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Research Article

Simplified Human Computer Interface Design Using EEG Signals

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ABSTRACT

Brain Computer Interfaces (BCI) are applications that allow users to communicate and control external devices directly by analyzing changes in brain activity without using muscle and nerve cells, which are normal pathways of the brain. It can also be said that BCIs are an alternative means of communication between the human brain and the outside world based on the electrical activities of brain activity, which can be measured by electroencephalography (EEG) devices. In the EEG measured from the human brain, when a person wants to move a limb, the potentials associated with the event are observed in the EEG. This suggests that information about changes in the activity of the human brain in the cognitive or movement decision process can be detected in the observed EEG.In this study, the attributes of the signals obtained using a four-channel EEG recorder are extracted and classified. Because the experimental study was performed while the user was awake, it processed beta signals. Considering the artifacts, the processed data was used as input data for the interface by realizing offline and online trial. The data obtained from the EEG device was processed in a computer and transmitted to a microcontroller used to control the model vehicle. Data communication is carried out wirelessly. The model vehicle is allowed to move forward-backward / right-left and diagonally.

Introduction

With the development of technology, human beings have tried to understand how the brain works more and combine it with innovative methods to communicate with the computer. The system that performs this process is generally called the Brain Computer Interface. Realization of the communication of the brain with the computer People who have brain damage but whose physical work is not damaged, people who cannot use their muscles, people with Multiple sclerosis (MS), amyotrofik lateral skleroz (ALS) or spinal cord injury can use BCI applications after trauma or impact. Thus, the lives of these people using BCI tools can be easier than their current situation. BCI is a link between human brain and computer. Unlike logical input devices (mouse, keyboard etc.), the BCI reads the waves generated from the brain at distinct spots in the head, converting these signals into movements and turning them into commandments that can control the output units.The BCI converts brain signals into outputs that transmit a user's purpose [1]. Since this communication channel is not connected to peripheral nerves and muscles,

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it can also be used by people with severe motor impairment. BCI allows patients who are completely paralyzed or locked by brain stem paralysis or other neuromuscular diseases in ALS to express their wishes to the outside world [2]. The BCI tools consist of data detection, attribute extraction, attribute conversion and output devices, and a protocol that is responsible for the management of these four components, which determines the start, end and run timing of the system.

There are studies in the literature that take EEG signals as inputs and analyze these input data and operate the corresponding output unit. In Banik et. al.'s study [3], a brain-controlled device was designed and EEG signals were studied for 3 states of mind (sleep, meditation and listening to music). In order to detect different mental states, EEG signals were taken from the brain with the EEG module on the developed device and used to move the vehicle back and forth. With this system, it is aimed to provide a new world of interaction to those who are lockedin syndrome but are cognitively sound and awake. In Ozturk et. al.'s study [4] the movement of a toy car is provided with real-time EEG data and head movements. Sevgili and Akin [5] worked on EEG signals of cursor movements classification. Li et. Al [6] improved quantum support vector machine with the arbitrary nonlinear kernel for prediction the label of the EEG signal.

Background

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The nerve cell, also known as neuron, is the unit whose primary function is to carry information and form the nervous system as a whole. All kinds of behavior arise from the activity of grouped neurons in different parts of the human brain. In order for neurons to communicate, a communication channel must be established. Neurons consist of three main parts called axon, dentrid and soma.

When a neuron explodes, signals are sent to all neurons connected to their axons via dendrites. Dendrites can be connected to a large number of axons. When the total input reaches a certain threshold, the neuron fires and sends a signal at its own axon. The power of this output signal is the same regardless of the size of the input. The basic functions of the neurons are to receive the signal that carries the information, to combine it with itself in order to understand whether the incoming information can be transmitted to the destination, and as a final process, to deliver the incoming signal wherever the target system is.

The human brain, which has many common features with other vertebrate brains, is the most important organ of the central nervous system. Understanding the parts of the brain will be useful for understanding the signals from the brain. Figure 1 shows sections of the brain.

