BRAIN COMPUTER INTERFACING

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Abstract – Adam O'Sullivan 19265808

A brain computer interface or BCI for short is a system that allows a user to take signals from their brain, converts them into usable data and inputs that data into a computer or some other device, allowing it to carry out a desired action.

Literature Review – Gabriel Rigaudie 19269315

Material for this report has been sourced from books, journal articles and some news articles. Some of which were read in order for us to form our own understanding of the topic but were not explicitly used in any way therefore they will still be named in our references page as without these we would not have been able to learn about the topic at hand or form our own points and conclusions.

Many of the sources used were found through the Glucksman Library website and thus, given the display method of the material, exact page numbers cannot be given for each reference however the book/article as a whole will be given for each reference.

An Introduction - Padraig Foley 19232845

Brain computer interfacing is one of the most revolutionary advancements in both medical and computer sciences. The simple description of it is; it is the control of computer systems using your brain. This is a concept which has been featured in a lot of sci-fi shows but up until now has not been possible. Thanks to researches run by some of the top computer and neurological scientists in the world, a lot of progress has been made in this field. In this essay I will explain the fundamentals of the field and elaborate on how it is achieved, as well as the multitude of uses for this technology in all areas of life such as the medical applications and also the effect it has had in understanding the complexities of the human brain.

Brain computer interfacing (BCI) can be broken down into three main categories: Active BCI, reactive BCI and passive BCI. Active BCI is one of the most common forms of BCI as it uses conscious thoughts from the user to control various computer systems. This has a lot of difficulties involved such as false signals often occurring from sub-conscious thoughts which can obscure the signal and give incorrect readings, resulting in the wrong action or output being recorded. It is one of the more useful of the three as it allows conscious control of a system. This can play a huge part in treating a variety of medical problems such as allowing disabled people who may not have the use of part of there body to communicate or control systems without the need for physical movement. Active BCI also has many applications in entertainment as with the rise of virtual reality and immersive gaming, it adds a new level as actions in the game can now be controlled through brain signals. (Paraphrasing Brain Computer Interfaces, 2010)

The main process for active BCI is electroencephalogram (EEG). This measures the electrical signals which are outputted by the brain. Although in the past there has been many invasive methods of doing this, in recent times the most common method is using electrodes which are placed in specific places around the subject's head in order to record these signals and output them. This is an example of a passive method which is a lot safer and easier to set up than more dated methods. Although this process has advanced a lot, there are still many flaws included. The most serious one of which is the inaccuracy that is involved, this is due mainly to the number of variables implicated between tests. The best example of this is the fact that it is extremely difficult to place the electrodes back in precisely the same location between tests, this can lead to variance in test results

and often completely different results as the electrodes pick up a different signal in the brain. Another problem associated with this method is the seemingly random patterns of the brain itself. We currently do not know much about the brain and how it works, so in most cases this leads to guessing whether the signal is the one needed or whether the signal will be strong enough to be picked up by the electrodes.

Reactive BCI is the process of measuring the brains reaction to a stimulus, it uses this reaction to generate a signal which can be outputted for a variety of uses. Passive BCI has a multitude of uses, much of which are very similar to those of active BCI. Because this method measures the brains reaction to stimuli, it allows a rudimentary form of emotion to be displayed. This is again very useful to those with disabilities as it allows them to express these emotions in a non-physical manner. It is also very useful for virtual reality gaming as a player can control a character's emotions in a much more organic and intuitive way, as it records the emotions the player is feeling using the game as the stimulus.

Much like active BCI, this process is again done using EEG to measure the electronic activity the stimulus causes in the brain, creating recognisable patterns and signals which can be assigned to emotions. Although as with active BCI, this is a very unreliable and inaccurate method as I discussed earlier. Another method which can be used to measure reactive BCI is Functional Near-Infrared Spectroscopy (FNIRS), this method involves measuring the blood oxygen levels in the brain using an infrared light. This again allows us to see which parts of the brain are active by the amount of oxygen in that area. This is very useful for measuring brain activity and can be used for a variety of applications such as communication.

