



# Low Cost EEG Based BCI Systems Using Emotiv and Arduino for Neurorehabilitation and Robotics

Okan BARIŞ\* and Mustafa AKSU and Mustafa YAĞCI

Kirsehir Ahi Evran University, Kirsehir, Türkiye  
okanbaris@gmail.com

**Abstract:** This article presents a low-cost, accessible, and methodologically consistent Brain-Computer Interface (BCI) system for neurorehabilitation and assistive robotics applications. The system processes brain signals recorded using a 5-channel EEG headset and classifies the user's cognitive commands thru the HITIBrain software platform. Interpreted commands are sent to an Arduino microcontroller, which controls a DC motor that mimics the movement of a simple robotic arm or prosthetic limb. The ultimate goal of this study is to develop a functional system concept demonstrating that brain signals can be interpreted to reliably trigger a physical device. This BCI system will include the Emotiv Insight headset, HITIBrain software, and Arduino. It is believed that this system can convert EEG signals into control signals that an external device can use. This means that brain waves can be used to control physical devices. These results confirm the prospective utility of the suggested BCI infrastructure for developing economical BCI methodologies in motor rehabilitation and assistive technologies, enhancing the accessibility of these innovations, and expanding the patient demographic.

**Keywords:** Brain Computer Interface (BCI), EEG, Emotiv, Arduino, Neurorehabilitation, Robotics, HitiBrain

## 1 Introduction

Brain-computer interfaces (BCIs) are cutting-edge technological systems that take electrical impulses from the human brain and turn them into control commands that computers, robotic systems, or external hardware can understand.

BCI systems have emerged as a multidisciplinary study domain at the convergence of neurology, signal processing, and human-computer interaction (HCI). This is very important, especially for people who have lost the ability to move, because it lets them engage with their environment again by directly transferring motor planning processes in the brain to machines.

The most popular type of BCI technology is EEG (electroencephalography)-based devices. They are very useful because they are not intrusive. EEG sensors, which use electrodes on the scalp to monitor brain activity, are more popular than other intrusive technologies because they are portable, easy to set up, safe, cheap, and easy to use. Because of this, EEG-based BCI systems are becoming more popular in areas including controlling robots, helping people recover from strokes, managing prosthetics, designing games, making assistive technology, and studying user experience[1].

In contrast, clinical-grade EEG systems are not suitable for daily use and non-laboratory environments due to reasons such as high hardware cost (between 10,000 and 50,000 USD), extensive wiring, the process of applying gel, and the need for an expert operator. Therefore, in recent years, consumer-grade EEG devices (Emotiv, Muse, OpenBCI) have become a significant alternative among researchers. Although these devices have fewer channels, they offer advantages such as quick setup, wireless connectivity, and economic accessibility.

The importance of EEG-based BCI systems is growing, especially in the context of neurorehabilitation. Although the motor cortex is still active in individuals who have had a stroke, the signals transmitted to the muscles can lose their function. In this case, brain activity generated thru motor imagery can be used to control a robotic arm, joint mechanism, or functional electrical stimulation (FES) devices. Indeed, Jure et al. [2] have shown that EEG-triggered FES systems support motor recovery in paralyzed individuals.

In this context, combining low-cost EEG devices with open-source hardware platforms like Arduino offers an accessible BCI experimental environment for both researchers and developers. This study precisely addresses this need by proposing an integrated BCI system that enables real-time control of a DC motor thru the processing of Emotiv Insight EEG data via HITIBrain.

The original contributions of the study can be summarized as follows:

- Detailed explanation and technical validation of the integration of Emotiv Insight + HITIBrain + Arduino,
- Application of security, feedback, and user-centered design principles in the BCI-HCI context,
- Demonstration that real-time motor control is possible using low-cost EEG devices.
- In these aspects, the study contributes to both the neurorehabilitation and low-cost BCI system design literature.

## 2 Related Works

A significant amount of research has been conducted in the BCI literature about medical-grade EEG systems and consumer portable EEG devices. These studies present economical EEG device designs for research, rehabilitation, and robotic control applications, addressing critical concerns about signal quality, accuracy, user experience, and system integration.