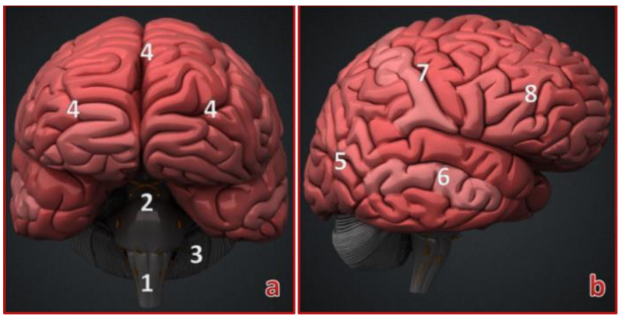

Figure 1 Brain sections b) Serebrum sections

The brain is mainly examined in four sections (Figure 1.a). The Brainstem (1) performs basic body operations autonomously without the need for conscious thinking. Limbic System (2) includes thalamus, hypothalamus and amygdala. The limbic system plays a central role in the realization of behaviors such as fighting or escaping. The cerebellum (3) is responsible for posture, balance and sensitive movements. Cerebrum (4) fulfils high brain functions such as conscious thinking, action selection and control.

The cerebral cortex is divided into four basic subsections called lobes (Figure 1.b). The occipital lobe (5) is a low-level visual-spatial processing center of the brain, such as color separation and motion detection. The temporal lobe (6) is responsible for long-term memory. The parietal lobe (7) combines resources associated with the outside world, such as internal sensory feedback from the skeletal system, muscles, head and eye. The frontal lobe (8) is the area where our eyes and limbs are controlled, where most of the conscious thoughts and decisions involving voluntary movements and motor parts are found.

Biomedical signals

Electrical or non-electrical signals detected by electrodes or transducers from a living biological organism are called biological signals. Biological Signs of electrical origin are obtained by medical measurement methods;

- *ECG (Electrocardiogram)*
- *EMG (Electromyogram)*
- *EEG (Electroencephalogram)*
- *ENG (Electroneurogram)*
- *ERG (Electroretinogram)*

EEG signals

The biological signals obtained as a result of neural activity of the brain are called EEG (10 µV to 100 µV in amplitude; 0.5-50 Hz band). EEG is a physiological signal capable of reflecting the underlying processes in the brain for understanding human behavior and inferring conclusions [7,8].

EEG is the electrical monitoring of brain waves. Both the alertness and electrical activity produced by the nerve cells in the brain during sleep are printed as brain waves on paper. Owing to EEG, brain electricity is made visible in a simple way. The EEG device receives the brain electricity and saves it on paper by strengthening it. The amplitude of the EEGs detected over the head is 1-100 µV from top to top and the frequency band is 0.5-100 Hz [8].

When the brain produces a neural activity, a huge number of signals could be applied for the BCI. These signals are divided into two categories: field potentials and spikes [9]. Spikes projects the action capacity of single neurons and are obtained owing to microelectrodes inserted by invasive methods. Field potentials are a reading of the unified synaptic, neuronal, and axonal activities of the neuron sets and can be weighed by EEG or inserted microelectrodes. The ordination of EEG signals by frequency /bands is given below (Figure 2).

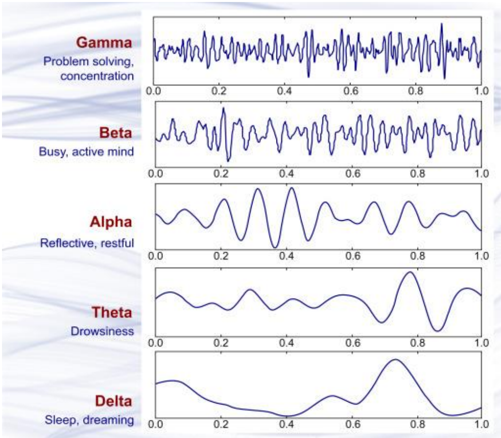

Figure 2 Brain waves in normal EEG [10]

a) Delta (δ) signal: The frequency range is 0.5-4.5 Hz and the amplitudes are 20-400 µV. The amplitude inclined in the slowest and to be the highest waves. It is observed ordinarily in adults in deep sleep and in infants.

