A Novel Design of Brain-machine Interfaces for Individuals with Motor Impairments

Abstract

The application of brain-machine interfaces (BMIs) in medicine is an important, yet often underestimated area of research. It has long been hypothesized that BMIs could be used to treat individuals with motor impairments, or at the very least, aid them in completing day-to-day tasks. Individuals with motor impairments find simple tasks like communication through speech or text difficult, leading to the question, can a brain-machine interface enable paralyzed individuals to communicate via various apps on a mobile phone? The research will thoroughly analyze the abilities and limitations of a brain implant to collect signals from the motor cortex, the best models to translate the signals, and the most effective ways to connect the translated data to the mobile phone and applications. Several research journals were examined to formulate a design of a successful brain machine interface. The results supported the hypothesis that a brain-machine interface can enable individuals suffering from motor impairments to effectively use and communicate through a smartphone, because relevant neural signals can be recorded by implanted electrodes and decoded before being transmitted to a speech synthesizer, typing algorithm, and bluetooth-mouse interface to holistically control a mobile phone.

Introduction

While brain-machine interfaces (BMIs) are often associated with superpowers, dystopian societies, and "super soldiers," their ability to significantly improve the lives of those affected by devastating neurological conditions is often overlooked. For decades, BMIs, an emerging technology that provide a direct communication pathway between the brain and an external device, have been in question as a promising solution to motor impairments and debilitating neurological diseases, such as cerebral palsy, amyotrophic lateral sclerosis, Broca's aphasia, and spinal cord injuries. Motor impairments are some of the most common conditions impeding quality of life, with about 1 in 50 Americans experiencing some form of paralysis, according to a study by the Christopher and Dana Reeve Foundation. Fortunately however, some motor and sensory functions lost due to those conditions can be replaced by brain-machine interfaces, as recent research shows that BMIs can, in fact, enable people to control their environment with their thoughts.

A successful brain-machine interface has four integral components: signal acquisition, feature extraction, feature translation, and device output (Jerry J. Shih, et al., 2012). The first component, signal acquisition, encompasses measuring neural signals through sensors such as microelectrode arrays. The signals can then be amplified and filtered before being digitized for the next step, feature extraction. Feature extraction is where the digital signals are analyzed to collect only the relevant parts, such as those corresponding to the individual's intent to speak a word or move a limb. The next step, feature translation, converts the selected features to appropriate commands for the output device, such as a speech synthesizer that imitates the speech activity intended by the brain. Lastly, in device output, the external device executes the commands given to it. Thus, paralyzed people are able to bypass their lost motor, sensory, and cognitive functions by controlling machines with their minds.

One of the first things that paralysed people can be enabled to do through this technology is communicate through a smartphone. With an estimated 6.378 billion people worldwide owning a smartphone (Statistica, 2021), the importance of communicating through apps like messages, email, and phone, is often taken for granted. However, many paralyzed people don't even have the ability to communicate verbally, much less through sophisticated smartphone apps. For instance, conditions like Broca's aphasia can inhibit people's speech, while conditions like quadriplegia disable people's limbs, inhibiting them from effectively using smartphones. However, BMIs can enable these people to speak and use technology through additional devices rather than their own bodies. By connecting an individual's mind to a speech synthesizer, bluetooth mouse, and typing algorithm, brain-machine interfaces will allow them to open and use the phone, text message, and email applications on their smartphones.

Analyzation of Research Sources

To determine how to create a brain-machine interface capable of giving paralyed individuals control over a smartphone, a variety of research sources were analyzed to comprehend signal acquisition, feature extraction, feature translation, and device output. Then, statistical analysis of data from a prominent experiment was conducted to prove the effectiveness of brain-machine interfaces in controlling a given screen.

The general capability of a brain-machine interface to successfully enable the brain to control an external machine has been proven by many experiments, including one by Joseph E.

O'Doherty, et al., titled *A brain-machine interface instructed by direct intracortical microstimulation*. In this experiment, two adult male rhesus monkeys were studied as they completed the task of selecting targets on a screen with a cursor, first through a physical joystick, and then through brain-machine interfaces. The various positions of the cursor on the screen from the different trials were graphed in a time plot to compare the similarity of the joystick and the brain-machine interfaces. The goal was for the graphs to overlap, meaning that the brain-machine interface was just as effective as the joystick in controlling the cursor, therefore establishing that the brain-machine interface was successful in connecting brains to an external machine, specifically a cursor interface for a screen.

After this, the specific logistics of connecting a human brain to a smartphone were studied. Prior research has indicated that brain-machine interfaces involving communication and motor movement should be centered around the cerebral cortex, where motor intent and sensory perceptions are best accessed (Donoghue, 2002). However, for the purpose of connecting an individual to mobile applications, the BMI can be further specified to the motor cortex, which involves the planning, control, and execution of voluntary movements. To accomplish signal acquisition, electrode arrays can be implanted to record brain activity, which is then picked up by EEG electrodes.