The final type of BCI is passive BCI which uses sub-conscious brain signals in order to create an output. As you can imagine, this is a lot more difficult to monitor and to control as the subject has very little control over there sub-conscious brain activity. Again, passive BCI uses the same methods to collect the data as active and reactive BCI, but they need to be implemented on a much larger scale to create a clear image from the weak sub-conscious brain signals. Magnetoencephalography (MEG) is a process which uses large scale EEG technology to measure brain waves which a much higher accuracy, although it is impractical for most uses as the technology needed is expensive and very large. Another method used for passive BCI is Magnetic Resonance Imaging (FMRI) which is a large-scale version of FNIRS technology which again is more accurate but is impractical due to the size of the equipment needed. With these methods it is possible to measure the sub-conscious brain signals and turn those signals into useful outputs. One of the primary uses for this technology is in a medical capacity as it allows patients who may have brain damage to communicate and control certain applications. Another popular use is in adaptive automation, more specifically safety features in vehicles. The subjects brain signals can be used to predict when an emergency brake is needed, allowing the car to brake sooner than if left to the user. This can be vital in preventing car accidents and making vehicular travel safer.

Applications of Brain Computer Interfaces - Adam O'Sullivan 19265808

There are many possible uses of BCIs and even more potential BCI users. There are two main routes in which manufacturers of BCI technology / products can choose to go down: clinical applications and consumer products.

Clinical Applications: - Adam O'Sullivan 19265808

In this field there is one main demographic of BCI users; and this is individuals who have been severely disabled in some way whether that be by injuries such as a spinal cord injury, lost limb etc. or by disorders such as muscular dystrophies, brain stem stroke, ALS etc. Obviously not everyone would be affected in the same way by an illness or an injury, therefore, especially in the cases which involve paralysis, it is necessary to categorize potential BCI users by the extent of their injury i.e. the level of control in which an individual has over their muscles. (Some paraphrasing from Mak & Wolpaw, 2009, SECTION III in this paragraph).

Knowing this, one can extrapolate what kind of BCI equipment would be needed / wanted for each individual. For example, if an individual suffers from severe paralysis, an EEG headset could be linked to a mobility scooter allowing the wearer to accelerate by simply focusing. According to Daly and Huggins (2015) "A recent review showed that 4 (17%) of 24 patients who had been diagnosed as being in a vegetative state were not only consciously aware but could answer yes or no questions." If an individual is in a vegetative state, an EEG device could be used in order for said individual to answer basic yes or no questions. With some advancements in BCI technology we may also see robotic prosthetic limbs which could be controlled by the brain thus allowing those who have lost a limb to come much closer to having a functioning limb once again.

EEG technology for treating some mental illnesses is also being / has been developed. Such as an EEG headset developed by BrainCo which is designed to treat ADHD by requiring and rewarding focus. There have also been numerous studies based around treating epileptic seizures using BCI technology such as the journal "Brain Computer Interface for Epilepsy Treatment" by L. Huang and G. van Luijtelaar.

Consumer Applications: - Adam O'Sullivan 19265808

As is the case with any new development with technology, the consumer is often prioritized as there is generally more profit in developing technology for consumers as opposed to developing it primarily for healthcare. Therefore, the success of consumer focused BCI products will have a large impact on the speed at which this technology is developed.

There are already many consumer BCI products that exist however for the most part these products are generally just gimmicky toys such as the Puzzlebox Orbit Helicopter which is described by puzzle box as being a toy helicopter which is "Operated with an EEG headset, users can fly the Orbit by focusing their concentration and clearing their mind". While, as I said, this is a gimmicky product, it does however showcase the potential of EEG technology and BCI technology as a whole. This concept alone lends itself to a slew of potential consumer products that may be created in the future such as EEG controlled vehicles in which drivers could potentially possess faster reaction times while driving however it isn't known if this would really be the case at this current point in time.