b) Theta (θ) signal: The frequency of these signals varies between 3.5-7.5 Hz and their amplitude varies between 5-100 µV. Theta is connected with insufficiency and dreaming. Actually, the measure of theta exemplifies the route of being awake or asleep. In adults, high levels of theta are considered abnormal.

c)Alpha (α) signal: This signal frequency ranges between 7.5 - 12 Hz and amplitudes range from 2-10 µV. Hans Berger called the first rhythmic EEG activity he saw as “alpha wave” [11]. It appears by closing eyes and loosening. It is about resting and before falling asleep.

d) Beta (β) signal: Beta is a brain signal in which the frequency ranges between 12 Hz - 30 Hz. Amplitudes vary between 1-5 μV. Beta waves are usually divided by β1 and β2 to obtain a more particular scope. These signals are small and fast, for example, when withstanding or compression a movement or solving a math task. In such cases an increase in beta activity is observed.

e) Gamma signal: A signal with a frequency area of 31 Hz and above. The amplitudes are less than 2 μV. Reflects the mechanism of consciousness [12]. They carry the characteristic sign of sleep [13]. The gamma wave is seen in the 4th stage of sleep, in moments of learning, in moments of extreme happiness and difficult to detect by EEG.

Types of BCI

The main purpose of BCI devices or variants is to capture electrical signals passing between neurons in the brain and convert them into a signal detected by external devices [14]. As shown in figure 3, there are three types of BCI signal collection methods.

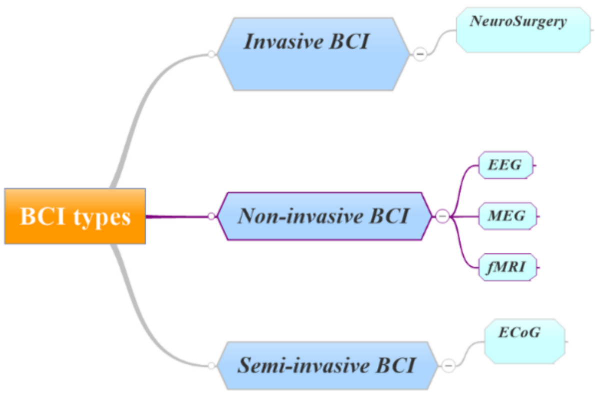

Figure 3 BCI signal collection methods

The first of these methods is that invasive BCI devices are placed directly into the brain and have the highest quality signals. These devices are used to provide functionality to people with stroke [15,16]. These devices, which are standing in the gray matter in the brain, produce the highest quality signals of the BCI devices. But when they react to a foreign object inside the brain in the body, they cause the signal to weaken or even disappear [14]. Second, Non-invasive BCI has minimal signal clarity as it disrupts the skull signals when it comes to communication with the brain. However, it is thought to be safer compared to other interfaces as it does not require any intervention to the brain [17]. The non-invasive technique is a technique in which medical scanning devices or sensors are mounted on the headbands and reads brain signals. It reads the signals less effectively because the electrodes cannot be placed directly in the desired part of the brain. EEG is easy to use, cheap and portable [14]. Third, partially invasive BCI devices are placed inside the skull, but not inside the gray matter, outside the brain. The signal strength here is slightly weaker compared to invasive BCI.

BCI Process Steps

The signals obtained in an EEG-based BCI system are transmitted to the application interface after entering the pre-processing, feature extraction and classification stages (Figure 4). The general structure of the brain computer interfaces consists of five main steps.

