Electric Brain and BCI: A Beginning for the Transformation in Controlling Mind and Body*

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Abstract

Brain-Computer Interface (BCI) is an innovative technology that is rapidly developing and researching and has the potential to revolutionize the way humans interact with technology. This article examines the history, challenges, and future of this technology. On one hand, BCI has created new hopes by providing communication and motor capabilities for individuals with disabilities. On the other hand, there are challenges such as the accuracy and speed of signals, interference from environmental noise, high costs, and ethical issues related to privacy and misuse of brain data. The future of BCI represents the great potentials of this technology in various fields including education, entertainment, and improving treatment of diseases, as well as humanitarian and military applications (cyborgs). Therefore, emphasizing further research in this area is vital to achieve a deeper understanding of brain function and its social and ethical impacts. BCI, as a bridge between mind and machine, promises an exciting future that can bring significant changes to daily life and human relationships.

Keywords: Brain-Computer Interface (BCI), EEG (electroencephalography), cyborg cockroaches.

1. Introduction

The nervous system is fundamentally electrical. When we move our hand, this movement is due to a signal sent to the controlling muscles, and this message consists of the movement of charged atoms inside and outside nerve cells. This is electricity. Since the brain is electrical, we can use electricity to record brain activities or even bypass it and control the body. This means we can use our minds to move the bodies of others, restore movement to paralyzed individuals, feel through a prosthetic hand as if it were our own, and even read people's minds. Although electricity was not well understood until the 18th century, its ability to influence the body has been known since ancient Rome, when the esteemed physician Scribonius Largus wrote about a man who accidentally stepped on an electric fish and suddenly found relief from his gout pain. Scribonius conducted experiments and found that placing an electric fish on one's head could relieve headaches. Centuries later, in 1804, Italian physicist Giovanni Aldini discovered that he could move people's muscles using electricity. He astonished the European world by using electricity to revive the corpse of an executed criminal. The corpse opened its eyes and even appeared to sit up. However, Aldini was not merely looking to shock people; he was demonstrating to the world that neurons, the cells that control both our thoughts and movements, operate through electricity. (Mind Field, Season 2, Episode 8: The Electric Brain, 2018) From this fundamental concept, innovative technologies such as Brain-Computer Interfaces (BCI) have emerged. BCIs enable direct interaction between the human brain and electronic devices. Using BCIs, the electrical signals produced by the brain can be instantaneously converted into understandable commands for external devices, meaning that individuals can control various electronic tools solely with the power of their minds. This technology holds great potential for improving the quality of life for individuals, particularly those with mobility limitations. As much as BCIs have allowed for the control of electronic devices through brain signals, the development of cyborg technologies shows that living organisms can be similarly controlled and directed. Cyborg insects, which are a combination of living insects and electronic components, allow us to control the movements of these creatures using fine electrodes and small devices. These advanced technologies represent a new stage of integration between biological and artificial systems that can be utilized in many areas, including scientific research and industrial applications.

2. Overview of BCI Technology

Definition and Purpose of BCI

A Brain-Computer Interface (BCI) is an emerging technology that allows individuals to communicate directly with electronic devices without using conventional neural pathways. This communication is established by recording and analyzing brain signals and translating them into understandable commands for devices. The main goal of developing BCIs is to create new communication pathways for individuals who have lost the ability to control their movements due to various reasons, such as stroke, spinal cord injury, or neurological diseases. Additionally, BCIs can be used to enhance cognitive abilities and improve performance in areas such as gaming, education, and industry.