An area in which there seems to be a large market for BCI technology is the video game industry, more specifically the area of virtual reality video games. There are already a number of advancements being made in this area by a company named Neurable, an American neurotech startup who have developed a game by the name of 'Awakening'. The premise of the game is that the user plays as "a child with telekinetic powers who must escape a government lab by using mind power to pick up various toys—a balloon dog, alphabet blocks, rainbow stacking rings—and throw them" (Mind-Controlled VR Game Really Works by Rachel Metz). This alone would be enough to get virtually any virtual reality enthusiast excited about the technology and its future.

It is clear that the creation of video games alongside BCI technology has the potential to have a great impact on furthering the research and development of more sophisticated and more powerful BCI devices. This is in part largely due to the size of the video game industry and the culture that comes with it. Once more and more companies decide to develop EEG controlled video games, more and

more hype will surround the technology. If the technology shows tangible results in this industry there will most likely be a large amount of people willing to crowdfund such projects thus allowing more funding to be put into the development of BCI technologies.

The idea of a game where a player can fully immerse themselves in a world where the player character moves in the ways in which the player wants them to without being held back by the clunky-ness of a controller or a mouse and keyboard is an ideal which is shared by a lot of gamers around the world. The vision of BCI in gaming in which many gamers hold is essentially the ability to play games in which when paired with virtual reality and BCI equipment will allow gamers to play through a game while feeling almost as though they are moving their own body throughout a virtual world without being confined by their own range of movement, stamina or room space.

Another application of BCIs that could enhance the lifestyle of consumers is the use of BCIs alongside the smartphones and personal computers of the consumer. Using BCIs in this way could allow for hands free operation of consumer devices, thus making them more accessible and/or potentially improving the efficiency of the devices i.e. improved typing speed.

There are many applications of BCI technology at this point in time and I am sure that as our understanding of the technology expands, the number of applications of said technology will also increase.

Notable BCI Developments

Neural Dust – Gabriel Rigaudie 19269315

Neural dust is form of brain computer interface. It is a collection of sensors which can be as small as 6.5 cubic millimetres which can be attached to various muscles and organs including the brain. Ultrasound is used in order to communicate with and power the neural dust wirelessly, allowing for a less invasive experience for the user. (Paraphrasing from Recent advances in neural dust: towards a neural interface platform by Neely, Piech, Santacruz, Maharbiz and Carmens, 2018) Ultrasonic vibrations are capable of penetrating every part of the body, thus allowing neural dust to also function wherever they are placed.

Neural dust through stimulation of the nervous system, has been successfully used to treat numerous disorders such as stimulation of the spinal cord in order to treat pain. At this point in time we don't fully understand how different diseases are influenced by the nervous system however as this understanding grows the number of potential diseases that could be treated will expand greatly as the neural dust could be placed on the correct specific neurons. That being said, current technologies are lacking in many ways which if some advancements in the field were made then this would further the expansion of this type of treatment. (Paraphrasing from Neely, Piech, Santacruz, Maharbiz, and Carmens, 2018)

The potential applications of neural dust appear to be nearly limitless. With the ability to place these sensors inside the body, individuals could have high precision 24/7 health monitoring or permanent constant never before seen therapy for various chronic ailments and pains. The applications of neural dust could also extend to consumer products such as a replacement for existing workout trackers / health monitors such as fitbits etc. as they would be less bulky than these traditional trackers. Neural dust could, in the future, also be used to detect certain oncoming illnesses much earlier than traditional methods by having round the clock monitoring. In theory neural dust could detect oncoming cancer much sooner thus potentially saving lives. Neural dust could also be used in place of tradition BCI equipment thus users would no longer be required to wear clunky and potentially uncomfortable headgear. This would also allow for a certain level of discreteness for

those who may be self-conscious about requiring BCI technology in order to go about their daily lives. Granted neural dust technology is still in the research and development stage and will most likely be very expensive to produce, that being said I have no doubt that one day this technology will be accessible to the average consumer.

