Proceedings of the 3rd International Conference on Biological Engineering and Medical Science
DOI: 10.54254/2753-8818/20/20230729

Brain computer interface and its application in games for people with physical disability

Yueyang Li

Computer Science Department, 1210 W Dayton St, Madison, WI, USA 53703-1820
Undergraduate, University of Wisconsin-Madison

ezelpub@outlook.com

Abstract. This paper will investigate the fundamentals of the Brain-Computer Interface, including various kinds of implantable Neural Probes, materials used to construct neural probes, and essential methods to detect crucial electrical and chemical signals from brain structures to building well-behaved Brain-Computer Interfaces. Beyond that, this paper will delve deeper into the Brain-Computer Interface (BCI) and its application in the modern time game industry and look into the future perspectives of BCI for helping underrepresented groups that could not utilize traditional input devices.

Keywords: brain computer interface, game, virtual reality, sensor.

1. Introduction

With the growing requirements for building sustainable, flexible, and highly integrated Brain-Computer Interfaces(BCI) that could minimize the damage to human physiological functions, great many scholars from different areas contributed to the realm of BCI, hoping to get optimal solutions. Starting from the primal description of electroencephalographic(EEG) by Hans Berger in 1929, there are callings for applications in communication between the human brain to act on the environment without the normal intermediate substances of human nerves and muscles [1]. The early blueprints find its presence not until the late 1970s, when Advanced Research Projects Agency(APRA) became growingly interested in the technologies that could provide a more immersive and efficient communication between human brain and electronic devices [1]. Shifting from the early era of conceptions, nowadays, researchers in the realm focuses more on the technologies that could lower down the invasiveness and overall reliability to achieve high-level communications, during which, neural probes that are made of biochemical signal sensitive transistors or chemical signal receivers are of vital importance [2]. On the other hand, modern game industry has already been critized for its long-year ignorance of underrepresented groups and their fallacious design that could not met the requirement of most people with severe body conditions that might hinder them from enjoying those video games available on the market. Therefore, this article will first introduce some fundamental BCI concepts, electro-chemical foundations, microfabrication methods, and more advanced neural probes that could detect more sensitive and minor signals from the brain area. Then, this paper will delve deeper into the application of above-mentioned techniques and the attempt to utilize them in the games that facilitate the disabled group.

DOI: 10.54254/2753-8818/20/20230729

2. Fundamentals of BCI

BCI is established on the basis of human nerval system, and its electrochemical signal transmission paradigm. This section will investigate the fundamentals of BCI: the human nerval system activities, and electrical signals that can be captured which are generated mostly by two main sources.

There are two major electrical potentials that can be recorded through various neural interfaces. First discovered in 1949, action potential was rigorously defined by Kandel, Schwartz and Jessell as the rapid sequence of changes in the voltage across the cell membrane [3]. The rapid rise in potential and the phenomenon of depolarization is a "globally" connected event which is primarily initiated by the opening of sodium ion channels within the plasma layer(membrane). To regain the equilibrium of ion level across the membrane, an ATP-driven pump(Na/K-ATPase) will propel the movement of sodium ions out of the cell and potassium ions into the cell [4]. As for field potentials, they are the averaged spatiotemporal summation of neural activities in large brain areas [5]. More specifically, Field Potentials can be decomposed into three subcategories in terms of signal type, namely the electroencephalography (EEG) signals, electrocorticography (ECoG) signals, and local field potentials (LFP).

To narrow down the scope of discussion, it is helpful to limit the topic within EEG, whose discovery could be traced back to 100 years ago. In general, EEG is a method to record an electrogram of the continuous electrical activity of the brain. It has been proven that EEG could be utilized to delegate the postsynaptic potentials of pyramidal neurons in the neocortex and allocortex [6]. Voltage fluctuations measured by the EEG bio-amplifier and electrodes allow the evaluation of normal brain activity including the posterior dominant rhythm. More importantly, EEG could detect abnormal electrical discharges, which in turn is widely applied in modern-day epilepsy detection [7]. Beyond that, EEG has been utilized in the game industry almost since the date it was invented. Due to its high resolution and instantaneousness, it has been widely used to record human brain signals, which are later encoded and decoded to transfer important bidirectional instructions. The next part of this paper will pay a closer look at the fundamentals of the Neural Probes and investigate the types of Neural Probes that are specifically favored by the EEG.

3. Fundamentals of neural probes and EEG

Neural probes are microstructures that connect human neural structures with outside electronics (Hajj Hassan et al., 2008). Neural Probes are one of the most crucial hardware pillars of modern-day BCI technology, and it has already positively affected the overall comprehension of biological neural networks. However, due to the challenges related to non-standardized fabrication and unconventional molding processes, many research teams are severely challenged.

