Final Report for Computer Systems Research Lab

Brain-Computer Interface Based RC Car Control Using EEG Technology and Arduino Integration

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Dr. Yilmaz Period 3

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Abstract

This project explores the development of a Brain-Computer Interface (BCI) controlled RC car using EEG technology and Arduino integration. By translating facial expressions into motion commands, the system offers an alternative to traditional manual controls, enabling hands-free operation. This innovation is particularly relevant in the context of assistive technology for individuals with physical disabilities. The prototype uses the EMOTIV EPOC X headset and integrates real-time signal processing with Arduino-controlled motors to validate directional control.

Introduction

Traditional RC cars require physical manipulation via joysticks or remotes (Saikrishna et al., 2017). This presents significant barriers to individuals with physical disabilities. Motivated by the need for inclusive technology, we identified a gap in intuitive control systems that eliminate manual interaction. We wanted to use facial expressions as a method of control, as this would use only brainpower to control an RC car. Facial expression detection is a possibility using EEG-captured brain signals (Al-Nifjan et al., 2017). The project idea originated from coursework in assistive technology and realizations that assistive technology is not as effective as it could be. The challenge of transforming brain signals into motor commands inspired us to bridge embedded systems and brain-wave control. Figure 1 above shows our initial EMOTIV setup to achieve 100% connectivity amongst our nodes.

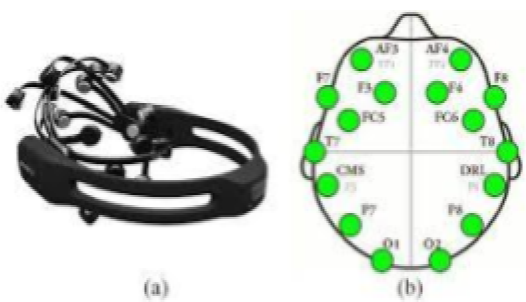

Figure 1. EMOTIV EEG Node Layout

Background

Brain-computer interfaces (BCIs) are systems that enable direct communication between a user’s brain and external devices. EEG-based BCIs are non-invasive and affordable, and are versatile with its possible applications in research. A particularly affordable and efficient EEG is the EMOTIV EPOC X headset, which captures EEG signals and processes them using software and an open-source software development kit (SDK).

Currently, most RC car control systems require manual inputs, either in the form of remotes or joysticks. These control mechanisms can be strenuous due to the attention, effort, and dexterity involved. Some alternative methods such as motion-based or voice-activated control systems still depend on physical movement or vocal commands, limiting their effectiveness in assistive scenarios. Additionally, some methods for RC car control include using pre-installed commands but these solutions don’t provide flexibility for control in situations where adaptations are required.

Applications

Our project has broad applications beyond simply hobbyist robotics. In assistive technology, it can serve as a model for controlling wheelchairs, prosthetic limbs, or any other mobility devices for users with limited physical input capabilities (Chaudhary et al., 2016). In the education system, it can be used to demonstrate concepts in machine learning and neuroscience. It also serves as an experimental platform for signal classification and hopefully provides a potential novel solution to adaptive control algorithms. By removing the need for physical interaction, the BCI-based system opens up many new avenues for inclusive design.

Methods

We began by capturing EEG signals through the EMOTIV EPOC X headset, which classifies facial expressions such as blinking, winking, or clenching teeth. These expressions are recognized in the EMOTIV software and passed to a Python script that maps each signal to a specific vehicle command. For example, a right wink indicates a right hand turn. These commands are then transmitted via serial communication to an Arduino board mounted on the RC car. The Arduino interprets the command and activates the appropriate motors. To maintain reliable communication between the software and the hardware components, we tried to secure good connectivity between our EEG readings and our facial expressions. To do this, we would apply generous amounts of saline solution to the EEG nodes so we are able to read the nodes in real time.