Brief History

The history of Brain-Computer Interfaces (BCIs) dates back to early efforts to control and understand neural and motor signals. One of the first successful efforts in this field was the surgeries performed by Dr. Harvey Cushing, the father of modern neurosurgery, which took place in the early 20th century. In 1903, Cushing successfully performed a complex surgery in which he used surgical techniques to control neural signals, restoring part of a patient's motor and sensory function. In this patient, who had suffered severe injuries to the head and facial nerves, Cushing's methods were employed to reconnect damaged nerves and electrically stimulate them. Cushing used galvanic batteries to stimulate the patient's nerves to aid in the recovery of facial muscle function and reduce paralysis. These early efforts to control neural signals and restore motor function in patients laid the foundation for the development of BCI concepts and technologies. The development of BCIs began in the 1960s when scientists first used electrical brain signals to understand brain function. In the 1970s, researchers started using electroencephalography (EEG) to record brain signals. The first BCIs were developed in the 1990s, allowing users to control a mouse cursor on a screen using only their thoughts. In the 2000s, further advancements in recording and processing brain signals led to the development of both invasive and non-invasive BCIs. In recent years, BCIs have become one of the key technologies in neuroscience and human-computer interaction.

Types of BCI

BCIs are primarily divided into two main types: invasive and non-invasive.

- **Non-Invasive Systems**: These systems use sensors placed on the scalp, such as Electroencephalography (EEG), to record brain activity. The main advantage of these systems is that they do not require surgery; however, their signal accuracy and clarity are typically lower than those of invasive systems. Non-invasive systems are more popular in research and public applications due to their safety and comfort.

- **Invasive Systems**: Invasive BCIs are systems that directly record neural activity by placing electrodes inside or on the surface of the brain (cerebral cortex). These methods obtain highly accurate signals from brain activity due to the proximity of the electrodes to neurons, which is crucial in situations that require precise control of movements or complex devices.

Advantages and Reasons for Using Invasive BCIs

- **High Accuracy and Clarity**: One of the main advantages of invasive BCIs is their ability to receive high-precision and high-clarity signals. These signals are less affected by noise compared to non-invasive methods like EEG and can control more complex movements.

- **Long-Term Stability**: Brain implants usually maintain the stability and accuracy of their signals over an extended period, which is vital for applications such as robotic prosthetics and direct communication with computers.

Applications of Invasive BCIs

- **Restoring Movement to Paralyzed Individuals**: One of the primary applications of invasive BCIs in the medical field is assisting individuals with spinal injuries or those who have lost the ability to move. Using invasive electrodes, motor signals from the brain are recorded and transmitted to robotic prosthetics or movement control systems, enabling these individuals to move again.

- **Controlling Advanced Prosthetics**: Invasive implants are used to control advanced prosthetics that require high precision and flexibility. These prosthetics allow individuals to perform more precise and natural movements and even communicate through touch sensations via their prosthetics.

- **Direct Communication with Computers**: Some invasive systems allow users to communicate directly with computers, performing tasks like typing, sending emails, and even browsing the internet solely using their mind.

Challenges and Limitations of Invasive BCIs

- **Surgical Risks**: One of the biggest challenges of using invasive BCIs is the need for surgery to place electrodes in the brain. These surgeries are associated with various risks, such as infection, inflammation, and damage to brain tissues.

- **Maintenance and Stability**: Invasive electrodes may face issues over time, such as signal quality loss or immune reactions from the body. Additionally, implants need to be periodically checked and replaced if necessary.

- **Ethical Issues**: The use of invasive BCIs, especially in military applications or for enhancing cognitive abilities, raises complex ethical issues. Many researchers and policymakers are seeking appropriate regulations for the use of this technology.

Notable Examples of Invasive BCIs

- **NeuroPace RNS System** is an invasive BCI system used for treating individuals with drug-resistant epilepsy. This system automatically detects abnormal brain signals and responds with electrical stimulation to suppress seizures.

- **BrainGate** is one of the well-known projects in the field of invasive BCIs that allows paralyzed individuals to control robotic prosthetics or computers using their thoughts. Despite the challenges and risks, invasive BCIs are among the most advanced and precise methods for direct communication with the brain and controlling external devices. This technology has great potential to change the lives of individuals facing mobility disabilities and could also lead to new and exciting tools in the future.

How BCI Works

A BCI system typically consists of four main stages:

1. **Recording Brain Signals**: Electrical signals from the user's brain are collected. This is done using electrodes placed non-invasively on the scalp (such as EEG) or invasively inside the brain.