There are three major types of neural probes: Metal Wire-based Neural Probes, Silicon-based Neural Probes, and Polymer-based Neural Probes. For Metal Wire Based Neural Probes, their electrodes typically consist of electrolytically sharpened wires that are "commonly less than 100 μm in diameter" and "completely insulated" where only tips are left for recording or simulation purpose [8]. It is statistically the most used Neural Probes worldwide, and has tapered structure to enable convenient insertion in the brain tissue [9] Moreover, materials ranging from platinum, platinum-iridium, gold, and stainless steel are normally used to construct the Metal Wire based Neural Probes.

With the growing stability and efficiency of in bulk micromachining techniques, Silicon Based Neural Probes are now gradually replacing the role of Metal Wire Based Neural Probes [10] The fabrication of silicon based Neural Probes includes deposition of a metal layer on insulated substrate and patterning the metal layer to form recording sites, read-out pads for connecting to external circuitry, and interconnecting traces between the recording sites and read-out pad [11].

In the category of Silicon Based Neural Probes, there is one major subcategory of silicon on Insulator based Neural Probe. SOI wafers are produced by placing a thin, insulating layer such as silicon oxide (SiO2) or glass sandwiched between a thin layer of silicon (device layer) and the silicon substrate (handle wafer). There exists many emerging MEMS and CMOS-MEMS process that can be applied to pertain the fabrication of Neural Probes with specific features. These features include ultra-long reinforced structures, and integrated signal processing capabilities.

There are studies recently that appeal for the support to replace traditional silicon based Neural Probes with polymer material based Neural Probes [12]. The rise of the Silicon based Neural Probes is

DOI: 10.54254/2753-8818/20/20230729

probably related to the growing dire need for the biocompatible interface between the probe and the brain tissue. Different biocompatible polymers are utilized to achieve the goal, such as polymide and Parylene-C. For example, Utah electrodes arrays could be used to be coated with polyimide, and Parylene-C could be utilized as the insulation layer on silicon probes [13].

As a conclusion to this section, we have discussed the basics of three major Neural Probes, and the thorough process of their fabrications. Neural Probes are the most fundamental constitution of a BCI interface, and they are also of vital importance to Deep Brain Stimulations. The rest of the article will look into the Deep Brain Stimulation, and close the discussion from there.

4. Games and BCI

Video Games are a good platform for researchers to get raw data on EEG-based BCIs. As outlined by Washburn (2003), games are helpful in the research environment that:

1. Games act as a stimulus for studying human behavior
2. Games could be utilized to manuscript data from experiments
3. Games could be used as instructions
4. Games could also be set as metrics in the measurement of the performance of participants

Gaming implementations of BCIs tackle perhaps the greatest challenges of BCI of today. For an interface to be proven useful and effective, the interaction must be seamless, and user experience should be coronated as the top priority. Since all of the BCI paradigm rely on the user-driven emotions and motivation, games are one of the naturally fitted research tools that could be used alongside BCIs. According to Marshell et. al. [14], due to the characteristics of high temporal resolution, relatively low cost, portability, noninvasiveness and navively guaranteed safety, EEG is most suitable for BCI gaming.

As most of the games in the current game markets lay in the category of action games [15], understanding how well-designed BCI action games work together with the target brains, and generate successful positive feedback to its users is crucial to develop and design well-knitted BCI games. To offer accurate measurement that could quantify how BCI based games interact with the players, Event-Related Potentials (ERPs) is required, which is essentially the electrical potentials that is generated by the brain area, corresponding to to certain events. For example, P300 event related potentials, as one of thoses ERPs, could effectively be evoked in an immersive environment. In an experiment conducted by Kerous et. al. [16], triggering stimuli was presented in the form of virtual traffic lights, where P300 was detected as reaction to a shifting light. What's more intriguing is that P300 can also be harnessed for control even when a person is engaged in a parallel motor task (handling the wheel control), which generates muscle artifacts. Therefore, P300 is thought to be related to a higher level attention process or an orienting response. However, in most BCI action games that give way to providing ample response time for the players, the P300 level is relatively low due to its intentionally perlonged game play to fit in with the latency of player reactions.

The above discussion has elicit the further aspects that are crucial to successful BCI games design: the balance between the accuracy and playability. To gain higher accuracy like accurate in-game feedback, the system in most BCI games are designed to be lengthy and less responsive. Moreover, to ensure no further factors might influence the controls, the visuals of BCI games are often oversimplified. Research shows that the simplicity of the games and their control schemes was also affecting most games' accuracies, leading to significantly better results [17]. Most BCI games to date have been used for mainly training purposes, or for the purposes of testing a BCI paradigm. BCI games need further development, as to employ simplified rule sets while get its players more immersive into the game world by elevate the playability of the game.