The next step, feature extraction, would involve modeling neural signals and algorithms that extract behavioral parameters from large amounts of data from EEG electrodes. The paper *Future Developments in Brain-machine Interface Research* (Lebedev, et al.) suggests the use of electrophysiological readings to model heavy volumes of neural signals, and Kalman filters for identification and extraction of signals regarding intent of speech or movement.

Translation follows extraction of signals and the specific decoding algorithms vary depending on the intended output of the signals. Neural-signals to text translation would involve a filtering algorithm incorporating prior knowledge of the English language to output text corresponding to recorded signals regarding intended speech, while translation of intended movement signals to cuodels with prior knowledge of various neural signals and their corresponding intended rsor movement would involve machine learning mcursor movement.

Lastly, the translated signals must be transmitted to the external device to execute the given signals. In the case of neural signals to text translation, the decoded speech signals would then be executed by a typing algorithm connected to mobile applications like text messages.

Similarly, in the research *Cortical control of a tablet computer by people with paralysis* (Nuyujukian, et al., 2018), decoded movement signals were transmitted to a blue-tooth mouse interface to enable patients to control a tablet's cursor with their thoughts.

Discussion/Conclusion

Brain-machine interfaces indisputably have the potential to aid people in their day-to-day lives. Communication and smartphone accessibility are basic needs that patients suffering from motor impairments often lack, but BMIs are capable of solving this problem.

It was hypothesized that if a brain-machine interface is implanted, individuals suffering from motor impairments will be enabled to effectively use and communicate through a smartphone, because relevant neural signals can be recorded by implanted electrodes and decoded before being transmitted to a speech synthesizer, typing algorithm, and bluetooth-mouse interface to holistically control an electronic device.

This hypothesis was supported by a thorough analysis of the abilities of a microchip to record signals from the motor cortex, the best models to extract and translate the relevant signals, and possible ways to connect the translated data to the mobile applications. To first establish a base for the capabilities of BMIs to record appropriate motor signals, translate them, and transmit them to a machine, results from Joseph O'Doherty et al.'s study *A brain-machine interface instructed by direct intracortical microstimulation* were examined. Data of a monkey's control of the cursor using a brain-machine interface was extracted and compared to the monkey's control of the cursor when using a joystick, which resulted in a p-value of approximately 0.0089, allowing us to reject the null hypothesis that if a brain-machine interface was implanted, its graph of the cursor would not overlap with that of the cursor controlled by the joystick. This proved that if properly built and executed, a brain-machine interface would enable patients to control the movement of a machine, or a feature like a cursor of an electronic device.

In regards to the type of implant necessary to accomplish signal acquisition for control of smart phones, indirect BMIs should be used for paralyzed individuals to complete discrete choices like moving a cursor on a computer screen, since they first record brain activity, while output BMIs send command signals from the cortex. An electrode array to record neural signals and EEG electrodes to read the signals form the base of an indirect BMI.

Next, for feature extraction, Kalman filters would be applied to electrophysiological readings. Thirdly, neural-signal to text and cursor translation would be conducted by machine learning models with prior knowledge of intended movements patterns and the English language. Finally, the decoded signals would be transmitted to a blue-tooth cursor interface and typing algorithm connected to the smartphone to enable people to open and use mobile applications like email and text messages.

A potential source of error in this research was the estimation of x-positions of the cursor as controlled by the monkey using a joystick versus the BMI. Exact x-values were not provided, but were represented in a graph by Joseph O'Doherty et al. Thus, there is a possibility that the estimated x-values derived from the graph skewed the p-value. However, given that the calculated p-value is 82.2% below the rejection range of the null hypothesis, this source of error was unlikely to affect the overall results. On the other hand, major limitations to this research stemmed from the nature of it being conducted online with little scope for original experimentation. However, with sufficient funds for proper equipment and a lab environment, and a sample of volunteers with motor impairments, the BMI design proposed by this research could be tested in a proper, controlled experiment.

The most significant way this research could be further developed is by determining how to create a two-way brain-machine interface, or a brain-machine-brain interface, to connect paralyzed individuals to smartphones which then provide feedback to the brain to optimize performance. This research will significantly improve the lives of paralyzed individuals by enabling them to better communicate in ways that they couldn't before. If research in the field of brain-machine interfaces is continued, it won't be long until commercial and medical BMIs that significantly improve quality of life become the new normal. Humanity can look forward to a world where a multitude of devastating debilitating diseases such as Alzheimer's, multiple sclerosis, and schizophrenia, can be consistently treated or mitigated with the aid of brain-machine interfaces.

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