2. **Signal Processing**: The recorded brain signals usually contain noise and interference. Therefore, these signals must be processed before being used to control devices. Signal processing involves various stages, such as filtering, amplification, noise removal, and feature extraction. The goal of signal processing is to improve signal quality and extract useful information from it.

3. **Interpretation and Transformation**: The processed data is converted into understandable commands for external devices. This is achieved using machine learning algorithms and signal analysis techniques.

4. **Command Execution**: The transformed commands are sent to external devices to perform specific actions. These devices can include robots, prosthetics, computers, or even household appliances, enabling the user to have complete control with their thoughts.

These four stages form the core functionality of BCI and make this technology one of the most advanced methods for direct human-device communication.

Machine Learning Algorithms

Machine learning algorithms play a crucial role in BCIs. These algorithms allow the system to identify patterns in brain signals and translate them into understandable commands for devices. Common algorithms used in BCIs include artificial neural networks, support vector machines, and random forests.

Methods of Recording Brain Signals

Our brain, as an electrical organ, transmits its activities through electrical and magnetic signals. These signals contain valuable information about our thoughts, feelings, and decision-making processes. Various methods are used to record these signals, each with specific advantages and limitations:

- **EEG (Electroencephalography)**: This is the most common method for recording electrical activity in the brain. In this method, electrodes are placed on the scalp to record electrical signals produced by neurons. EEG has advantages such as low cost, non-invasiveness, and portability.

- **fMRI (Functional Magnetic Resonance Imaging)**: This method images the activity of different brain areas by measuring changes in blood flow. fMRI has high accuracy in determining the location of brain activity, but it is expensive and requires complex equipment.

- **MEG (Magnetoencephalography)**: This method works by measuring the magnetic fields produced by the electrical activity of the brain. MEG has high temporal resolution and can accurately record rapid brain activities.

Models of Brain-Computer Communication

Brain-computer communication models are divided into two main categories:

- **Direct Feedback Models**: In these models, brain signals are directly transmitted to external devices, causing an action. For example, imagining hand movement can cause a robotic arm to move.

- **Indirect Feedback Models**: In these models, individuals learn to control their brain signals to achieve desired outcomes by observing the results of their actions. These models are often used in computer games and BCI training.

Advantages and Disadvantages of Different Models

Each brain-computer communication model has specific advantages and disadvantages. For instance, direct feedback models require high speed and accuracy, while indirect feedback models may need more time for learning. The choice of the appropriate model depends on various factors, including the application of the BCI, the type of brain signals, and the user's abilities.

Applications and Challenges of BCIs

Applications

BCIs have significant applications across various fields, from medicine to industry and even entertainment. Below are the current and potential applications:

1. **Medical Field**

   - **Restoring Mobility to Paralyzed Individuals**: One of the most important applications of BCIs in medicine is assisting individuals who have lost their mobility due to spinal cord injuries or strokes. Using BCIs, these individuals can control robotic prosthetics or even activate their muscles through electrical stimulation.

   - **Neural Prosthetics**: BCIs enable individuals to control prosthetics connected to amputated limbs with their thoughts. These prosthetics not only allow for more precise movements but can also provide sensory feedback to the user, offering an experience similar to a natural hand.

   - **Assisting Individuals with Neurological Disorders**: Some BCI systems have been developed to assist individuals suffering from conditions such as epilepsy, Parkinson's disease, and sleep disorders. These systems automatically identify abnormal brain activities and help regulate brain functions through electrical stimulation.

2. **Industrial and Military Applications**

   - **Controlling Machines and Robots**: In various industries, BCIs are used to control robots and heavy machinery. This technology allows operators to control complex devices with high precision without using their hands.

- **Enhancing Human Capabilities**: In military applications, research is underway to develop systems that enhance individuals' cognitive and physical abilities using BCIs. These technologies could enable soldiers to make decisions faster and more accurately or operate complex military equipment with minimal physical intervention.

3. **Entertainment and Gaming**

- **Mind Games**: One of the most intriguing applications of BCIs in entertainment is their use for controlling video games. Players can control game characters using only their thoughts, creating a new and exciting experience in the gaming world.