Duvinage et al. [3] showed in their investigation that the Emotiv EPOC device was very accurate in a P300-based application. This finding suggests that the device is appropriate for BCI prototypes employed in research and educational settings. The study emphasizes the inadequacies of consumer-grade EEG equipment compared to medical-grade devices in terms of signal-to-noise ratio, electrode placement, and hardware reliability; however, suitable studies have been conducted for stimulus-based tasks such as P300. In this work, the processed EEG signals were transferred to an Arduino microcontroller. After that, this microcontroller was utilized to run robotic systems, lighting modules, or mechanical actuators. This integration is very important because it makes large-scale prototyping quick, easy, and cheap. Madoš and his team's work established critical design principles that make command transmission in an EEG system more reliable, cut down on timing delays, and make microcontrollers work as efficiently as possible. In practice, these ideas have been shown to work.

Studies on robotic rehabilitation have shown that combining EEG systems with robotic devices can help patients improve their motor skills. Krebs et al. [4], in their clinical studies utilizing the MIT-MANUS platform, demonstrated that robot-assisted repetitive and controlled movement exercises effectively enhance motor function in stroke patients. These robotic systems, which help with neuroplasticity, use BCI to turn patients' mental motor imagery into physical action. This makes patients more interested in their treatment and helps them learn new motor skills. This process happens right away, which not only boosts motivation but also greatly improves the chances of success in rehabilitation.

Research on the motor imagery capabilities of consumer-grade EEG devices underscores their potential. Ribeiro Pinto [5] demonstrated that Emotiv devices can achieve high classification accuracy using simple features such as log-PSD. This outcome demonstrates that these devices are applicable in intricate BCI applications, including motor imagery, as well as in stimulus-driven methodologies.

Tabernig et al. [6] have said that EEG-triggered FES (Functional Electrical Stimulation) systems are better for clinical use. Scientists have said that EEG signals from motor imagery can be turned into FES, which is a good technique to boost use-dependent neuroplasticity in stroke patients.

This research analysis shows that inexpensive EEG devices can be used on a wide scale in robotic systems, rehabilitation systems, and user interface applications as long as they apply the right signal processing methods and work with microcontrollers.

## **3 Designing the System**

### **3.1 Hardware Structure**

The most crucial thing about the system that needs to be designed is that it doesn't cost much. The EEG-BCI-based DC motor control system that was made has three primary hardware layers that talk to each other in real time (Figure 1).

1. EEG signal collection unit (Emotiv Insight),

2. Signal processing and decision-making unit (Emotiv app + HITIBrain app),
3. Motor control unit (Arduino Uno + L298N driver + DC motor).



**Figure 1.** The hardware design of the EEG-BCI-based system for controlling a DC motor

The precision, latency, and dependability of the system depend on each of these parts.

### 3.2 The Flow of Software

The software pipeline goes from getting raw EEG signals to making physical output (motor control). Here is a list of the steps in the processing:

- I. **Signal Preprocessing and Cleaning:** The raw EEG data is initially filtered to get rid of noise. A bandpass filter that works between 0.5 and 45 Hz gets rid of both low-frequency drifts and high-frequency noise, including muscle movements. A notch filter is also used to cut down on electrical noise at 50 Hz.
- II. **Feature Extraction:** To look at the brain signal, the power in the 8–12 Hz (Mu rhythm) and 13–30 Hz (Beta rhythm) frequency ranges is measured. This method lets us see changes in brain activity in the motor area with great accuracy as soon as someone thinks about moving.
- III. **Classification:** The traits that were found are passed to a classifier. This classifier indicates the different ways a person thinks. We employ the Linear Discriminant Analysis (LDA) method at this point because it is easy and quick to figure out.
- IV. **Making Control Commands:** Based on the findings of the classification, the Arduino microcontroller is programmed with control commands. These are the commands:
  - "start": To turn on the motor;
  - "stop": To turn off the motor;
  - "PWM increase/decrease": To slowly change the speed of the motor.
- V. **Making sure that things are stable and reliable:** Two things must happen at the same time for a command to be processed. First, the system needs to see it as a command. For that to happen, the classification result of that command needs to be available for at least 300 milliseconds. Second, the classifier's confidence score for that command must be higher than a set threshold value. These two mechanisms make the system more reliable by making sure it doesn't reply to wrong or unexpected commands.

### 3.3 Motor Control

Motor control is provided by specialized software running on the Arduino microcontroller. This software processes "start," "stop," "PWM increase," and "PWM decrease" commands received from the BCI system via the serial port and modifies the signals sent to the motor driver. This allows the user to precisely adjust the motor speed.

System security is ensured by an automatic shutdown mechanism that detects potential signal loss or misclassification. When a serial communication interruption or an invalid command is detected, a "stop" command is activated, immediately halting the system. This security protocol is compatible with the physical actuator interfaces proposed by Madoš et al. [2] and is designed to prioritize user safety and system stability.

