vector and this feature vector is sent to Stepwise Linear Discriminate Analysis (SWLDA) block for dimension reduction and then to determine the target point, it goes to a linear classifier. After identifying a target point amongst thirteen, this point is transferred to Com1 by Local Area Network (LAN) as the output of Com2 process. Corresponding to the selected point in Com1, the movement command is imposed in VE. After choosing a point, user can change the velocity during attaining the destination to pass the moving obstacles. In this part, to achieve the real time feeling of speed variation, only one channel is applied to record. The algorithms were written and used to have minimum computational cost in order to decrease the reaction delay. Figure 1 shows different parts of the above mentioned system along with their connections.

III. Three Dimention Graphical Interface (3D GUI)

This interface is designed for two specific applications in one: virtual environment to simulate and represent the movement of virtual robot and two; producing proper virtual stimulation (VS) to evoke P300 and presenting feedback to the user to be able to control the robot.

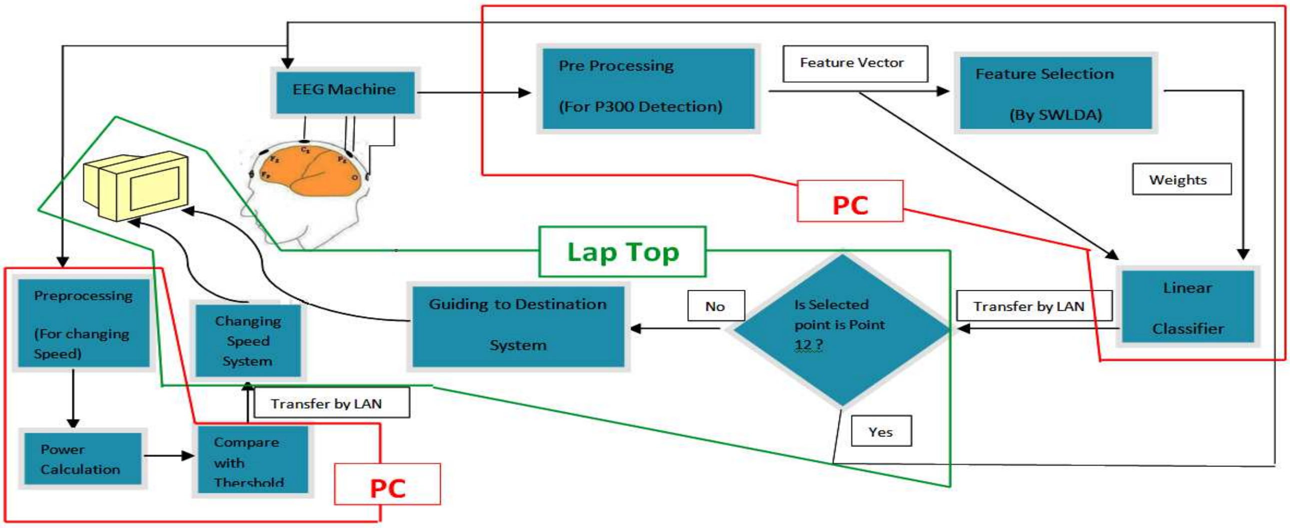

Figure 1. Block diageram of the different parts of system and their connections

A. *Virtual Environment (VE)*

In the different articles, various designs have been used to construct 3D GUI for communicating with user. For example in the work [19], this environment is only a simple GUI contains a screen with five options of 'forward', 'backward', 'right', 'left' and 'stop' to create VS in the P300 evoke. The design in [20] is also similar to [19] with slight difference. The design in [19] is a rather more complex and user instead of determining the movement direction, selects destination which includes series of other options and destinations (such as; deferent parts of a building). The only BCI project which is based on P300 and its VE is a perfect 3D GUI for VS and user's movement is Itturate's project [21]. Therefore this project is considered as a model to design VE in our prototype.

Designing environment was performed by V-Realm Builder software [22]. In this GUI, the user is able to explore entire surface of 3D environment via selecting a series of point, instead of determining the movement direction or choosing specific places. This environment generally is composed of below components:

- A flat plain contains several trees and high hills with deferent color as the fixed obstacles.
- Two moving spheres which traverse environment latitude in parallel paths almost randomly and the user's movement from particular part of environment as the moving obstacles.
- Three movement directions of turn right, left and forward, plus ten destination points that altogether specify thirteen options for the user

B. *Visual stimulation (VS)*

In different P300-based BCIs which are implemented as practical, corresponding response to the each option stimulation are averaged in the different trial to detect P300 template usually after pre-processing [19-21, 23-25]. In these works, up to fifteen trial stimulations are fulfilled to detect each option. In current prototype for the sake of detecting the target, all the options, one by one, are stimulated twelve times in random sequences. Stimulation of each option includes bolding and changing its color from grey to white in order to more efficiently evoke P300 potential. The time interval of this stimulation for each option is 100 ms considering six mentioned works. The time interval between stimulation start of an option till stimulation start of next option which is called Inner Stimulation Interval (ISI) in the study [25], is 175 ms.

Two seconds before starting a 12 trial set stimulation, surface of circle quarter contains options becomes dark brown color to create high contrast, improve user's concentration and so improve P300 evoke. One second later, sign “Go!” is displayed in the center of display for 1 sec in order to user gets ready to concentrate on new option. Then various options start to stimulate after 750 ms. User is requested to count each time of his/her intended option stimulation mentally to keep his/her concentration.

IV. Data Aqcuisition

The machine Procomp Infiniti made by USA which is a clinical and semi-investigative machine is applied to EEG signal acquisition. This machine is manufactured to investigate in the field of biological feedback and specially neurofeedback [26]. Using battery as power supply and ability of measuring skin-electrode impedance are advantages of this machine cause to improve signal to noise in different records.