Signal acquisition: Signal acquisition is the first step in the BCI process. Considering that the brain is simply composed of parts that perform different operations, the electrodes to be placed close to the relevant section provide information about that region. BCI systems are realized by analyzing different combinations of electrodes and electrical signals received from these electrodes in different ways. There are three ways to detect the electrical reflections of electrochemical interactions of electrodes and neurons in BCI systems [18]. The electrodes are placed directly into the brain shell as micro electrodes. In this method, the skull is opened and the micro-electrode matrix is attached to the brain by an operation [2,19]. This method is also called an invasive method. The skull is opened, but this time the electrodes are not inserted into the brain's shell, but are laid on the brain shell in the form of an electrode matrix. The electrodes here are not micro structured as in the first method. This method is called partial invasive. Electrodes attached to the skull with a conductive gel are used. This method is called non-invasive technique.

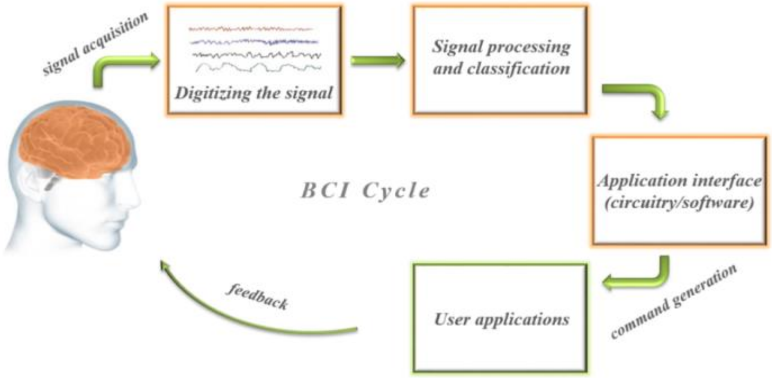

Figure 4 BCI functioning block diagram

Extracting an attribute: Digitalized signals are subjected to many analyzes, such as spatial filtering, voltage amplitude measurements, spectral analyzes, or single neuron separation. This analyzes reveal the signal properties of user-encoded messages or commands [2]. In order to use the recorded signals purposefully, some features that best express the signal should be determined and studied with these features. Extraction is the process of purifying neurophysiologic signals from noise and other unnecessary information, but at the same time preserving the distinctive characteristics of the signal. Another purpose of the feature extraction process is to reduce the size of the data to be classified. The selection of the attribute is done in such a way as to answer the questions about which features will be selected and what the amount will be [20].

Conversion algorithm: The conversion algorithm converts the signal properties into device command orders in order to fulfill the user's requests. Each independent algorithm (such as signal properties) is converted to dependent algorithms (such as device commands) [2]. Classifiers used in BCI research can be grouped as linear classifiers, neural networks, nonlinear bayes classifiers, closest neighborhood classifiers, and combined classifiers.

Output device: Today, many devices can be used as output units. These are the orthosis devices, especially the monitor, which output unit to use can be determined according to the needs of the user.

Operating protocol: BCI has a protocol that manages and maintains operation. This protocol provides feedback to the user by managing processes such as system on and off, frequency and format of use.

Materials and Methods

This section describes the steps of operating an output unit designed as an embedded system by processing and classifying the signals received from the EEG device.

System Design

The BCI control system developed within the scope of this study includes three subsystems: signal processing system, interface and vehicle control system. The signal processing system records analyzes and converts EEG signals from the computer into control commands. The interface system, on the other hand, transmits signals received from the Muse EEG to the microcontroller (arduino) via bluetooth to determine the model car motion states and to monitor the commands sent to the model car. The control system receives control commands and converts them into electrical signals to drive the vehicle (Figure 5).

EEG signals were obtained from four different male volunteer participants (age range 22-26, average 24). Users were informed about the experiment before recording EEG signals. Muse EEG device was used to obtain the signals (Figure 5.b). Figure 6 shows the plan of the

Figure 5 a) Prototype of the developed model b) EEG device used in this study c) software developmentinterface

electrode placement of the Muse EEG. The EEG device used in the research can receive data from four channels as TP9, AF7, AF8 and TP10.