5. Conclusion

This research write-up examines the basics of BCI, the human body Field Potential and Actional Potential that constitutet the theoretical fundamentals of BCIs design and development. After researching EEG and looked into various brand new transmitters that could achieve better signal transmission and accuracy, we then discuss the necessitity of combing BCI research with modern time game-development. With the growing development of Computer Graphics rendering techniques and stronger hardware support, modern video games have reached magnificent visual effects, while leaving a huge hole of the BCI based games to catch up, whose contents are also educational, meant for training purposes and often less enjoyable. The article urge the current industry to look into better way to

DOI: 10.54254/2753-8818/20/20230729

establish bidirectional communication between disabled video game players, to enhance their enjoyment in BCI game play.

References

[1] Wolpaw, J. R., Birbaumer, N., Heetderks, W. J., McFarland, D. J., Peckham, P. H., Schalk, G., Donchin, E., Quatrano, L. A., Robinson, C. J. and Vaughan, T. M., "Brain-computer interface technology: a review of the first international meeting," IEEE Trans. Rehab. Eng. 8(2), 164–173 (2000).

[2] Nunez, P. and Srinivasan, R., "Electroencephalogram," Scholarpedia 2(2), 1348 (2007).

[3] Clayton, D. F., "The genomic action potential," Neurobiology of learning and memory 74(3), 185–216 (2000).

[4] Grider, M. H., Jessu, R. and Kabir, R. (eds.), [StatPearls [Internet]], StatPearls Publishing (2022).

[5] Herreras, O., "Local Field Potentials: Myths and Misunderstandings," Frontiers in neural circuits 10, 101 (2016).

[6] Schomer, D. L., Da Lopes Silva, F. H. and Amzica, F., [C2Cellular Substrates of Brain Rhythms], Oxford University Press (2017).

[7] Berger, H. and Gloor, P., [[Über das Elektrenkephalogramm des Menschen.] Hans Berger on the electroencephalogramm of man. The fourteen original reports on the human electroencephalogram; translated from the original German and edited by Pierre Gloor], Elsevier, Amsterdam (1969).

[8] HajjHassan, M., Chodavarapu, V. and Musallam, S., "NeuroMEMS: Neural Probe Microtechnologies," Sensors (Basel, Switzerland) 8(10), 6704–6726 (2008).

[9] Najafi, K., "Solid-state microsensors for cortical nerve recordings," IEEE Engineering in Medicine and Biology Magazine 13(3), 375–387 (1994).

[10] Ensell, G., Banks, D. J., Richards, P. R., Balachandran, W. and Ewins, D. J., "Silicon-based microelectrodes for neurophysiology, micromachined from silicon-on-insulator wafers," Medical & biological engineering & computing 38(2), 175–179 (2000).

[11] Galindo-Rosales, F. J. (ed.), [Complex Fluid-Flows in Microfluidics], Springer International Publishing, Cham (2018).

[12] Xu, C., Lemon, W. and Liu, C., "Design and fabrication of a high-density metal microelectrode array for neural recording," Sensors and Actuators A: Physical 96(1), 78–85 (2002).

[13] Musallam, S., Bak, M. J., Troyk, P. R. and Andersen, R. A., "A floating metal microelectrode array for chronic implantation," Journal of neuroscience methods 160(1), 122–127 (2007).

[14] Marshall, D., Coyle, D., Wilson, S. and Callaghan, M., "Games, Gameplay, and BCI: The State of the Art," IEEE Trans. Comput. Intell. AI Games 5(2), 82–99 (2013).

[15] Piñeiro-Chousa, J., López-Cabarcos, M. Á., Pérez-Pico, A. M. and Caby, J., "The influence of Twitch and sustainability on the stock returns of video game companies: Before and after COVID-19," Journal of business research 157, 113620 (2023).

[16] Kerous, B., Skola, F. and Liarokapis, F., "EEG-based BCI and video games: a progress report," Virtual Reality 22(2), 119–135 (2018).

[17] Bai, O., Lin, P., Vorbach, S., Floeter, M. K., Hattori, N. and Hallett, M., "A high performance sensorimotor beta rhythm-based brain-computer interface associated with human natural motor behavior," Journal of neural engineering 5(1), 24–35 (2008).

Publication bibliography

[1] Berger, Hans; Gloor, Pierre (1969): [Über das Elektrenkephalogramm des Menschen.] Hans Berger on the electroencephalogramm of man. The fourteen original reports on the human electroencephalogram; translated from the original German and edited by Pierre Gloor. Amsterdam: Elsevier ((Electroencephalography and Clinical Neurophysiology. Supplement no. 28.), no. 28).

DOI: 10.54254/2753-8818/20/20230729

[2] Schomer, Donald L.; Da Lopes Silva, Fernando H.; Amzica, Florin (2017): C2Cellular Substrates of Brain Rhythms: Oxford University Press (1).