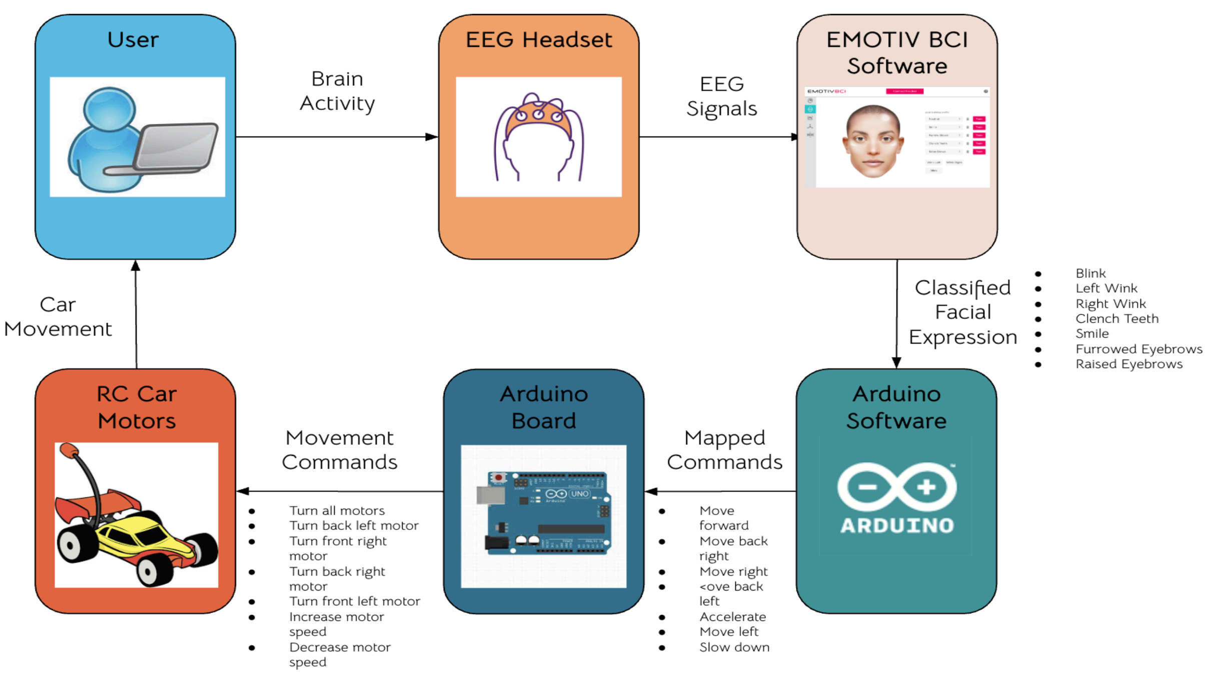

Figure 2: Systems Architecture

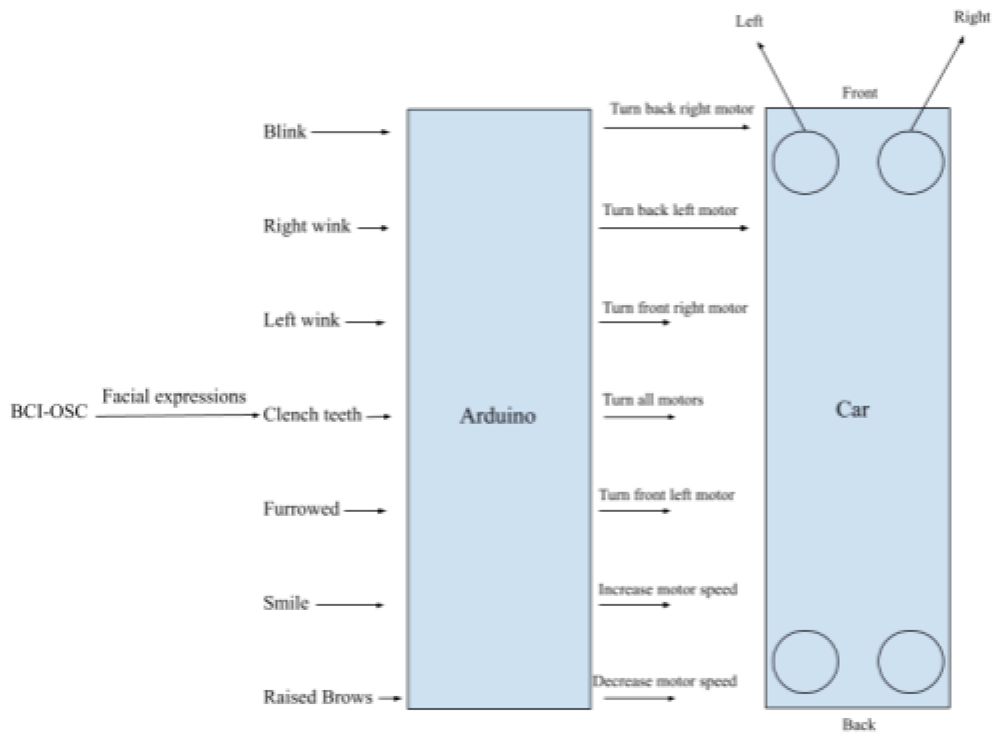

Figure 3: Arduino Systems Integration

A flowchart of our systems architecture shows five main components: signal acquisition, preprocessing, classification, transmission, and actuation. Each of these stages played a critical role in ensuring the accuracy and responsiveness of the system. Figure 2 maps this out visually, showing how brain signals travel from the EEG headset to motor activation via the Arduino. We used packages including EMOTIV-BCI, NumPy, SciPy, Pandas, and MatPlotLib for processing and visualizing data. These libraries allowed us to clean, format, and analyze EEG readings, as well as track command execution latency. Calibration was a key step, as expression patterns varied day to day despite keeping the user consistent. We conducted individualized training sessions using the EMOTIV BCI interface to ensure the system could reliably detect facial expressions for our user, adjusting the headbands and making sure the nodes were in place accordingly. Our system was tested through repeated trials and real-time adjustments were made to improve responsiveness.

As shown in Figure 3, which captures a snapshot of our diagram for what is happening in the Arduino in real time, our systems were clearly mapped out, revised and tested many times.

Results

Our system was successfully able to convert the brainwave-based expressions into motor commands. These commands allowed the RC car to move in various directions. Mainly, we were able to command the RC car to move forward. Precise control of the turning wasn’t achieved, and this could have been a result of the EEG nodes receiving varying saline solution amounts, leading to varying node activation.

We experienced packet loss and latency during the transmission of the EEG data, and the input was highly sensitive in most situations, which resulted in incorrect command responses. Also, the facial expressions used as control inputs had to be repeated at times for a command to be registered successfully due to signal delay.

Although motor commands could be recognized, their consistency varied significantly across different testing conditions. Despite this, we were able to confirm that motor activation could be triggered using the EEG-based commands. Additionally, our system successfully indicated a method for brain controlled vehicle movement while presenting limitations in signal quality and responsiveness that can be addressed in the future.