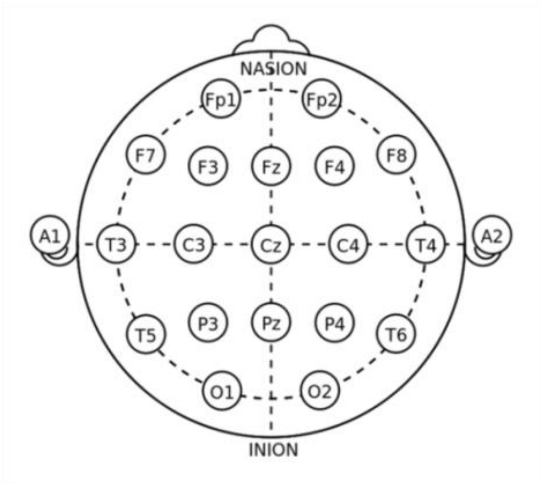

Figure 6 Muse electrode placement scheme according to 10-20 international standards

In the study, a remote-controlled model car with a working frequency of 2.4GHz, which was reduced by 1/12. The model car, which is guided by using radio frequency, can be used as full function as forward-back-right-left and cross.

With the microcontroller, the code written in Python language which enables the movement of the vehicle is executed and this is transmitted to the control of the vehicle in real time. Thus, the movement of the vehicle is ensured by EEG signals.

The attributes of field potential signals are different from each other. These threshold values also differ. The threshold value for beta varies from person to person. Considering the data obtained from the offline trial from four volunteers participating in the experimental study, the threshold value for the beta was determined as 20%. A distinctive increase in beta signals is observed in the motions performed while the person is awake. For this reason, in this experimental study, the attributes of beta signals received from the user are extracted and used as input data for the interface.

System operation

Both offline and online users' experience has been taken for the operation of the system. In both stages, users were asked to mount the EEG device.

In the offline trial, users were asked to use the remote control for the model car and move the car forward, backward, right and left. In this process, data were obtained with EEG device.

In the online trial, users were asked to concentrate on moving the car without using the model car controller and explained how they could “use their heads” for direction. In the case of no concentration, “eye closure” is mentioned. If they are concentrated, the car is activated and the “chin tightening” is explained to stop the car.

With the obtained EEG signals, the car was started to move and stop. In this process, online EEG recordings of the users were obtained.

For the Beta values calculated from the EEG raw output obtained from four channels with the EEG device, the range was determined as 0.20. If the average Beta value obtained from four channels is above 0.20, the concentration value required for the movement of the model car is provided. When this threshold value is exceeded, the car moves forward. When this value is below 0.20, no movement is possible.

The movement of the head in the right, left, front and rear directions is determined by the gyroscope on the Muse EEG and the forward, back, right and left movements of the vehicle are defined. Field potentials also change when some motor movements occur. EEG recorders can detect and filter artifacts such as heartbeat. The beta value change in the “chin tightening” motion was determined to be used as an input data to stop the vehicle.

In Ubuntu, a Linux-based operating system, to transmit information from the EEG to microcontroller, Muse is paired with Bluetooth, then MuseIO is used to connect to Muse with the following codes.

muse-io - -device “MAC address of the matching muse device” --dsp --osc osc. udp: //localhost: 5000

The software that will analyze the data that contains Muse device information and move the car is run with Python code to be written to Terminal in Ubuntu operating system (python beta.Py).

The interface developed as a result of the execution of this code shows whether the device moves with concentration or not, and if it is moving, the direction of the device is determined by the gyroscope.

In case the required concentration value could not be provided, the “eyes closed” was used as an alternative method for movement. The value obtained as a result of “eyes closed” made the vehicle move forward. The flow chart of this system designed in figure 7 is given.