The different number and arrangement of electrodes were used in the different P300-based BCIs. For example in the work [21], sixteen channels in the allover of scalp were recorded in the begin and after analyzing on the P300 response of these channels , number of six to ten channels corresponding to the proper response and accuracy for different users were selected for work continuation. In the work [19] also ten electrodes in the frontal, central and central-parietal lobes and in the system [20] 15 channels were used to reach sufficient precision and accuracy. In the research [24] , in the begin , signal was recorded from 64 channels and then eight channels which had better response (from frontal to occipital lobe) were selected for research continuation.

In our system and research, channels O_z, C_z, P_3 and P_4 were investigated at first and then in the other period it was repeated with channels F_z, C_z, P_3 and P_4 and the results were compared with former period. Result of this evaluation was shown that first electrode set had 10% better performance (precision in classification) in compare with second set. At last the same first arrangement accompanies with left ear lobe reference and FP_z as ground was used in the 10-20 standard with sampling frequency of 256 Hz.

V. MOVEMENT CONTROL

Since the stimulation and recording process must be synchrone to a great extent in both computers and system would has ability of real time response, it had been tried to use the most simple algorithms in whole parts of processing. Figure 2 shows the practical implementation of this system.

Figure 2. Practical implementation of proposed system

A. *Choosing Movement Destination*

When the visual stimulation begins, a flag is transmitted to Com2 from Com1 to inform start of one trial data recording for synchronizing stimulation and record. Random arrangement matrix of stimulation of options also is transmitted to Com2 to segment one trial signal into the corresponding segments of stimulation of each option. Each 4 channel signal is band pass filtered between 0.1 and 45 Hz in Com2 to eliminate power line noise and other common artifacts. Then signal of each channel is segmented in a manner that about 700 ms data after stimulation of each option is obtained. The different segments are down sampled after passing through Moving Average (MA) filter of relation (1) by factor M=5. The resulting data of each channel are incorporated to each other corresponding to each option to compose feature vector. Then this vector is stored and in the end of 12 trials these vectors are averaged on 12 trials and are passed through MA filter with M=3 again then are normalized in the magnitude.

$$Xma[n] = \frac{1}{M} \sum_{k=-(M-1)/2}^{(M-1)/2} x[n-k]. \tag{1}$$

$$Y = W.X + B. \tag{2}$$

The resultant vector of these pre-processing (X) is sent to SWLDA block to extract features and calculate weights of linear classifier relation (2). In the study [25], this method was introduced to classify P300 generally. The SWLDA is implemented from combination of stepwise forward and backward statistical analysis. The entered features to analysis are weighted by using recursive least square error method to predict labels of classes [24]. It would be started with initial features, and then statistical significance of these features would be compared. In the each step, P-Value of F-statistic is computed to test model with and without these features. If a feature is not in the model in the present step, the null hypothesis is that it would have a zero coefficient if entered to the model (relation (2)). If there is sufficient proof to reject the null hypothesis, the feature is entered to the model. Inversely, if a feature is in the model in the present step, the null hypothesis is that the feature has a zero coefficient. Thus if there is not sufficient proof to reject the null hypothesis, the term is eliminated from the model [27]. The feature vectors which contain P300 with label +1 and other vectors with label Y=-1 are entered to the model to train the classifier. With having W and placing it into the relation (2) , the largest output for input of 13 feature vectors corresponding to 13 options are computed whereupon user's intended option is indentify and transmitted to Com2 in order to corresponding movement is applied to the virtual environment.

B. *Changing the Velocity*

Only the signal of channel C_z is used to change the velocity in real time with 256 Hz sampling rate. This process is begun by transmitting a flag to Com2 from Com1. In the Com2, a signal is recorded for 5 sec and in this time, user is able to change velocity during passing through two moving spheres via changing power of alpha band in rang of 8-11 Hz by closing and opening her/his both eyes, about each 250 ms . Power of the above signal is computed by using Zero-Padding and calculating 512 pt. FFT each 250 ms, and compared with the alpha band power threshold. The threshold is obtained from each user in the beginning of each test in the state of relaxing and opened eyes. After comparing, corresponded velocity factor is transmitted to the Com1 each about 250 ms to apply to the virtual environment.

VI. RESULTS

The system has been evaluated for four healthy, male young participants with the mean age of 25.87 years old. One session for introducing with the system, one for training and acquiring proper weights, two sessions for four times system validation is composed of choosing destination and passing through moving obstacles are specified for each user. The validation results are shown in the Table I and Table II.

TABLE I. Results of P300- based system for four times evaluation for each participant

Participant	Average of number of correct recognition from 13 cases	Mean recognition accuracy
No1	10.5	80.7%
No2	11	84.6%
No3	11	84.6%
No4	10.5	80.7%
Average	10.75	82.69%

TABLE II. Results of alpha-based system for five times passing through moving obstacles.

Participant	No. of no-collision passing from 5 passing	recognition accuracy
No1	4	80%
No2	5	100%
No3	5	100%
No4	4	80%
Average	4.5	90%

VII. CONCOLUTION AND SUGESTION

With considering the explanation of last parts, the proposed system unlike past works which use complicated software and hardware systems based on the planners and complicated sensors, only performs based on the brain waves. Meanwhile, it has the acceptable precision compared with other works, by using very little channel number and has high ability in reaction to the dynamical environment, for appalling as the EW for the individuals have sever motor disability. According to the essence of P300 in the perceptual brain activity and prepared the virtual environment, current system is the suitable platform for neurofeedback Experiments.

The single trial P300 detection, using more channels and applying training session for alpha band control without using closing and opening eyes can be benefit in the sake of reducing identification time of user's aim, increasing accuracy and applying the system for persons who are not able to voluntary blink.

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