Neuralink – Adam O'Sullivan 19265808

Recently in July of 2019, Elon Musk, the founder of Neuralink hosted the Neuralink launch event in which he unveiled his plans for the company. Later on 31/10/2019 Musk and Neuralink released a peer reviewed paper highlighting, in depth, what the Neuralink device is. The Neuralink device is a high-bandwidth BCI system made up of arrays of small flexible electrode threads (currently 96 threads with 3072 electrodes distributed across them) that would be implanted directly into the users brain. They then outline that they have created a robot capable of inserting six threads per minute. A hole is drilled in the skull and is essentially filled in with the package. When fully assembled the package ends up being a little over an inch in diameter. A USB-C cable will be used to stream the data from the device out a computer or some other machine. (Musk E, Neuralink, An Integrated Brain-Machine Interface Platform With Thousands of Channels)

The capabilities and potential of this device is virtually unheard of in not only the technology industry but the entire world. Musk has gone one record saying that the Neuralink device will be capable of fixing a large array of neurological disorders / injuries etc. and he gave a few examples of this such as: if a person has suffered a stroke and has lost the ability to speak or some other muscular control then this device would be able to restore this control to the individual. Another example would be if someone was getting old and they were beginning to suffer from Alzheimer's or some other form of memory loss then this device would be able to solve this. In theory this device could solve any problems that occur in the brain. Musk also went on to say that he expects Neuralink to undergo the first human trial come a year's time (Musk E, Joe Rogan Podcast). But it's not just the potential medical benefits that make this device so exiting but there are also a slew of other lifestyle benefits that this device could create. This is after all a BCI device, therefore, it would have the same benefits if not more than all of the other BCI devices and technologies that exist.

The Neuralink device has already undergone successful trials using the technology with rats. The idea behind testing with rodents is that a) it allows for quick refinement and prototyping of devices, software and the manufacturing process, b) it also serves as a prototype for the future implants that will be used on Humans. Obviously when it comes to the use of these devices on humans we cannot say for sure how / if they will work as intended, that being said Neuralink has already shown some promising results despite the short length of time since the company was founded.

BCI and Neurons – Eryk Wolak 19277156

A Brief Analysis of Neurons

The Human brain is partly made up of around 100 billion "Neurons". There are two types of neurons: Sensory and Motor Neurons. Sensory neurons carry information from our sense organs to the brain and the Motor Neurons carry information from nerve cells in the brain to our muscles, giving us the ability to control muscle activity such as speaking or moving. Neurons are in charge of everything we do and everything we think. Neurons work together by sending each other signals that allow us to have such functions as memory, thought, movement and also all our senses. Due to the neurons required for that being in different areas of the brain, the connection between them can be severed by damage caused to the brain, or even sometimes the Neurons themselves can outright be killed or

disabled. This damage can occur both naturally and by accident. Natural causes include diseases such as Parkinson's, Alzheimer's and Strokes. This damage can also occur from blows to the head/brain or Spinal Cord Injury. The lost connection can make a person lose access to that part of the brain and all the functions it was responsible for – making it look like they have lost that function. In reality, the function is still there, but it loses its ability to communicate to the rest of the brain. While the brain will try compensating for the lost connection such as by strengthening some of the weaker neuron to neuron connections and also by forming new ones, this is greatly increased and accelerated thanks to the advancements in technology (Brain Basics: The Life and Death of a Neuron – some information learned from this site).

What happens to neurons? – Eryk Wolak 19277156

-For Parkinson's disease neurons that produce dopamine die of in the area of the brain responsible for controlling our body movements. This results in difficulty in moving.

-In Alzheimer's disease protein builds up in the part of the brain that controls memory. This causes the neurons to die and as a result people lost their ability at remembering and doing everyday tasks.

-Getting hit in the head (common injury in contact sports), or damage caused by a stroke can outright kill neurons.

-Injury to the spinal cord can break the contact between the Motor neurons and muscles leaving them with no or limited communication. This can cause severe injuries such as paralysis which is the complete loss of movement or paresis which is a weakening of the muscles.

Dopamine is a chemical released by neurons that acts as a neurotransmitter to send signals to other nerve cells in our central nervous system.