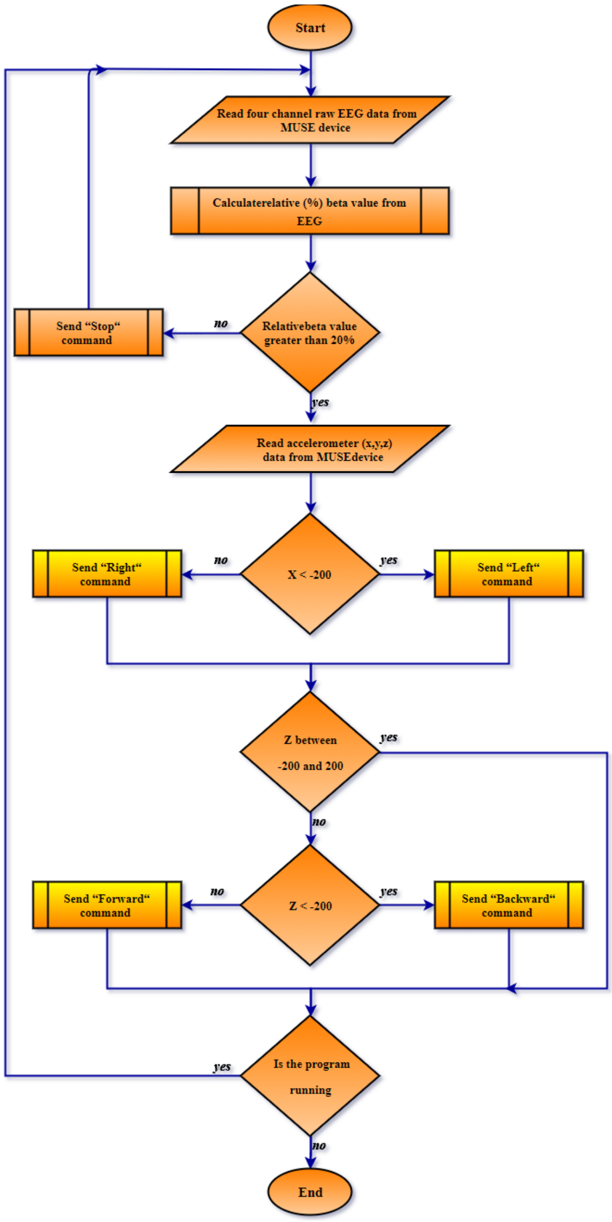

Figure 7 Designed system general flow chart

Results

In the interface designed within the scope of this study, first the beta value from four channels are read and the average value is obtained. If the value calculated for beta is below the threshold value (20%), the EEG record continues to be read from user. If the beta value is above the threshold value, direction information is obtained by using the gyroscope located on the muse device (2D, xz). Unless an interrupt occurs, the process loops. Interrupt is the deterioration in beta signals that occur during the " chin tightening" action.

In figure 8, a screen shot of the developed interface is presented. The value of the obtained beta signal is 0.295428350568, exceeding the specified threshold. Thus, the vehicle moves. It is seen that the direction information is forward with the forward movement of the head obtained from the gyroscope on the EEG Muse. It is also understood that the obtained signal value is good.

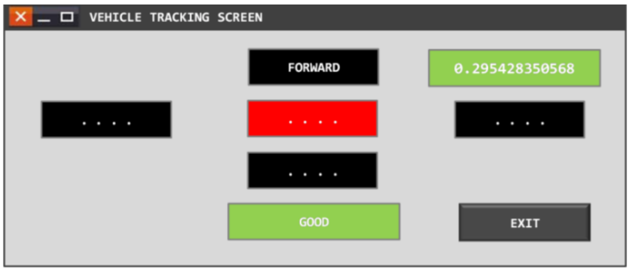

Figure 8 Forward acceleration of the model car in the interface software developed in Python

The value of the beta signal obtained is 0.250078838319, which exceeds the specified threshold. However, because the necessary “chin tightening” movement is made to stop, the vehicle appears to be stopped and parked (Figure 9).