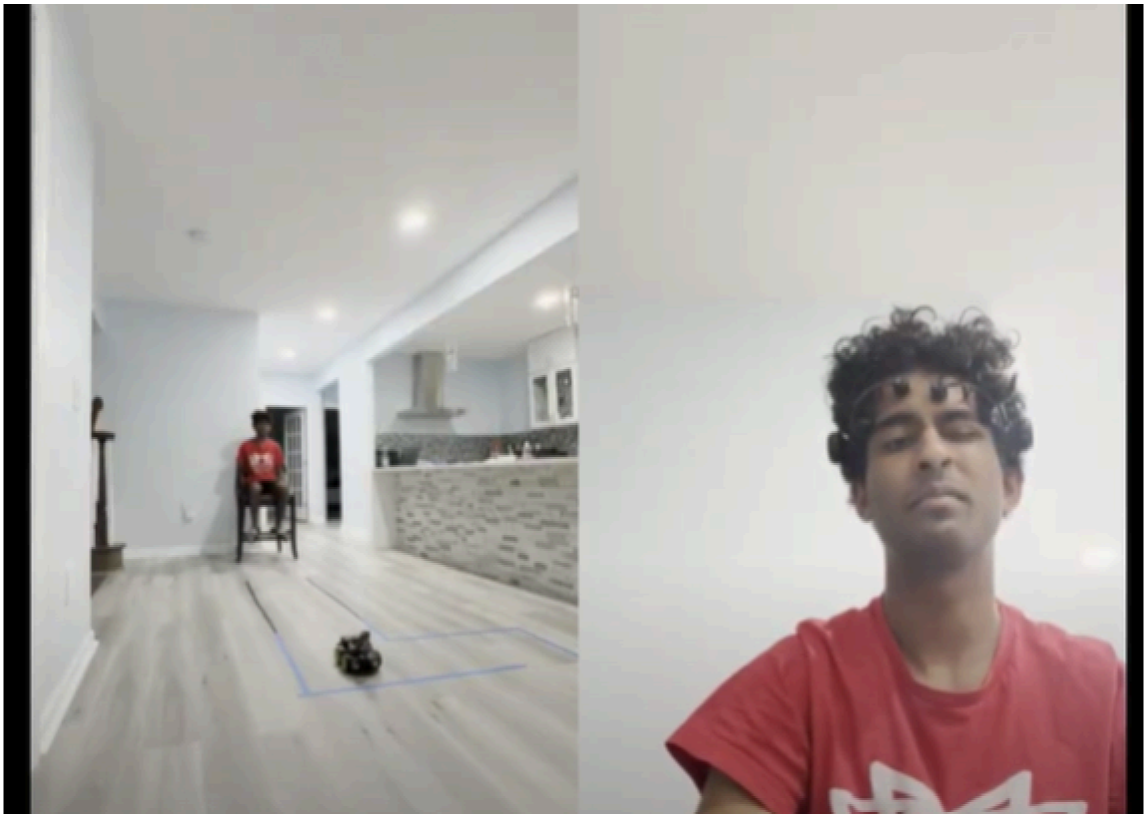

Figure 4: Live Demonstration of Technology

Limitations

While our project demonstrates the possibility and feasibility of EEG-based control for RC vehicles, it also shows multiple limitations that affect the performance of the RC car control system. The main limitations within this system relate to the signal capture, RC car motors, and EEG devices.

Noise and artifacts can often be detected when capturing brainwave signals using an EEG. This can lead to a misclassification of user commands, and the noise can be caused by factors such as inconsistencies in EEG signal strength and user movement. As a result, the reliability and accuracy of the system aren’t as high as it is intended to be.

Also, RC car motors have varied response thresholds, which affect how consistently the RC car can execute identical commands. Small fluctuations in the motor voltage could produce different command responses, making the movement of the vehicle difficult to predict and control.

EEG signals can vary significantly between individuals, creating the need for the system to be calibrated for each user. Without normalization of signal inputs, one user's successful command could fail to be detected when attempted by another user. This variability in brain waves creates the necessity for training to be done on each individual before the usage of the RC car control system.

Lastly, the EEG headset can have limited electrode sensitivity. Over time, signal quality can degrade, and the node sensitivity can vary between different testing environments as there are multiple factors to consider. As a result, the device's performance may not be consistent, leading to possible differences in brain wave readings between different tests.

Conclusion

Overall, the problem that we addressed is the obstacles associated with the current methods of RC car control. Traditional methods of RC car control, such as joysticks and remotes, require manual control, leading to intense physical and mental stress. Additionally, other methods can overly rely on automated control or may lack the adaptability required in RC vehicle control systems. Furthermore, other RC car control systems don't provide accessibility to individuals with physical disabilities, so our system aimed to combat that. We were able to implement fundamental controls for the RC car through our EEG-based system. The RC car can move in all directions using the commands powered by facial expressions.

Future Work

Going forward, we plan to improve the precision of expression-to-command mappings through the use of deep learning classifiers and probabilistic models to reduce misclassification errors in our testing process. Enhancing signal filtering, incorporating feedback loops, and using higher-quality equipment can improve accuracy and provide some more options for our project. Adding models such as obstacle detection, path planning, or mobile app integration could also be extremely beneficial to pushing the limits of this project. We can build classroom kits as well that could allow this technology to be used in STEM education all across the world. Like we previously mentioned, we are also looking to extend this technology to be used in wheelchairs, prosthetics, and other forms of assistive technology in order to combat limb sensitivity issues in patients. Our control system, based on facial expression detection, can be used in existing projects on EEG-controlled wheelchairs using eye movement as well (Siledar & Verma, 2021).

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