- **Virtual Reality and Augmented Reality**: BCIs can enhance virtual reality and augmented reality experiences. Users can move in the virtual world, manipulate objects, and interact with the environment using their thoughts.

Challenges

Despite significant advancements, BCIs still face numerous challenges and limitations. Some of the key challenges include:

1. **Signal Accuracy and Quality**

- **Noise and Interference**: Brain signals are very weak and sensitive to external noise. Factors such as other physiological activities of the body (like eye movements or muscle contractions) can affect the quality of brain signals and reduce the accuracy of BCIs.

- **Signal Interpretation**: The human brain is highly complex, and its signals are very diverse. Proper interpretation of these signals requires complex algorithms and precise processing, which may limit the accuracy and performance of BCIs.

2. **Cost and Accessibility**

- **High Costs**: Developing and implementing BCI systems, especially invasive systems, requires advanced equipment and incurs high costs. This limits public access to this technology, making it primarily available to advanced research and medical centers.

- **Maintenance and Repairs**: BCI systems require continuous maintenance, adjustments, and repairs, which can also be costly.

3. **Ethical and Security Issues**

- **Privacy and Security**: Direct access to and recording of brain signals raise significant concerns about privacy and data security. If brain signals fall into the wrong hands, it could lead to serious misuse and threats.

- **Ethical Concerns**: Some applications of BCIs, particularly in military or cognitive enhancement fields, raise ethical concerns. Questions arise about the boundaries of using this technology, individual choice, and potential impacts on personal identity and character.

- **Addiction and Dependency**: With the increasing use of BCIs in entertainment and gaming, concerns have emerged about excessive reliance on this technology and its psychological effects on users.

These challenges and limitations indicate that, despite notable advancements, the path to the development and public acceptance of BCIs still requires further research and regulation. However, the potential of this technology is vast and could significantly improve individuals' lives.

So far, we have discussed BCI technology and its applications, as well as the challenges ahead. This technology can not only enhance human abilities but also serve as a means to better understand the interactions between the brain and machines. As the accuracy and capabilities of BCIs increase, scientists are seeking new and advanced methods to study and control not only the human brain but also other living organisms. This is where the concept of cyborgs enters the discussion.

Cyborgs: Cyberroaches

In today’s world, cyberroaches are seen as a symbol of technological advancements in the field of controlling neural and robotic systems. These technologies enable us to control the movements of living organisms, such as cockroaches, through electrical stimulation. To achieve this goal, a deep understanding of the complex behavior of the cockroach's nervous system is essential, particularly the stimulation of ganglia and motor neurons.

Recent research in controlling cockroaches through antenna and circuitry stimulation has shown that these methods can be effective tools for controlling movements; however, their effectiveness is limited in practice due to the habituation of the cockroaches to the stimuli. After several stimulations, cockroaches gradually stop responding to these signals, posing a significant challenge in controlling their movements.

In response to this challenge, researchers have turned to more innovative methods, such as stimulating the ganglia. In this method, precise placement of electrodes and manipulation of electrical signals allow for direct control of the cockroach's movements. This technique enables us to control the natural movements of cockroaches without the limitations imposed by habituation to stimulation.

Cyborgs, known as hybrid robotic systems, offer numerous advantages. These systems combine the natural behaviors of living organisms with electronics and can be utilized in various fields, including national security, emergency services, and search and rescue operations. For instance, these hybrid robots can be effectively deployed in locations where conventional robots cannot function effectively.

Ultimately, the integration of robotic systems with living organisms can aid in the development of control robots that retain the unique characteristics of a biological and responsive system. Thus, cyberroaches not only represent scientific and technological advancements but also allow us to address challenges related to the control and practical applications of neural technologies with greater precision.

The Connection Between BCIs and Cyberroaches

BCIs were initially designed to assist humans and enhance cognitive and motor abilities. However, the technologies developed for recording and controlling human brain signals can easily be applied to control other living organisms. Cyberroaches are a prime example of this technology transfer, where BCI technology is employed to transform organisms like cockroaches into controllable devices.