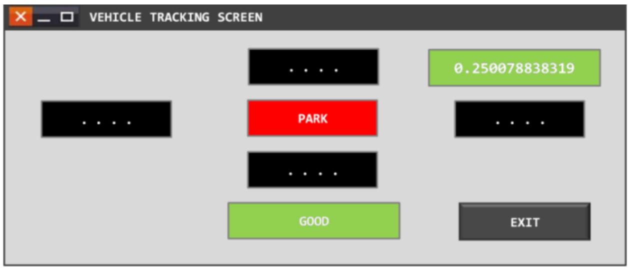

Figure 9 Stopping the model car in the interface software developed in Python

Discussion and Future Works

The aim of this study is to measure and evaluate the electrical signals in the brain and to activate a radio-controlled model car and to direct the model car movement with an EEG device with accelerometer. The desire of the user to move any limb is called motor intent and causes a change in the motor cortex in brain signals. Therefore, hand movements (physical and imaginary) can be observed mainly in the motor cortex of the brain [21]. Alpha and beta activities in the sensorimotor cortex change at the moment of motor intention [4]. Beta signal measurement as the electrical signal to be measured was successful. In the evaluation phase, the threshold value and the target of moving the radio-controlled car in the forward direction was achieved. In addition, the EEG device used in the research has been used to determine the direction of movement of the device in the measurements made according to the mass position of the device and these values have been successfully transferred to the radio-controlled model car. In this experimental study, the communication with the microcontroller was realized in real time. In order to minimize the delays caused by the microcontroller structure, it will be beneficial to use hardware interfaces with less latency time tolerance in future studies. Using microcontrollers with a BUS structure, such as ARM® architecture, with a multi-stage pipeline structure with minimum interrupt latency, which allows the use of embedded cache for data transfer, as well as the buffer structure, will reduce the total delay time.

In the study, since the device has four channels, mathematical operations have been performed by taking into consideration the values from here and the radio-controlled model car has been directed. If EEG headbands or EEG devices with more channels are used, an even clearer signal measurement will be obtained as the diversification of incoming data will be greater. The results obtained from this study confirm the results obtained from similar studies in the literature [3,4]. Using EEG signals and motor movements together as input makes this study different from similar ones. These study results are important in terms of showing that the required concentration can be achieved while recording EEG signals during physically performed motor movements. Systems designed in these and similar studies can also be used to increase focus, especially in children with attention deficit and hyperactivity disorder. It is possible to use such structures in the entertainment games and toys sector.

In addition, the low-cost design of interfaces on different platforms will expand the application areas of these systems as it is performed in this study which facilitates the classification and use of data obtained from EEG devices. In future studies, multiuser applications can be made in which direction information is obtained by using EEG signals. Users with different demographic characteristics can be selected as a sample. It will contribute to the literature to make applications where EEG signals obtained from male and female participants are compared and used as input data. The use of multi-channel EEG recorders with less artifact tolerance will increase the reliability of the studies.

References

[1] Wolpaw JR, Birbaumer N, McFarland DJ, Pfurtscheller G, Vaughan TM. "Brain–computer interfaces for communication and control". Clinical neurophysiology, 113(6), 767-791, 2002. https://doi.org/10.1016/S1388-2457(02)00057-3

[2] Leuthardt EC, Schalk G, Wolpaw JR, Ojemann JG, Moran DW. "A brain–computer interface using electrocorticographic signals in humans". Journal of neural engineering, 1(2), 63, 2004.

[3] Banik BC, Ghosh M, Das A, Banerjee D, Paul S, Neogi, B. "Design of mind-controlled vehicle (MCV) & study of EEG signal for three mental states". Devices for Integrated Circuit (DevIC), Kalyani, Nadia, India, 23-24 March, 2017. https://doi.org/10.1109/DEVIC.2017.8074065

[4] Öztürk N, Yilmaz B, Önver AY. "Real-Time Robotic Car Control Using Brainwaves and Head Movement". Medical Technologies National Congress (TIPTEKNO), Magusa, Cyprus, 8-10 November 2018. https://doi.org/10.1109/TIPTEKNO.2018.8596956

[5] Sevgili, Z., & Mehmet, A. K. I. N. (2019). İmleç Hareketlerine Ait EEG Sinyallerinin Sınıflandırılmasında Adaptif ve Adaptif Olmayan Filtrelerin Uygulamaları. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 11(1), 57-67.https://doi.org/10.24012/dumf.584345

[6] Li, Y., Zhou, R., Xu, R., Luo, J., & Jiang, S. X. (2020). A quantum mechanics-based framework for EEG signal feature extraction and classification. IEEE Transactions on Emerging Topics in Computing. https://doi.org/10.1109/TETC.2020.3000734

[7] Ergün E, Aydemir Ö. "Etkin epoklar ile motor hayaline dayalı EEG işaretlerinin sınıflandırma doğruluğunun artırılması". Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 24(5), 817-823, 2018.