Example of BCI Implementation – Eryk Wolak 19277156

Brain-Computer Interface (BCI) allows us to monitor and determine a person's intentions by analysing the signals generated by the brain. (Brain Computer Interfacing for Stroke Rehabilitation – Maynooth University). Thanks to advancements in this field we now have the ability to help regain some of the lost functions. A great example of someone who was using BCI to help them function was Stephen Hawking. Just by blinking or even just twitching his cheek muscle, he was able to operate an interface that allowed him to express himself and communicate to the outside world. There is around a half a billion people in the world with speech disabilities. This is just a small example which doesn't include lost functions such as hearing and vision loss, or even movement. A company which uses BCI to help people is Cognixion. Cognixion is a neurotech A.I. company that created a mobile app to help people with speech and or movement disabilities to communicate using their mind. The app uses eye-tracking technology to navigate a screen with your eyes and allows the person to select letters or words etc. by blinking or holding their sight on it. This advanced version of the app can also use facial recognition to detect emotions such as smiling or laughing. The desired output is then spoken by the voice using a programmed voice. The "Pro" version of the app is designed for people with movement disabilities while the more basic version is designed for people with just speech. The basic version allows the person to simply tap words or functions on the phone screen which will then also be spoken out by the AI. In the future, Cognixion has plans to develop direct brain-software technology that will allow a person to control computers using just brainwaves by use of a headband with electrodes attached to the scalp. (Some Paraphrasing from Cognixon – Giving AI-Superpowers to Humans with Disabilities).

To Conclude – Adam O'Sullivan 19265808

Brain computer interface technology is in an exciting state at the moment with many new technologies being researched and developed. There is also a slew of BCI devices that have already been created which are already displaying promising results and are paving the way for newer more powerful technologies to come in the future. There are many uses for this kind of technology in the various different industries, such as medical technology with advancements in communication and control for those with disabilities, entertainment in the area of virtual reality and immersion into games. These advancements would not have been possible without research by scientists such as C. Kothe, J. R. Wolpaw, S. R. Santacruz, E. Musk and many more who have added valuable inputs into the field.

References

O Zander, T., Kothe, C., Jatzev, S. and Gaertner, M., 2010. *Brain Computer Interfaces*. London: Springer //(Not explicitly used, but was read before writing this report)

Clinical Applications of Brain-Computer Interfaces: Current State and Future Prospects by Joseph N. Mak and Jonathan R. Wolpaw published in 2009 in IEEE Reviews in Biomedical Engineering, p.187-199.

Brain-Computer Interface: Current and Emerging Rehabilitation Applications by Janis J. Daly and Jane E. Huggins published in 2015 in Archives of Physical Medicine and Rehabilitation, p.S1-S7

Recent advances in neural dust: towards a neural interface platform by Ryan M. Neely, David K Piech, Samantha R. Santacruz, Michel M. Maharbiz and Jose M. Carmena, published in 2018 Current Opinion in Neurobiology Volume 50, p.64-71.

Mind-Controlled VR Game Really Works by Rachel Metz (MIT Technology Review) https://www.technologyreview.com/2017/08/09/68005/mind-controlled-vr-game-really-works/

Puzzlebox - https://puzzlebox.io/product/orbit/

Musk E, Neuralink, An Integrated Brain-Machine Interface Platform With Thousands of Channels, 2019

Musk E, Joe Rogan Podcast, http://podcasts.joerogan.net/podcasts/elon-musk-2

Maynooth University, Brain Computer Interfacing for Stroke Rehabilitation, https://www.maynoothuniversity.ie/research/human-health/health-medical-technologies/projects/brain-computer-interfacing-stroke-rehabilitation

Brain Basics: The Life and Death of a Neuron -https://www.ninds.nih.gov/Disorders/patient-caregiver-education/life-and-death-neuron

Cognixon – Giving AI-Superpowers to Humans with Disabilities, https://artificial-intelligence.cioreview.com/vendor/2018/cognixion