Why Cyberroaches?

- **Neuroscience Studies and Research**: Cyberroaches serve as research tools in neuroscience studies. By directly controlling living organisms, scientists can examine complex patterns of neural behavior and better understand the functioning of biological systems.

- **Advanced Testing**: Before using invasive or non-invasive BCIs on humans, cyberroaches act as a safer experimental environment for investigating the efficacy and impacts of these systems. This way, the risks associated with human surgeries can be minimized.

- **Practical and Military Applications**: Cyberroaches are utilized not only as research tools but also in practical fields. For example, cyberroaches equipped with sensors can be sent to hazardous areas to assess conditions or explore locations inaccessible to humans.

Ethical and Technological Challenges in Cyberroaches

The development of cyberroaches is accompanied by not only technical challenges but also ethical issues. Questions about the rights of living organisms, the limitations on using technology to control creatures, and the potential environmental impacts are important matters that need to be considered. Just as we face ethical challenges with human BCIs, cyberroaches grapple with similar issues.

The Future of Brain-Computer Interfaces

Technological Advancements

The future of Brain-Computer Interfaces (BCIs) will be significantly influenced by technological advancements in hardware, software, and algorithms. With the development of more precise and affordable sensors, the possibility of collecting higher quality brain data will increase. New software and advanced machine learning algorithms can also help in faster and more efficient processing of brain signals. These advancements can lead to improved accuracy and speed of BCIs, enabling more complex tasks. Additionally, the use of cloud computing and big data processing can enhance BCI performance and data analysis.

New Applications

The potential of BCIs across various fields is significantly expanding. One new application could be in education, where BCIs might be used as tools to analyze and optimize learning methods. Additionally, in entertainment, BCIs could lead to the creation of unique interactive and virtual experiences, including video games and virtual reality. In the arts, artists could use BCIs to create unique interactive artworks that respond to the emotions and thoughts of the viewer. These applications can not only provide new experiences for users but also create new avenues for creativity and innovation.

Impact on Society

The development and expansion of BCIs could have profound effects on society, the economy, and human relationships. On one hand, BCIs can help improve the quality of life for individuals, especially in the fields of treatment and rehabilitation of patients. This technology could create new opportunities in the job market and lead to economic growth. On the other hand, the use of BCIs may result in social and economic disparities, especially if access to this technology is distributed unevenly. Furthermore, as this technology becomes integrated into daily life, ethical and social concerns such as privacy, misuse, and changes in human relationships will arise. These issues require careful attention and consideration by researchers, policymakers, and society.

Conclusion

This article examined Brain-Computer Interfaces (BCIs), analyzing various dimensions including history, similar technologies, challenges, and the future of this technology. As an emerging technology, BCIs have significant potential for improving quality of life, treating diseases, and facilitating communication. From the earliest attempts at controlling neural signals to recent advancements in the design of complex systems, this field has witnessed remarkable transformations. However, BCIs also face challenges. Accuracy and speed in detecting brain signals, signal interference, high equipment costs, and ethical issues are among the current barriers that require more attention. These challenges may hinder public acceptance and widespread use of this technology unless further research and developments are conducted to improve performance and reduce costs.

Looking to the future, it seems that BCIs are on a path of evolution and advancement. Technological progress, including hardware and artificial intelligence algorithms, can increase the accuracy and efficiency of these systems. Additionally, new applications in various fields such as education, art, entertainment, and rescue operations could transform BCIs into multifunctional tools that will have profound impacts on society. Therefore, emphasizing the importance of further research in this vital area is crucial. Only through comprehensive and interdisciplinary research can we gain a deeper understanding of brain function and the social, ethical, and psychological impacts of BCIs. Furthermore, understanding this technology and establishing appropriate regulations can help ensure its correct and optimal use in the future. Overall, BCIs represent a significant step toward deeper interaction between mind and machine, and their future prospects may lead to monumental changes in the way we live and interact with one another.

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