[8] Sezer E. "EEG signal analysis for the diagnosis of epilepsy". Doctoral dissertation, Selçuk University,Konya, Turkey, 2008.

[9] Wolpaw JR. "Brain-computer interfaces: signals, methods, and goals". In First International IEEE EMBS Conference on Neural Engineering, Capri Island, Italy, 20-22 March 2003. https://doi.org/10.1109/CNE.2003.1196894

[10] Abhang, P. A., Gawali, B. W., & Mehrotra, S. C. (2016). Introduction to EEG-and speech-based emotion recognition. Academic Press. ISBN: 9780128044902

[11] Lebedev MA, Nicolelis MA. "Brain–machine interfaces: past, present and future". TRENDS in Neurosciences, 29(9), 536-546, 2006. https://doi.org/10.1016/j.tins.2006.07.004

[12] Ramadan RA, Refat S, Elshahed MA, Ali RA. Basics of brain computer interface. Brain-Computer Interfaces Editors: Hassanien AE, Azar AT. Basics of Brain Computer Interface (pp. 31-50). Springer, Cham, 2015.

[13] Novák D, Lhotská L, Eck V, Sorf M. "EEG and VEP signal processing". Cybernetics, Faculty of Electrical Eng, 50-53, 2004.

[14] Anupama HS, Cauvery NK, Lingaraju GM. "Brain computer interface and its types-a study". International Journal of Advances in Engineering & Technology, 3(2), 739, 2012.

[15] Ang KK, Chua KSG, Phua KS, Wang C, Chin ZY, Kuah CWK, Guan C. "A randomized controlled trial of EEG-based motor imagery brain-computer interface robotic rehabilitation for stroke". Clinical EEG and neuroscience, 46(4), 310-320, 2015. https://doi.org/10.1177/1550059414522229

[16] Mane R, Chew E, Phua KS, Ang KK, Robinson N, Vinod AP, Guan C. "Prognostic and Monitory EEG-Biomarkers for BCI Upper-limb Stroke Rehabilitation". IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2019. https://doi.org/10.1109/TNSRE.2019.2924742

[17] González M, Rojas E, Bolaños W, Segura JP, Murillo L, Solano A, Yu L. "Auditory imagery classification with a non-invasive Brain Computer Interface". 9th International IEEE/EMBS Conference on Neural Engineering (NER), CA, USA, 20-23 March 2019. https://doi.org/10.1109/NER.2019.8716946

[18] Argunşah AÖ, Çürüklü AB, Çetin M, Erçil A. "EEG Tabanlı Beyin-Bilgisayar Arayüzü Sistemlerinde Sınıflandırmayı Etkileyen Faktörler". IEEE 15th Signal Processing and Communications Applications Conference, Eskisehir, Turkey, 11 - 13 June 2007

[19] Behm A, Kollotzek MA, Hüske F. "Brain Computer Interfaces–Controlling computers by thoughts", 2006. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.187.9534&rep=rep1&type=pdf (4th May 2019).

[20] Hyvärinen A, Oja E. "Independent component analysis: algorithms and applications". Neural networks, 13(4-5), 411-430, 2000. https://doi.org/10.1016/S0893-6080(00)00026-5

[21] Chatterjee R, Bandyopadhyay T, Sanyal DK, Guha D. "Comparative analysis of feature extraction techniques in motor imagery EEG signal classification". In Proceedings of First International Conference on Smart System, Innovations and Computing, Jaipur, RJ, India, 15 - 16 April 2017. Springer, Singapore.