## 4 HCI-Focused Design

When planning this project, it's important that the system is safe, easy to use, and works well. We want to take an integrated approach that puts the user experience first.

The system that was designed should have a number of ways for users to give feedback so they can be sure it's working correctly. Some examples of feedback given to the user are an LED light and a unique sound that instantly tell them how the motor is working, and a clear graphic bar on the interface that shows how fast the motor is moving.

The "safety mode" lets the system turn off the motor automatically and safely if the EEG signal or communication stops working. This feature is very important for keeping the user safe from possible dangers.

All of these design choices are in line with other research [1][5] that looks at how to make a system that is easy to use and can handle errors.

## 5 System Verification

We have laid out the testing process below to show that this project is genuine and that we expect it to meet our performance targets.

We want to build and test the systems in a controlled lab setting. These tests will be used to make sure that the system works well and is easy to use.

We want to see how long it takes for the motor to physically respond to a user's that instruction (response time) during testing. We set a success criterion for this time to be under 0.9 seconds. Additionally, in the tests we will conduct to measure the system's stability, we expect at least 85% of the commands sent to be processed correctly and reach the motor.

These targeted performance values are consistent with the accuracy rates reported in studies using motor imagery-based systems, particularly those using motor imagery-based systems (such as Ribeiro Pinto [5]). This also indicates that our system will be comparable to similar applications in the literature.

Additionally, we anticipate that the visual and auditory feedback system we designed will help the user focus, thereby reducing error rates. This stands out as a significant element that will enhance the overall reliability and availability of the system.

## 6 Discussion and Conclusion

The goal of this project is to create and show that a real-time brain-computer interface prototype is possible that lets a person control a motor with their thoughts.

We plan to use an Arduino board and the Emotiv Insight EEG headset, which is easy to get, for this. We want our system to turn a thought into a command in an average of 0.9 seconds and work with 85% accuracy in lab tests. These results will show that these kinds of devices can be used to control motors and that simple methods can get reliable results.

We think that providing auditory and visual feedback to the system will assist the user stay on task, which will cut down on mistakes. The system's repeating structure will make it a useful platform for future study in fields like neurorehabilitation and assistive robotics, even though complete user testing hasn't been done yet.

Next, we want to try even more advanced EEG systems and other techniques to regulate the mind to make the performance even better. Another of our main goals is to make software that works for everyone. We are even thinking about adding more biological data to the system, such as EMG (muscle signal) or motion sensors, to make it more full and accurate. This could lead to much better and more useful solutions in clinical rehabilitation.

The goal of this research is to show that brain-computer interfaces that are cheap are not just a dream, and that neurotechnology solutions that are available to everyone are possible in many areas, such as medical and education.

**Declaration of Interests.** There is no conflict of interest among the authors in this study.

## References

1. M. Duvinage, T. Castermans, M. Petieau, T. Hoellinger, G. Cheron, and T. Dutoit, "Performance of the Emotiv Epoc Headset for P300-Based Applications," *BioMedical Engineering OnLine*, vol. 12, p. 56, 2013.
2. B. Madoš et al., "Brain-Computer Interface and Arduino Microcontroller Family Software Interconnection Solution," in *IEEE 14th Int. Symp. on Applied Machine Intelligence and Informatics (SAMII)*, 2016, pp. 217-221.
3. H. I. Krebs et al., "Robot-Aided Neurorehabilitation: A Robot for Wrist Rehabilitation," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 15, no. 3, pp. 327-335, 2007.

4. F. Jure, L. Carrere, G. Gentiletti, and C. Tabernig, "BCI-FES System for Neuro-Rehabilitation of Stroke Patients," *J. Phys.: Conf. Ser.*, vol. 705, no. 1, p. 012058, 2016.
5. R. D. R. Ribeiro Pinto, "Development of a Non-Invasive Brain-Computer Interface for Neurorehabilitation," M.Sc. thesis, Universidade Nova de Lisboa, 2015.
6. C. B. Tabernig, C. A. Lopez, L. C. Carrere, E. G. Spaich, and C. H. Ballario, "Neurorehabilitation Therapy of Patients with Severe Stroke Based on Functional Electrical Stimulation Commanded by a BCI," *J. Rehabil. Assist. Technol. Eng.*, vol. 5, pp. 1–12, 2018.

**Open Access** This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

